Management of Fruit Flies in the Pacific

A regional symposium, Nadi, Fiji 28–31 October 1996

Editors: A.J. Allwood and R.A.I. Drew

A symposium sponsored by:

The Australian Agency for International Development (AusAID)
The Australian Centre for International Agricultural Research (ACIAR)
The United Nations Development Programme
The New Zealand Government
The South Pacific Commission/European Union Plant Protection Service
The Food and Agriculture Organization of the United Nations
The Crawford Fund for International Agricultural Research

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and developing country researchers in fields where Australia has special research competence.

Where trade names are used this does not constitute endorsement of nor discrimination against any product by the Centre.

ACIAR PROCEEDINGS

This series of publications includes the full proceedings of research workshops or symposia organised or supported by ACIAR. Numbers in this series are distributed internationally to selected individuals and scientific institutions.

Allwood, A.J. and Drew, R.A.I. 1997. Management of
Fruit Flies in the Pacific. A regional symposium, Nadi, Fiji 28–31 October 1996.
ACIAR Proceedings No. 76. 267 p.

ISBN 1 86320 200 5

Production management: P.W. Lynch
Production editing: P.J. Knight
Typeset and layout: Sun Photoset Pty Ltd, Brisbane, Australia
Printing: Brown, Prior and Anderson, Melbourne

Contents

Address of Welcome

A.J. Allwood

On behalf of the Organizing Committee, welcome to the Regional Symposium on the Management of Fruit Flies in the Pacific: Now and Into the 21st Century.

One could think of this symposium as the culmination of six years and many, many hours of identifying fruit flies from trapping programs, or collecting and processing fruit samples or carrying out research into protein bait sprays or quarantine treatments.

I would prefer to look upon this symposium as the start of a common desire to understand and, in the long term, to be able to manage fruit flies regionally in an effective, environmentally sound way, in a way that will protect the horticulture industries from the ravages of pests such as papaya fruit fly and allow countries to trade in fresh fruits and vegetables in the knowledge that quarantine security is not jeopardised.

One way of fostering this common desire is to share the wealth of information that has been accumulated over the past six years. This has been possible through very productive technical linkages between the Regional Fruit Fly Project, national governments and expertise in Australia, New Zealand, Hawaii and now Malaysia. One cannot forget the very generous support that has come from the Australian Government through AusAID and ACIAR, the United Nations through UNDP and FAO, from other governments such as New Zealand and the USA, from the European Union, and from the South Pacific Commission. We thank you sincerely for your support in the past and, hopefully, into the future. I believe the work in the Pacific region is only just beginning.

We have several distinguished guests present. I wish to thank you for giving your valuable time to be with us. In particular, I wish to express appreciation to the chief guest, the Hon. Mr Militoni Leweniqila, Minister for Agriculture, Forestry, Fisheries and ALTA for travelling from Suva to be with us. Thanks also to Mr Mike Ahern, former premier of Queensland and now the Queensland Chair of the Crawford Fund of Australia and to Dr Paul Ferrar of the Australian Centre for International Agricultural Research.

I welcome everyone to this symposium and draw your attention to its objectives. They are to:

- present data on fruit flies and their management, that have originated from the Regional Fruit Fly Project and complementary projects funded by ACIAR and USAID and other related projects in the South Pacific region;
- discuss the future needs for fruit fly research in the region;
- provide the opportunity for national staff to hone their skills in presentation of scientific data; and to
- publish the proceedings of the symposium with the assistance of ACIAR.

Regional Fruit Fly Project,
South Pacific Commission,
Suva, Fiji

Official Opening of the Regional Symposium on the Management of Fruit Flies in the Pacific: Now and Into the 21st Century

Hon. Militoni Leweniqila

I wish to thank the Organising Committee of the symposium for giving me the opportunity to address this body of national plant protection and quarantine officers. It is very pleasing to see the large number of countries and organisations represented here. This surely demonstrates to everyone the enormous importance of fruit flies to the Pacific Island region — the importance to the production and export of fresh fruits and vegetables in this region.

Earlier this month, Ministers and officials of eight Pacific Island countries met in Fiji to discuss the future needs of agricultural development and research. A number of important resolutions, relevant to the deliberations of this symposium, were generated at the meeting. Ministers recognised that there is declining interest in agricultural research, development and services and agreed to reassert the importance of agricultural and rural development. Also, every effort should be made to continue to command a significant share of aid that flows into the region for agricultural research and development. Among other resolutions, the Ministers also want to ensure that policies and funds are available to protect the agriculture industry and export trade and that adequate resources are available to address losses of agricultural produce because of poor post-harvest handling and facilities.

These resolutions are important to pursue but, at the end of the day, we need technical assistance to improve production and to protect our developing horticultural industries from the scourges of exotic pests. We also need practical, economic results from the collaborative research, results that are applicable to both the subsistence and commercial sectors of the rural community.

When we look at the Regional Fruit Fly Project and the related projects, we see these practical results to which I am referring. This symposium is evidence of the practical approach that has been followed.

Let us spend a short time highlighting some of the major findings of the project that are particularly relevant to the horticultural industry in Fiji.

- Up-to-date knowledge on the fruit flies that occur in Fiji and on fruits that are attacked has given quarantine authorities confidence to negotiate with overseas trading partners. This information has been used to guide quarantine decision-makers in preparing quarantine pathways for the export of pawpaws and chillies to New Zealand and produce to Canada through Hawaii. The information will also be used to carry out pest risk analysis to determine the risks that are involved in importing or exporting particular commodities and the treatments that are required to maintain quarantine security.
- Environmentally sound, inexpensive field control systems based on the destruction of damaged or over-ripe fruits, early harvesting where appropriate and protein bait sprays have increased production of fresh fruits. I am told that it is possible to reduce levels of damage to guava fruits from 40% to less than 4% by applying bait sprays. The equipment used for applying the bait is simple, so the technique is appropriate for control of fruit flies at both village or commercial levels.
- Generation of data on the heat tolerances of eggs and larvae of fruit flies has assisted in overcoming export constraints for various crops, but particularly pawpaws and chilli. For pawpaws, a heat treatment using forced hot air has been accepted by New Zealand and the first consignment went to New Zealand recently. This is a major achievement for a developing country. Chillies are exported to New Zealand because

they are categorised as non-hosts to fruit flies following exhaustive laboratory and field testing done at the Koronivia Research Station.

- Last but certainly not least, through on-the-job training, a corps of well trained professional and technical staff is now available to carry on the research and quarantine surveillance and provide advice on fruit flies and their control.

If the benefits originating from the fruit fly projects in Fiji reflect what has, or is happening, in other countries, then it has been a very practical project regionally and certainly fits into the scenario that I portrayed earlier.

This regional symposium has been designed to present data that has been generated over the past six years, to discuss the future needs for fruit fly research in the region, and to provide an opportunity for national staff to improve their skills in presentation of scientific information on fruit flies and their management. The format encourages the exchange of information. I ask that you take full advantage of this opportunity. I also suggest that you take the newly learned information back home and apply it to your situation. The reason for saying this is that the only way that we as members of the Pacific Island communities, will address this important problem effectively is to adopt a regional approach to the management of fruit flies. An essential component of this approach will be open and frank information exchange, as I hope that you will have during the coming week.

I wish you well in your presentations and discussions. I have great pleasure in opening the Regional Symposium on the Management of Fruit Flies in the Pacific: Now and Into the 21st Century.

Honourable Minister for Agriculture,
Forestry, Fisheries and ALTA,
Rodwell Road, Suva, Fiji

Food Security, Pre- and Post-harvest Food Losses and Integrated Pest Management

G.G.M. Schulten[1]

Abstract

The world population could increase from 5.7 billion to about 8.7 billion by the year 2030, but at the present time, more than 800 million people in developing countries are undernourished. The achievement of food security for the ever-growing world population is the first priority of the third millennium. Increases in agricultural production per se and at all costs is not the solution to the problem. It should be achieved within the context of sustainable agricultural and rural development. One of the underlying causes of food insecurity is poverty. When food is scarce many people lack the funds to ensure a balanced diet. An increase in the purchasing power of the undernourished rural and urban population is essential for food security.

The reduction of pre- and post-harvest food losses is an important contribution to the increase of food availability. Pre- and post-harvest food losses are location and situation specific. Inappropriate handling and storage of fruits and vegetables from harvest to consumption and underdeveloped marketing channels are main causes of losses in these commodities.

Pesticides play an important role in the prevention of food losses. While the use of pesticides in developed countries seemed to have reached its ceiling, a strong increase in pesticide use in coming years is expected in developing countries. The integrated pest management (IPM) approach for pest control was formulated in the 1960s as a reaction to the over-reliance on pesticides. In IPM as much use as possible is made of combined natural controls of pests while pesticides are used only as a last resort. IPM strategies are being used on an increasing scale in developed and developing countries. It is FAO's experience that cost effective and environmentally safe plant protection can only be achieved when farmers are empowered to take informed decisions on the most appropriate production and protection methods for their particular situation.

FOOD security was defined by the International Conference on Nutrition in 1992 as the access of all people at all times to safe and nutritious food to maintain a healthy and active life. Food insecurity has been a major concern of mankind since its earliest days. After the Green Revolution of the 1960s, the world food situation has improved considerably. The 1974 World Food Conference showed much optimism when it set the objective to eradicate hunger, food insecurity and malnutrition within a decade.

At present, the world food situation is more than ever a cause of great concern. As many as 88 nations fall into the category of low-income, food-deficient countries: 42 in Sub-Saharan Africa, 19 in Asia and the Pacific, 9 in Latin America and the Caribbean, 6 in the Near East/North Africa and 12 in Europe and Central Asia. More than 800 million people in developing countries are undernourished. The world population may increase by the year 2030 from 5.7 billion to 8.7 billion. Therefore, the first priority of the third millennium is not only to provide food security for those that presently lack it, but also to provide it for a rapidly growing world population. The reduction of pre- and post-harvest food losses would represent a substantial contribution towards food security.

World Food Summit

Although there seems to be a general awareness of the need for food security, commitments of external

[1] Senior Officer (Entomology), Plant Protection Service, Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy

assistance (bilateral and multilateral) to strengthen the agriculture of developing countries, have declined from the US$10 billion available in 1982. At the same time due to various causes, the growth rate of agricultural production in many countries, in particular in Africa, has been too slow to meet the ever-increasing demands.

Because of the present food insecurity of many people and insufficient prospects for improvement, the Director-General of FAO, after consultation with FAO members, convened a World Food Summit in Rome from 13–17 November 1996.

The Summit provided a forum at the highest political level to address the need for global commitment and action to provide food security for all. It is expected to lead to the adoption of appropriate policies and strategies at both national and international levels, as well as to a plan of action for implementation by all parties concerned: governments, international institutions, and all sectors of society.

The Summit was preceded by consultations at FAO regional conferences on the specific needs and priorities of the regions. Regional NGO consultations were also held.

A number of technical background papers were prepared and are available on the Internet. Some key documents are: Food Requirements and Population Growth; Food Production and Nutrition; Food Production and Food Security; Food Production and Environmental Impact; Role of Research in Global Food Security and Agricultural Development; Food and International Trade; Food Security and Food Assistance; Food Security Success Stories.

Major issues raised in these documents are summarised in the following:

The underlying causes of food insecurity are many-fold and interrelated. There is no simple solution to the problem. The availability of food and a secure supply are essential for the nutritional well-being of the individual. Poverty is recognised as one of the main causes of food insecurity and poor health. The poor lack the financial means to obtain the desired quantities and qualities of food. Their situation is worsened when food becomes scarce due to natural disasters or civic unrest.

Agriculture's crucial role in improving nutrition is the production of food of the right quality and quantity. The amount of land that is the best suited by its topography, soils and climate is about 11% of the land surface. Almost all of this land is under some form of cultivation. The necessary increase in food production largely has to be achieved by intensifying the production on land with a good production potential. The scientific knowledge and technical means to obtain the necessary food from the earth is presently available and can be further developed. However, much of this science and technology was developed at locations that have different environmental, social and economic conditions than where they are to be applied today. Short-term strategies aiming at food production per se, based on a heavy dependency of inputs and an unequal distribution of wealth, resources and know-how has led in many instances to negative environmental and social impacts that could have been prevented. Agenda 21 of the 1992 United Nations Conference on Environment and Development (UNCED) provides direction for achieving food security. It stresses the need to use natural resources in a sustainable manner. This requires technical innovations and empowerment of the farming community in their use that have to be complemented by supporting environmental and social policies.

The actual production of food and related activities, such as storage, small-scale processing and marketing, provides income to the farming population at all levels and is of much relevance to food security, in particular, in low-income countries.

Food trade is essential to world food security. Trade allows food consumption to exceed food production and is an important source of income for the producers. In the past, food self-sufficiency was given a high priority in many countries. It may make, however, more economic sense to follow a more flexible policy of food self-reliance under the condition that importers can rely on the world market as a dependable and efficient source of supply and that there are good export markets. Market liberalisation is expected to contribute to economic growth. The question arises if this economic growth reaches the poor.

Malnutrition and hunger reduce productivity of the affected group and are major constraints for improving their situation. They are manifestations of poverty and, at the same time, a cause of poverty. The removal of hunger contributes both toward eradicating poverty and toward food security. Food aid has been and still is an important tool in combatting poverty and hunger.

Food aid in recent years has been declining. On the other hand, the need for relief food in the total food aid basket to meet the consequences of various natural and man-made disasters has increased from 30% to 50% in two decades. There is a need to optimise food assistance programs giving due consideration to the following objectives: appropriate and adequate relief interventions in case of emergencies; support to the chronically hungry with little prospect to improve their situation, in particular, the urban poor; and food assistance as a tool for development. Through interventions for enhancing

nutrition, hungry people will benefit from health, education, skills and income-earning initiatives.

At the World Food Summit an action plan was agreed upon to achieve universal food security based on a number of commitments.

- National commitment for the creation of a political, social and economic environment, based on the equal participation of women and men, that is conducive to food for all.
- National commitment that institutions and policies will contribute to improving access for all to nutritionally adequate and safe food at all times.
- National and international commitment to meet transitory and emergency food requirements in ways that encourage recovery, development and a capacity to satisfy future needs.
- National and international commitment to promote sustainable and rural development.
- National and international commitment to ensure that food and agricultural trade policies are conducive to improved food security.
- National and international commitment to promote appropriate investments in sustainable agriculture, forestry and fisheries production and post-production development and in supporting research, infrastructure and services.
- National and international commitment in implementing and monitoring of the World Food Summit Plan of Action.

Pre-and Post-harvest Losses

A continuous increase in agricultural production is essential for achieving food security, but this should not be achieved at all costs. The Green Revolution which started in the 1960s was very successful, but very dependent on a high use of inputs and a top-down extension strategy. In later years, it became obvious that the approach had to be revised because farmers could no longer afford the costs of inputs, and undesirable environmental consequences became more and more obvious.

The Draft Action Plan of the World Food Summit was very explicit on how a food production of 2% annually at global level and a 3% increase in the developing countries should be achieved: the food production potential of natural resources should be maintained and, where necessary, rehabilitated and their degradation and depletion arrested. Food production is to be intensified and diversified with due respect to sustainability, efficiency and safety; wastes and losses are to be reduced and the environment protected.

The prevention of pre- and post-harvest food losses has already been the focus of attention of national and international efforts for many years. Much experience in this field has been gained, but notwithstanding this, over-simplistic views exist or are promoted by interest groups on what can be gained by loss reduction and how it should be tackled. Pre-and post-harvest losses are location and situation specific. They can be assessed, but extrapolating such data to arrive at country, regional or global loss estimates is very questionable. Loss survey techniques have in general a low level of accuracy.

More detailed information can be obtained from the results of pesticide trials. Such trials, however, are mostly conducted at research stations or at locations where the pest is found in abundant numbers, while the crop varieties grown are susceptible to the pests. Loss figures based on such data are therefore likely to be over estimated. Loss assessment methodologies vary. The quotation of loss figures without explaining where, when and how the losses were assessed is almost meaningless and often misleading (Schulten 1988).

An effort was made by Cramer (1967) to estimate global food losses based on information collected in pesticide trials and loss surveys. He concluded that without pesticides the attainable yields were much reduced, and that with an intensified pesticide usage, agricultural production could be boosted to meet the increasing demands for food. In the heydays of the Green Revolution, such a conclusion might have been justified, but since then, the dangers of a total reliance on pesticides and the need for a sustainable agriculture that can be afforded and safely conducted by large and small-scale farmers are widely recognised.

As a reaction, integrated pest management are being developed and implemented on an increasing scale (Stone 1992; Thrupp 1996; Schillhorn van Veen et al. 1996). Oerke et al. (1994) prepared a follow-up to Cramer's book and provides detailed calculations of the potential losses for a number of key crops using the same methodology. This publication supplies interesting information on agricultural production, potential yields and procedures relating to pest control. It mentions correctly that the adoption of technologies from industrialised countries often is not feasible as local problems need local solutions. Reference is made to integrated pest management, but in essence the publication is a straight plea for an increased use of pesticides without an in-depth discussion on how the pesticides can be used in an economic, user- and environment-safe way and on a needs basis only. The negative side effects of pesticides are played down to a 'few adverse experiences' while the impression is created that the risks inherent in pesticide usage are only perceived in the affluent areas of the world. It is a

pity that the opportunity was missed to present a balanced view on how pesticides could contribute to food security.

Pre- and post-harvest losses in durable crops can be assessed with some difficulty as losses in weight. Loss estimates can be refined when quality losses are taken into consideration as well. Loss assessment in perishables is much more difficult because quality losses are much more prominent. Losses in perishables can be very high because the post-harvest life is much shorter.

Losses depend on many factors such as:

- the type of loss under consideration (physical, cosmetic, nutritional, economic);
- the handling and storage conditions between harvest and the time the assessment was made;
- the storage period;
- the condition of the crop at harvest;
- the storage life of the perishables;
- the supply and demand.

Examples of losses in perishables are given by Thompson (1996). If fruit flies were not controlled in Australia, it is believed that the potential losses would exceed A$100 million. If a certain fruit fly species invaded California, crop losses could be in the area of US$900 million. The eradication of the Oriental fruit fly from the south-western islands of Japan using the sterile male technique cost approximately US$32 million.

Fruit flies are a main cause of loss in the Pacific region, because they affect the export potential of the island states.

Integrated Pest Management (IPM)

A new concept for plant protection emerged in the late 1950s in Western Europe and North America as a reaction to the sole reliance on pesticides for pest control. At that time, the negative aspects of chemical control became better known, such as environmental contamination, residue problems, the killing of non-target organisms, the development of man-made pests because natural enemies were eliminated, the development of resistance to pesticides and the increasing cost of pesticides. Consequently, a more integrated approach to pest control was advocated, giving due consideration to ecological factors such as natural mortality which may keep insect pest populations below economic damage levels.

This new concept called Integrated Pest Control (IPC) and later Integrated Pest Management (IPM), was stimulated by symposia organised by the Food and Agriculture Organisation of the United Nations (FAO) in 1966 and the International Organisation for Biological Control (IOBC) in 1967.

Integrated Pest Management (IPM) is the careful integration of a number of available pest control techniques that discourage pest population development and keep pesticide and other interventions to levels that are economically justified and safe for human health and the environment. IPM emphasises the growth of a healthy crop and the least disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms to play their role. Pesticides are applied on a need basis only, with the necessary precautions to avoid negative side effects.

During the past 30 years, many activities have been undertaken by FAO to bring IPM to the farmer. The experience of the FAO-Intercountry Rice IPM Program has made it evident that IPM cannot be considered as a package of technologies, but as a set of skills. These skills allow the farmer to make informed decisions on the best cost effective and safe options to prevent pest damage and, if necessary, to control the pest.

Innovative, participatory training methods are the key to IPM application. IPM needs to build on people's understanding of local agro-ecosystems to be successful. IPM training builds community-based ownership of science and technology, without which it cannot be socially sustained. A key innovation has been the establishment of Farmers' Field Schools in Indonesia, which was subsequently expanded in other national IPM programs. In these schools, field/laboratory training plots for learning activities are set up, together with ongoing farmer experimentations. Farmers return to the school every week, for 10–12 weekly sessions, totalling about 40 hours during the whole cropping season. During this season they grow a rice crop.

The training stresses the need to cultivate a healthy crop as the first line of defence against pests. Much attention is given to the selection of crop varieties, the use of cultural practices and correct use of fertilisers. An understanding is developed of the role and importance of natural enemies and their preservation. The negative impact of pesticides on natural enemies is explained and demonstrated. Farmers are trained in regularly inspecting their fields and weekly observations of the status of the crop and presence of pests and their natural enemies. The collected data are analyzed and informed decisions are taken on the need for control measures that may include the use of pesticides.

The Farmers' Field School approach has proven to be very effective for farmer training and has resulted in considerable reductions in pesticide use, while yields remain stable or even increase, due to better management.

The number of Farmers' Field Schools is regularly expanding in Southeast Asian countries and besides rice, they now also cover vegetables and cotton.

After the FAO IPM Global Workshop in Bangkok in 1993, Farmers' Field Schools were also successfully introduced in Africa (Burkina Faso, Côte d'Ivoire, Ghana and Sudan). IPM has meanwhile become a 'buzz word' accepted by actors in the field of plant protection. Unfortunately, this has led to a considerable confusion in the interpretations of what IPM is supposed to be and what can be expected from it. On one extreme view, IPM is seen as pest management without pesticides; another extreme view stresses that pesticides are still the major component of IPM. In reality, the need for pesticides varies from situation to situation. FAO's IPM projects and programs show each time that there is considerable over-use of pesticides that can be reduced without lowering yields or quality of the produce.

Conclusion

The food insecurity for many people on the globe is unacceptable. A holistic approach is required giving due attention to removing the many interrelated constraints for food security. The necessary increase in agricultural production is to be achieved in a sustainable and environmentally safe way. The reduction of pre- and post-harvest losses caused by pests is an important contribution to food security. This reduction has to be obtained by means of integrated pest management. Essential for the large-scale adoption of integrated pest management is the empowerment of farmers in its application, supported by appropriate national and international policies.

References

Anon. 1988. Report of the Expert Consultation on Progress and Problems in Controlling Fruitfly Infestation. Bangkok. RAPA Publication 28: 1–18. Food and Agriculture Organisation. Regional Office for Asia and the Pacific. Bangkok.

Cramer, H.H. 1967. Plant Protection and World Crop Production. Pflanzen Schultz-Nachrichten. Bayer 20: 1–524.

FAO, 1996. World Food Summit. Technical Background Documents Vol 1–3.

Oerke, E.C., Dehne, H.W., Schonbeck, F. and Weber, A. 1994. Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops. Elsevier, Amsterdam. 808 p.

Schulten, G.G.M. 1988. FAO's Experiences with Crop Loss Assessment. Insect Sci. Applic., 9(6): 63–767.

Schillhorn van Veen, TJaart, W., Forno Douglas, A., Joffe, Steen, Umali-Derninger, Dina, L., Cook, Sangiva. 1996 (in draft). Integrated Pest Management. Strategies and Polices for Effective Implementation. Environmentally Sustainable Development Studies and Monographs, Series No. 13. The World Bank.

Stone, R. 1992. Researchers Score Victory over Pesticides and Pests in Asia. Science. Am. Ass. Adv. Science, 256 (5061) 1272–1273.

Thompson, A.K. 1996. Post-harvest Technology of Fruit and Vegetables. Blackwill Science, Ltd. 420 p.

Thrupp, L.A. 1996. New Partnerships for Sustainable Agriculture. World Resources Institute, 136 p.

The Importance of Fresh Fruit and Vegetables in the Pacific Region

M. Hazelman[1] and B. Pilon[1]

Abstract

Fruit and vegetables are essential to daily life as food, as a source of vitamins and minerals, as items for barter and trade, for food security, as means of employment, and as a source of cash and foreign exchange. Examination of the status of fruit and vegetables in traditional and changing uses, their potential, and the constraints to their production and use are examined to highlight what may be feasible for their further development, and to provide a background to the threat posed by fruit flies to vital fruit and vegetable industries in the Pacific region.

THE range and uses of fruit and vegetables is large and varied in the Pacific region, especially in the traditional agricultural systems and at both home and subsistence levels. Their uses are influenced by social, cultural, environmental and market factors. Thaman and Whistler (1996) recently provided an extensive overview of agroforestry and indigenous systems occurring in four Pacific island countries which highlight the importance and potential of many traditional crops (which include those that qualify as fruit and vegetables, such as the Pili nut and Pele) and their cropping systems.

Given that the subsistence economies of most Pacific region countries involve a large proportion of the population as well as an ever-increasing involvement in the cash economy, fresh fruit and vegetables play an important role, especially regarding the achievement of food security at household and at national level, and for foreign exchange earnings.

Fully developed fruit and vegetable production would assist Pacific region countries to achieve food security and to offer opportunities for trade and employment. However, the range of crops and commodities for trade are limited unless markets are developed or created for new uses, and technologies developed to make them more accessible and affordable especially to urban dwellers and acceptable also for overseas markets.

Home or subsistence production of fruit and vegetables includes a range of crops that do not appear in formal export oriented trade but are nevertheless most important for food security and for meeting nutritional requirements. Many may, however, have potential for export trade but require assessment and market creation, production technology innovations including post-harvest and processing technology applications developed and evaluated to make them more readily available, especially to urban and overseas consumers.

International trade in fruit seems to be concentrated on a few crops which include pineapples, avocados, mangoes, passion fruit, papayas, guavas, litchis, limes, mangosteen, durian, star-fruit, rambutan, longan and bananas. Of these, major imports into developed countries are limited to pineapples, avocados, mangoes and papayas, all being crops that have market potential also for other Pacific region countries. The fact that there are many other fruit crops grown and used as food nationally indicates that there is potential for many of these to meet specialty and niche markets in different market sectors.

Trade in vegetables is similarly limited both in area and range, especially in relation to exotic vegetables. In the Pacific region, trade in vegetables is currently restricted to only a few countries (Cook Islands, Fiji, PNG, Tonga and Vanuatu). Increasing quantities are now traded intra-regionally and internationally, and include mainly capsicums, chillies, eggplants, tomatoes, beans, squash and watermelons.

[1] South Pacific Commission, Private Mail Bag, Suva, Fiji

Much of the vegetable production in the Pacific region is, therefore, mostly oriented to local or national use, but even so, supplies tend to be seasonal and demands not fully met.

Constraints to Fruit and Vegetable Production

Vegetable production, and to some extent fruit production, are high value but also high risk business enterprises. Some of the major causes of risk relate to problems of marketing, pests and diseases, weather (cyclones, hurricanes and drought), transport, information and technology.

An international consultation on tropical fruits held in Malaysia in 1995 identified the following constraints to growth in the fruit industry in producer countries:

- lack of comprehensive, timely and accurate market information;
- weakness in consumer awareness;
- need to develop and to disseminate technologies in production, post-harvest handling, processing, product development and distribution;
- policy related issues affecting production and international trade.

Examination of the situation in the Pacific region shows a similar situation for both fruit and vegetables. Trade opportunities are there, but currently, the vast majority of fruit and vegetables are consumed where they are produced because they are a valuable source of nutrients, a situation not unlike that in other regions of the world.

Development of fruit and vegetable industries in the Pacific region currently lags behind those of the traditional industrial crops like coconuts, cocoa, coffee and sugar cane. Given their high value and more intensive requirements for labour, and coupled with the potential for more intensive land use, efforts to improve their production and marketing hold promise for Pacific region countries, provided that constraints are met.

Issues Requiring Attention

Several important and related issues require attention and these are examined briefly.

Food security and nutritional concerns

Should the current trends of population development continue, the Pacific islands' population will double in about 30 years, with the fastest growth occurring in towns and cities (South Pacific Commission 1994). The need for increased food production to meet caloric and nutritional demands would therefore need to increase many fold to meet food security and nutritional requirements. According to UNICEF (1991), children in some Pacific region countries (especially the Federated States of Micronesia, Kiribati, Marshall Islands) suffer some of the highest rates of vitamin A deficiency known in the world, a tragedy that is entirely preventable via a diet which includes adequate supplies of yellow fruit and green vegetables which are high in vitamin A. Here, improved and well coordinated educational and awareness programs would go a long way towards addressing these problems.

Tourism links

There have been continuing discussions about the potential for local fruit and vegetable production to meet the demands of the increasing hotel and tourist trade. Tourist arrivals have grown steadily from more than 600 000 in 1988 to some 744 584 in 1993 with projections for further increases. In 1993, 39% of tourists visited Fiji, with 20% going to French Polynesia and 11% to New Caledonia.

Tourism represents a great potential for local production that is currently not fully met. The major problems and limitations encountered by hotel and hospitality operators relate especially to unreliability of supply, but quality and price considerations have also led to a continued reliance on fruit and vegetable imports.

The potential for hydroponic production of vegetables is being tapped to some extent in Fiji, and also in the French territories who together receive more than 70% of tourists. Closer collaboration between all parties concerned — hoteliers, farmers, advisory and technical service personnel, planners, nutritionists and home economists could help to improve the supply of fruit and vegetables to meet the requirements of the tourist trade.

Information requirements

Different types of information are necessary for different target markets and to meet differing goals and objectives. In addressing nutritional concerns, educational and awareness information for the general public is required on the virtues of fruit and vegetables in combating nutritional disorders such as vitamin A deficiency.

Similar information is also needed in promoting production and marketing with a greater focus on planning, market prices, demands, trends and quarantine.

Quarantine concerns

Trade possibilities exist for fresh fruit and vegetables but exporting countries will need to meet increasingly stringent quarantine requirements set by importing countries, be it inter- and intra-regional or international trade. In relation to trade, fruit flies are of significant importance.

With trade liberalisation under the General Agreement on Tariffs and Trade (GATT), transparency regarding quarantine is a standard requirement. The use of bilateral agreements (for quarantine and trade) are instruments being employed to facilitate trade between countries. Tonga, for instance, has agreed on individual comprehensive quarantine work plans with New Zealand which cover everything from planting to marketing of commodities such as tomatoes, capsicums and zucchini (Faanunu 1991). Within the Pacific region, the use of quarantine protocol arrangements between several countries (i.e. Fiji, PNG, Tonga and Western Samoa) have been used in a similar manner. Pest research and surveillance activities will certainly help to provide information on which quarantine decisions are made.

National commitment to meeting such needs is paramount if Pacific region countries are to be successful in trade. There is no way around these requirements.

Quality standards

Apart from meeting quarantine standards which basically relate to freedom from pests and diseases, there are the complementary standards relating to production and crops which include aspects such a crop size and weight, color, maturity and cleanliness. Effective and efficient agricultural research programs and technical advisory services play a very important role in providing appropriate and timely information and backup services during the production, post-harvest and marketing phases.

Cropping systems

Given that most farms in the Pacific islands are small, ranging from backyard operations to farms of several hectares, with only a few large-scale farms (or orchards in the case of fruit), greater intensification of production is a possibility. Potential for greater inter- and multiple-cropping systems exist and can be trialled. Crop combinations for coconut-based farming systems, for instance, can include a range of crop combinations with coconuts which can include bananas, pineapples, passion fruit and various vegetable crops. Traditional agroforestry systems as well as home garden production also offer a basis for improvement on a smaller scale to meet home and local requirements and opportunities.

Markets and marketing

Successful agricultural businesses today are market led rather than production driven (CTA 1993). Issues relating to quantity, quality and regularity of supply are of great importance in the former. Reliance on surplus production, the traditional system of production, has resulted in a production driven marketing attitude which gives less importance to these important requirements.

Traditionally, markets for fruit and vegetables originating from Pacific island countries were limited to a few countries, namely Australia and New Zealand, but there is increasing trade with markets in North America, Canada and Japan. As mentioned previously, there has also been increasing intra-regional trade.

Recognising the need for regional effort in the area of agricultural marketing, the lack of marketing expertise available and the need for vital information at national level lead to a recommendation in 1991 for the creation of a Regional Marketing Service (RMS) to be established at USP Alafua Campus. Unfortunately, although some preliminary activity in this area occurred via a USAID initiative under the Commercial Agriculture Development (CAD) project, this has since been discontinued due to lack of resources. However, it is an area requiring continued attention.

Post-harvest concerns

Fruit and vegetables are prone to post-harvest losses brought about by a number of factors. These include improper harvesting and handling techniques, poor transportation systems, improper storage temperatures and facilities, and pest and disease infestations. Appropriate attention to these factors will greatly improve the life and quality of fruit and vegetables.

Processing opportunities

Although there exists in some Pacific region countries some level of processing of mainly fruit products, many processing businesses have faced difficulties of various types. Continuity of cheap supplies of raw materials and effective marketing are two areas that will require close attention, together with some degree of protectionism within local markets, if processing possibilities are to be successful.

Conclusion

Fruit and vegetables are very important to the Pacific region. They have many and varied uses, as well as potential for commercialised production and trade nationally, regionally and internationally. To achieve this potential, national, regional and perhaps international support and attention are required. However, efforts in this regard must also address aspects such as food security and nutrition as well as purely trade-related matters.

References

CTA 1993. Producing commodities that meet market needs. SPORE No. 43, February, 1993.

Faanunu, H. 1991. Keynote address. Workshop Proceedings on Agricultural Marketing in the South Pacific, 22–23 April 1991, University of South Pacific, IRETA.

South Pacific Commission. 1993. Pacific Island Populations, Report prepared by the South Pacific Commission for the International Conference on Population and Development, 5–13 September 1994, Cairo.

Thaman, R.R. and Whistler, W.A. 1996. A review of uses and status of trees and forests in land-use systems in Samoa, Tonga, Kiribati and Tuvalu with recommendations for future action. RAS/92/361 Working Paper 5, June 1996.

UNICEF. 1991. The State of Pacific Children 1995, 2–26 April 1991, University of South Pacific.

The Impact of Australia's Aid Program on Fruit Fly Research in Developing Countries

Hon. Mike Ahern

FRUIT flies are now recognised as the major pests of fruit and vegetable crops worldwide. The enormous losses they cause in food production at all levels of society, from subsistence living to large-area farming, demand that all should work together to research the problem and to provide the answers. Australia suffers significantly from the fruit fly menace and the recent introduction of the Papaya fruit fly has made the situation even worse. Because of a long history of involvement in fruit fly research, Australia has some of the world's leading fruit fly entomologists. With this reserve of experience, together with an interest in what is happening within neighbouring countries, Australia has been prepared to support fruit fly research within Southeast Asia and the south Pacific region.

Australian Donors

Australia's financial contributions to fruit fly research in developing countries have come from three major sources:

- ACIAR—the Australian Centre for International Agricultural Research;
- The Crawford Fund for International Agricultural Research;
- AusAID.

ACIAR has provided approximately $A900 000 for fruit fly research since 1990. This has covered work in Malaysia, Thailand, Cook Islands, Fiji, Federated States of Micronesia (FSM), Solomon Islands, Tonga, Vanuatu, and Western Samoa. The research has been based on the following primary areas:

- surveys of fruit fly faunas by male lure trapping and host fruit collections;
- identification of fruit fly species, their geographic distributions and host fruit records;
- conduct of protein bait spray trials for field control of fruit flies;
- collation of all data into a computer database.

The Crawford Fund has joined ACIAR in sponsoring international fruit fly training workshops. Through them, data generated in the ACIAR projects have been distributed to more than 25 countries from Southeast Asia to the southeastern Pacific region. The Crawford Fund has provided more than $A120 000 for these training courses. It is worth noting that the Crawford Fund was established by the late Sir John Crawford, the pioneer of the ACIAR concept. The Crawford Fund supports projects covering research, training and public awareness in areas of agriculture.

AusAID has provided approximately $A1.4 million for fruit fly research in the south Pacific region since 1990. This support has been through the Regional Fruit Fly Project (RFFP) that has been undertaken in the Cook Islands, Fiji, FSM, Solomon Islands, Tonga, Vanuatu and Western Samoa.

It is important to note that the research and training supported by all three donors has been designed to progress in complete harmony under the leadership of Allan Allwood and Dick Drew.

Outcomes of the Research

Some of the most important results that have come from the abovementioned fruit fly research are:

- a marked increase in scientific knowledge of fruit fly species throughout Southeast Asia and the Pacific region, and particularly the pest species;
- an understanding of the geographic distributions and pest status of all fruit fly pest species;
- the development of effective preharvest field control strategies using protein bait spray technology;
- the establishment of a computer database that provides access to an extensive amount of data on fruit flies.

Training Workshops

Since 1991, six training workshops have been conducted in Brisbane, Cairns, Fiji and Malaysia,

providing in-depth training for more than 100 national workers from more than 25 countries. Topics covered included:

- identification of fruit fly species;
- methods of scientific artwork used for illustrating fruit flies;
- fruit fly biology and ecology;
- protein bait spray field control techniques;
- operation of the computer database.

The training programs resulted in many workers in different countries being able to conduct fruit fly research independently and to provide their industries with advice on the management of fruit fly problems. For example, as a result of the workshops:

- Tahitian personnel detected an invasion of *Bactrocera dorsalis*, the Oriental fruit fly, in 1996;
- Fiji has successfully developed new export trade initiatives;
- PNG officers are now conducting regular fruit fly surveys for the Australian Quarantine and Inspection Service (AQIS) in the Western Province of PNG.

Cooperation of Donors

The willingness of the three Australian donors to cooperate in the fruit fly research activities has, without doubt, has a synergistic effect. Certainly, the collaboration in research by the RFFP and the ACIAR projects, supported in training by the Crawford Fund, has ensured the generation and communication of valuable data that have been used to combat fruit fly problems. It is certainly hoped that this strong collaboration continues.

Conclusion

The aims of ACIAR and the Crawford Fund are:

- to contribute to strong and harmonious international relationships, especially between countries within the region;
- to assist in solving serious agricultural production problems and so contribute directly to the increase in food supplies in developing countries.

As already mentioned, fruit flies are the major worldwide pest of horticulture and they contribute significantly to:

- fruit and vegetable production losses;
- food shortages in developing countries;
- severe trade restrictions that prevent export of horticultural commodities without the application of market access technologies.

During this symposium, gaps in the scientific knowledge of fruit flies in Southeast Asia and the Pacific region will be discussed. As well, stress will be placed on the need for further research efforts to provide the answers needed to manage expanding fruit fly problems, and the need to develop a regional approach to research and extension on fruit flies.

ACIAR and the Crawford Fund are proud to have been partners in past fruit fly research and training efforts and are very pleased to have seen such excellent results. Both organisations are keen to participate in future fruit fly programs and look forward to what opportunities may arise.

On behalf of ACIAR and the Crawford Fund, I extend greetings to all in attendance and wish all an enjoyable and profitable symposium.

I trust that this symposium will lead to continuing close collaboration between many countries throughout the region and also between the donors who have been contributing to the past research and training efforts, all with the aim of continuing progress towards developing long-term solutions to the fruit fly problem.

Fruit Fly Research and Development in Tropical Asia

S. Vijaysegaran[1]

Abstract

The region known as tropical Asia comprises the countries of India, Sri Lanka, Thailand, Laos, Vietnam, Kampuchea, Myanmar, Malaysia, Singapore, Philippines and Indonesia west of Irian Jaya. Infestation by fruit flies is common and is a major constraint to the production and export of horticultural produce in the region. There are about 20 species of *Bactrocera* of economic importance, some of which belong to species complexes and thus have only been recently described. New and extensive host records have also led to a new understanding of the distribution of pest species in the region. This new knowledge on the species, their host range and current known distributions, requires countries in the region to reevaluate the risk of spread of pest species to new areas within tropical Asia. Research efforts in tropical Asia have been directed primarily at reducing losses to production in the field and developing postharvest disinfestation to enable export of horticultural produce to markets where fruit flies are considered serious quarantine pests. Control methods commonly used include cover sprays of insecticides, spot sprays of protein baits, orchard sanitation and fruit wrapping, and these are aimed primarily at preventing direct damage to fruits or at achieving population suppression in individual orchards. These field control techniques enable production of fruit of sufficient quality to meet the needs of domestic consumption as well as that for export to some countries in Asia and Europe where fruit flies are not quarantine pests. Export to markets where fruit flies are quarantine pests is more complex and is facilitated through additional postharvest disinfestation treatments. Future research and development that is required to further resolve the various problems faced by expanding horticultural industries in the region are discussed.

THE REGION known as tropical Asia comprises the countries of India, Sri Lanka, Thailand, Laos, Vietnam, Kampuchea, Myanmar, Malaysia, Singapore, Philippines and Indonesia west of Irian Jaya. Some countries, like Malaysia, Taiwan, Thailand and Singapore, represent some of the fastest growing economies in the world today. Coupled with this economic growth are changing dietary patterns leading to increased consumption of fruits and vegetables (Cheng and Lee 1991). Countries like Thailand (US$909 million), Philippines (US$348 million) and India (US$106 million) also earn considerable incomes from exports of fruits. Thus the development of horticultural industries to meet the needs of domestic consumption as well as those for the lucrative export market is an important component of the economic development process of countries in tropical Asia.

[1] Horticulture Research Centre, MARDI, GPO Box 12301, 50774 Kuala Lumpur, Malaysia

Many types of insect pests afflict horticultural industries in the region, but perhaps none have gained greater notoriety than the highly injurious group commonly known as fruit flies (Diptera: Tephritidae). Tropical Asia, with its equitable climate and rich diversity of plant life, is home to several species of highly damaging fruit flies. Besides causing extensive losses to production in the field, infestation by fruit flies also restricts the free trade and export of fresh horticultural produce to large and lucrative markets like Japan and the United States of America where fruits flies are regarded as major quarantine pests. Consequently, the success of horticultural industries in tropical Asia, whether it be for the rapidly expanding domestic market or for export, is heavily dependant on sound fruit fly management. This paper examines the various constraints posed by fruit flies to rapidly expanding horticultural industries geared towards the production of high quality fruits and vegetables in tropical Asia. It

then describes the various management strategies, the control techniques in use, and future research and development needs to alleviate existing problems.

Current Problems Associated with Fruit Flies

Species diversity and plant quarantine

For the better part of this century one fruit fly species, *Bactrocera* (previously *Dacus*) *dorsalis* (Hendel) (Oriental fruit fly) has been thought responsible for causing extensive economic losses to horticultural crops throughout tropical Asia. Recent taxonomic studies of the older type material and of fruit fly adults and larvae collected extensively in Southeast Asia and other Asian countries during 1983 to 1993, however, have revealed a vastly different picture. It is now known that a complex of at least 52 sibling species exists in the region, 40 of which are new species described, and eight of which are of economic importance (Drew and Hancock 1994, Table 1).

This new information on the pest species and their distribution poses several new problems to fruit industries in the region as well as requiring a reevaluation of existing quarantine procedures within the various countries in Asia regarding fruit flies. The spread of pest species in the *dorsalis* complex to new regions within tropical Asia where they do not yet occur is a matter to be considered seriously as some species have already amply exhibited their ability to spread and establish in regions far removed from their native range. For example, the carambola fly *B. carambola* was detected in Surinam in 1975 (van Sauers-Muller 1991), and more recently in 1995, the papaya fly *B. papayae*, was detected in Queensland where it has caused extensive problems to the local horticultural industry.

Besides pest species in the *dorsalis* complex, there should also be concern about the spread of other pest species of fruit flies that are found in the Oriental, Australasian and Oceanic regions (Table 2). These three regions share many climatic and vegetational similarities that would favour the establishment and spread of several of these species should accidental introductions occur. Some of these could be potentially devastating to fruit industries in the Asian region. For example, the banana fruit fly *Bactrocera musae*, is a unique species in that it lays its eggs in immature green banana. It is major pest in eastern Queensland where banana is an important commercial crop. None of the pest species in the Asian region are known to lay their eggs in immature green banana and consequently the banana industry in the

Table 1. Fruit flies of economic significance in the *Bactrocera dorsalis* complex (compiled from Drew and Hancock 1994).

Scientific name	Common name	Lure[a]	Current known distribution	Commercial hosts	Comments
B. caryeae	—	Methyl eugenol (ME)	Southern India, Sri Lanka	Ciitrus, guava, mango	Serious pest
B. dorsalis	Oriental fruit fly	ME	Southern China, Taiwan, Sri Lanka, India, Myanmar, northern and central Thailand, Vietnam, Laos, Cambodia, Hawaii	Citrus, carambola, guava, mango, papaya, peach, pear	Major pest of international quarantine importance
B. occipitalis	—	ME	Philippines	Mango, guava	Serious pest of mango. Other host data lacking
B. carambolae	Carambola fly	ME	Andaman Islands, Indonesia, Peninsular Malaysia, Singapore, Southern Thailand, Adventive in Surinam and French Guiana	Carambola, guava, mango, breadfruit and several other fruits	Major pest. First record of *Bactrocera* spp. in S. America
B. papayae	Papaya fly	ME	Peninsular Malaysia, Indonesia, southern Thailand, Borneo, Sulawese, Christmas Island	Banana, carambola, citrus, mango, papaya and others	Major pest
B. philippinensis	—	ME	Philippines	Breadfruit, mango, papaya	Major pest. Host data lacking
B. kandiensis	—	ME	Sri Lanka	Garcinia, mango	Serious pest. Host data lacking
B. pyrifoliae	—	—	Northern Thailand	Guava, peach, pear	Serious pest

Table 2. Fruit flies considered major or serious pests in the Oriental, Australian and Oceanic regions (compiled from White and Elson-Harris 1992).

Scientific name	Common name	Lure[a]	Current known distribution	Commercial hosts	Comments
Bactrocera atrisetosa	—	—	Papua New Guinea	Cucumber, pumpkin, tomato, watermelon	Serious pest
B. correcta	Guava fruit fly	ME	India, Nepal, Pakistan, Sri Lanka, Thailand	Polyphagous, guava, mango, peach, rose apple, sapota and others	Major pest
B. cucumis	Cucumber fruit fly		Australia	Cucurbits, tomato, papaya	Serious pest
B. cucurbitae	Melon fly	CUE	Oriental Asia, Papua New Guinea area. Adventive in eastern Africa, Hawaii, Mauritius, Reunion, Iran, Solomon Is.	Highly polyphagous. Gourds, luffa, cucumber, melons, pumpkins, and a wide range of other cucurbits and some non cucurbit hosts	Major pest. Long considered as one of the world's most damaging tephritids.
B. decipiens	—	—	Papua New Guinea area: New Britain	Pumpkin	Serious pest of pumpkin. Potential pest of other cucurbits.
B. depressa	—	—	Japan (Ryu Ku Islands). Taiwan	Cucumber, pumpkin, tomato, watermelon	Serious pest
B. facialis	—	CUE	Tonga	Polyphagous, Avocado, bell pepper, citrus, guava, tomato and others	Major pest
B. jarvisi	—	CUE (weak)	Australia	Highly polyphagous. Apricot, banana, guava, mango, peach, pear, persimmon and others	Major pest
B. kirki	—	CUE	South Pacific: Austral Islands, Niue, American and Western Samoa, Tahiti, Tonga	Highly polyphagous. Apricot , banana, guava, mango, peach, pear, persimmon and others	Major pest
B. latifrons	Solanum fruit fly	CUE	China, India, Pakistan, Sri Lanka, Taiwan, Laos, Thailand, Malaysia, Vietnam, Adventive in Hawaii	Chilli, tomato, and solanaceous crops	Serious pest
B. melanotus	—	CUE	South Pacific: Cook Islands	Citrus, guava, mango	Major pest
B. musae	Banana fruit fly	ME	Australia: eastern Queensland, Papua New Guinea, Solomon Is., Bismark Archipelago	Banana, guava, papaya	Major pest of banana. Eggs laid in immature green fruit
B. neohumeralis	—	CUE	Australia, Papua New Guinea	Polyphagous. Apple, apricot, citrus, guava, tomato and others	Major pest, often simultaneously infesting fruit with *B. tryoni*
B. passiflorae	Fijian fruit fly	—	S. Pacific: Fiji, Tonga (Niuas Group only), Niue Island	Avocado, breadfruit, citrus, guava, mango, papaya	Major pest
B. psidii	—	CUE	S. Pacific: New Caledonia	Citrus, guava, mango	Serious pest
B. tau	—	CUE	Oriental Asia	Cucumber, luffa and a range of other cucurbits	Serious pest. Potential major pest of cucurbits
B. trivialis	—	CUE	Indonesia (Irian Jaya and Sulawesi), Papua New Guinea, Australia: Torres Strait islands	Guava, grapefruit, peach	Serious pest
B. tryoni	—	CUE	Australia: eastern Queensland and eastern New South Wales, Adventive in French Polynesia, Papua New Guinea and New Caldeonia	Highly polyphagous. Infests almost all commercial fruit crops except pineapple	Major pest
B. tsuneonis	Japanese orange fly	—	China, Japan (Ryu Ku and Kyushu Islands)	Citrus	Serious pest of citrus
B. tuberculata	—	ME	Myanmar, S. China, Thailand, Vietnam	Mango, peach persimmon and others.	Serious pest; host data lacking
B. umbrosa	—	ME	Indonesia, Malaysia, Philippines, Southern Peninsular Thailand, Papua New Guinea, Solomon Islands, Bougainville Island, New Caledonia and Vanuatu	Breadfruit, jackfruit	Serious pest
B. xanthodes	—	ME	Cook Islands, Fiji, Tonga, Vanuatu, Western Samoa	Breadfruit, bell pepper, citrus, guava, papaya, tomato	Major pest
B. zonata	Peach fruit fly	ME	India, Sri Lanka, Laos, Vietnam, northern Thailand (rare)	Polyphagous, Apple, citrus, guava, mango, sugar-apple, papaya, and others	Major pest

[a]ME - methyl eugenol; CUE — Cure-lure, 4-(p-acetoxyphenyl)-2-butanone

region currently flourishes without the worry of fruit fly infestation by harvesting banana at a green stage. Malaysia and other countries in the region have also been exporting bananas to Japan for several years based on the nonhost status of green banana. The banana fruit fly, if introduced, could drastically alter the current scenario in the Asian region.

Several other species mentioned in Table 2 could also have a highly deleterious effect on tropical fruit industries if they were to spread to new regions. Thus any efforts to seriously develop the tropical fruit industry in a country should also incorporate plans to monitor and minimise the accidental introductions of exotic fly species. Such plans should incorporate contigency measures to immediately contain accidental introductions and deal with outbreak situations so that establishment of new pest species does not occur.

Field Control and Management Strategies

Tropical Asia possesses a warm, equable climate that allows for continuous cultivation. Coupled with the common practice of monoculture of fruits, this provides an abundant and uninterrupted supply of host fruits for fruit flies to breed in and multiply rapidly. If left unchecked, it is common to find that adult populations of fruit flies easily build up to very high numbers and can destroy some fruit crops completely. Unprotected carambola, for example, readily suffers 100% damage (Vijaysegaran 1983). Breeding in wild host fruits may also contribute to high fly numbers.

Under such circumstances, the approach that has been adopted in most fruit growing regions in Southeast Asia has been to utilise a number of control/population suppression techniques in order to: 1) prevent direct damage to the fruits, and; 2) to reduce damaging populations of flies to tolerable levels. The various control techniques that are commonly used in tropical Asia have been reviewed by Vijaysegaran (1985; 1994) and are discussed below.

Insecticide cover sprays

The use of insecticides applied as cover sprays to the affected crops to prevent fruit fly damage is common practice in many Asian countries (FAO 1986). A wide range of insecticides are used, with the carbamate, organophosphate and synthetic pyrethroid types being preferred. These insecticides are usually applied on a calendar basis beginning at the time the respective fruits becomes susceptible to oviposition and continued at weekly intervals until about 1–2 weeks before the fruits are harvested (Rejesus et al. 1991; Meksongsee et al 1991; Isnadi 1991).

Insecticides, when used properly, are extremely useful compounds, but when misused, can lead to a number of problems. The following are important considerations in relation to tropical horticulture:

1. For some fruits like mango which are seasonal and bear one or two crops a year, insecticide use will be lower compared to other non-seasonal fruits like carambola, guava or sapodilla that fruit continuously throughout the year. For these non-seasonal fruits, continuous insecticide applications would have to be made and this is not a desirable practice.
2. Most fruits become increasingly susceptible to fruit fly damage close to harvest. It is a delicate problem in trying to prevent fruit fly oviposition and damage during this (harvest) period and at the same time ensuring that excessive insecticide residues are not present in the fruit.
3. If possible, insecticides should not be used as cover sprays when fruit flies are the only or major problem on the crop. Alternative control methods such as bait sprays may be more effective and safer. For example, in the Philippines, for mango, early in the season during flowering and early fruit development a foliage pest and other pests (other than fruit flies) necessitate the use of insecticide cover sprays which also provide some degree of fruit fly control. However, in the late stages of fruit development when other foliage insect pests are not important, protein hydrolysate bait sprays are used instead of insecticide cover sprays to prevent fruit fly damage (Rejesus et al. 1991).
4. In carambola cultivation where fruit flies are the major problem, and other insect pests minor, the regular use of insecticides as cover sprays for fruit flies has led to a host of other problems. Pollinating and other beneficial insects are severely affected by these cover sprays. Orchards that use cover sprays regularly were also observed to have persistent problems with other lepidopteran fruit borers, leaf and flower feeding caterpillars, and mites.

   Selected orchards that used only protein bait sprays for fruit fly control and conducted only 2–3 cover sprays or none at all in a year, were observed to be free of other pest problems (Vijaysegaran, unpublished data).
5. Regular insecticide applications on a calendar basis invite problems associated with insecticide resistance. This topic has been dealt with previously by Georghiou (1986). Although no case of resistance of fruit flies to insecticides in the field has been reported, the regular and continued use of insecticides in tropical areas could provide the environment for such an event to take place. This should be avoided.

Bait sprays

Attempts have been made by various workers to formulate a strong attractant or bait for both male and female fruit flies using an assortment of substances ranging from fruit juices to sugar, molasses and ammonia. However, none have met with as much success as protein baits (both hydrolysed vegetable protein and autolysed yeast). Steiner (1952) first showed the effectiveness of hydrolysed protein in poison bait formulations for fruit fly control. Since then, protein bait sprays have become a major method of suppressing or eradicating fruit fly populations in many parts of the world. What is surprising, however, is that there appears to have been little progress in bait spray technology, as the commercial protein formulations available now are quite similar to what Steiner used almost 40 years ago.

Recent studies on 'fruit fly type' bacteria (Drew et al. 1983) have shown that bacteria are an important natural source of food for adult fruit flies. These and later studies on attractancy of these bacteria to fruit flies in field cages (Drew and Fay 1988) and in carambola orchards (Vijaysegaran et al. 1990) indicate that some valuable information on new fruit fly attractants may be obtained by further in-depth research in this area.

The use of protein baits for fruit fly control, particularly for mango, has been reported in Thailand (Meksongsee et al. 1991), Philippines (Rejesus et al. 1991) and for carambola in Malaysia (Vijaysegaran 1989). However, the use of protein-based bait sprays is not as widespread as it should be.

A major factor is that protein baits used in Asian countries have to be imported from foreign sources, thus making them expensive and inaccessible to a large number of fruit growers. Also, many growers probably apply bait sprays in high volumes, much similar to insecticide cover sprays, thus providing little additional benefit. Research in Malaysia has shown that a protein bait formulated from brewer's yeast obtained as an industrial by-product, when applied in very low volumes as a spot spray, provided excellent control of fruit flies infesting carambola (Vijaysegaran 1989). Research should be conducted along similar lines in other countries in the region and the use of protein bait sprays should be promoted. Many of the undesirable side-effects experienced with insecticide cover spraying may thus be avoided.

Physical control (fruit wrapping or bagging)

Wrapping or bagging of individual fruits on the tree with paper bags to prevent oviposition and thereby produce fruit fly free fruit even in the presence of high adult fly populations is a control method which appears unique to some countries in Asia. In Malaysia, for example, carambola has been cultivated for over 70 years using this technique. In 1989, 17 000 tonnes of carambola worth 20 million Ringgit (US$8 million) were produced and exported to Europe, Hong Kong and Singapore using the bagging technique (Dept. of Statistics 1989). Fruit wrapping is also carried out for mango production in the Philippines, particularly in Cebu Island (Hapitan and Castillo 1976) and for a number of fruit crops in Taiwan (Cheng et al. 1991) where even a number of specially designed bags are produced for the industry, and finally in Thailand and Indonesia as well. Bagging is environmentally safe, it is effective, and can be used for a number of fruits such as carambola, mango, guava and some gourds but is not possible for others like papaya, citrus and sapodilla.

Crop hygiene

In tropical climates, uncontrolled breeding of fruit flies in poorly managed or abandoned orchards and in a variety of wild hosts results in high populations of adult flies. Orchard sanitation, i.e. collection and destruction of all unwanted fruit on the trees and on the ground, contributes significantly towards reducing damaging fly populations (Vijaysegaran 1985). While it is realised that orchard sanitation is important, it is somewhat difficult to implement and enforce. Removal of alternate and unwanted hosts is also a difficult problem in the tropics because of the wide host range and large number of alternate hosts of flies, particularly of the *dorsalis* complex. Well planned and carefully implemented government sponsored programs over large areas with grower cooperation are necessary for success with this method.

The most impressive record of destruction of host fruits to reduce fruit fly damage was reported from China by Yang (1991). *Bactrocera citri*, a serious pest of citrus in China, was controlled by orchard sanitation. In Jangjen county, Sichuan province, more than 8 million infested fruits were destroyed during the operation which lasted from 1951–1952. Infestation was reduced from 25% in previous years to 0.5% in 1953. In another exercise in Chenggu county, Shaanxi province, more than 17 million infested fruits were destroyed during 1953. The following year infestation fell from 80% to 5%. These sanitation programs are being maintained together with other suppression methods (baits etc.) for large area fruit fly control in China (Yang 1991).

Early harvesting

Development of fruit flies does not appear to occur in certain fruits such as papaya, sapodilla and banana

when they are 100% green, although (tree) ripe fruits are good hosts. Thus early harvesting is an important technique in the production of these fruits. For example, papaya var. Eksotika, a major export variety developed in Malaysia, if carefully harvested when a tinge of yellow appears on the skin (Harvest index 2), is completely free of fruit fly damage. In 1988, about 24 000 tonnes of papaya worth US$5 million were produced and exported using this early harvesting technique. Banana var. Mas is also free of fruit flies if harvested 100% green. Japanese Plant Quarantine authorities currently accept such banana without any other postharvest quarantine treatments for entry into Japan from Malaysia. Early harvesting is a useful control technique which may also be applied to other tropical fruits and needs to be investigated further.

Resistant varieties/non-host status

Some tropical fruits such as mangosteen (*Garcinia mangostana*), rambutan (*Nephelium lappaceum*) and duku/langsat (*Lansium domesticum*) are not normally attacked by fruit flies. Occasional damage may be observed when the fruit are over-ripe and/or cracked or damaged on the tree and such fruits support complete larval development. No control measures for fruit flies are required in the production of these fruits, although they are frequently found growing in areas with high endemic populations of fruit flies.

Sterile insect technique

The sterile insect technique (SIT) has seen successful application with the Mediterranean, Oriental and melon fly. These successes have elicited interest in the application of SIT to the fruit fly problem in Southeast Asia. Both Thailand and Philippines have conducted small-scale field experiments with release of sterile males (Meksongsee et al. 1991, Rejesus et al. 1991). The use of SIT will continue to receive attention and it is therefore important to address several pertinent issues relating to the application of this method in the Southeast Asia region.

Historically, SIT has been viewed as an eradication technique. Hooper (1991) proposed that if it was economically viable, SIT could also be used as a control technique. The application of SIT in Southeast Asian countries, whether for eradication or control, would face some unique problems not encountered in previous SIT programs. With the species complexes, often two or even three species may infest a single fruit and elimination of one species may result in resurgence of another. For example, Sultantawong (1991) reports an interesting study in Thailand (at Antkhang near Chiang Mai from 1984–1987) that used mass release of sterile flies to suppress natural populations of *B. dorsalis* and *B. correcta*. Damage to fruit was observed to decrease in the third year of the experiment but the following year, another species, *B. zonata*, became a major pest instead. This experience underlies the critical need, especially in the Southeast Asian region, to study the species complexes before embarking on SIT or similar programs.

Behavioral control

Apart from some information on the response to male lures such as methyl eugenol and Cue-lure, little is known about the pheromones, mating habits, attraction to colour and shape, etc. of fruit flies in Southeast Asia. Information in these areas is lacking for most flies described from this region and research along these lines could yield valuable information for improved trapping, male annihilation, mating disruption, etc.

Many of the damaging species known such as *B. carambolae*, *B. papayae* and *B. occipitalis* respond to methyl eugenol. Although widely used by growers because of the impressive catches of flies obtained, little organised work has been done using such male lures to suppress fly populations over large areas either alone or in combination with other methods such as bait sprays. There appears to be potential for developing a good population suppression system using protein bait sprays in combination with male annihilation.

Biological control

The use of natural enemies (parasites and predators) to suppress pest populations is desirable because it is relatively safe, permanent and economical. Several species of parasites and predators have been reported from Thailand (Meksongsee et al. 1991), Malaysia (Vijaysegaran 1983; Serit et al. 1986; Palacio 1990) and India (Agrawal and Mathur 1991). A major biological control effort against the Oriental fruit fly was carried out in Hawaii during the period 1947–1952 using importation of hymenopteran parasites collected from Malaysia and surrounding countries (Bess et al. 1961).

Southeast Asia and surrounding countries are undoubtedly a rich centre of diversity for fruit fly parasites. Further studies should yield some valuable new information on parasites and their role in population regulation.

It is generally felt however, that, as in the Hawaii experience, while introduction of natural enemies caused an overall reduction in fly populations, it was not sufficient to provide economic control in important crop hosts of economic importance (Newell and Haramoto 1968). The search for and

research on biological control agents should continue but they should not be solely relied upon as control agents and supplementary control methods have to be used.

Area-wide control

In general, many of the fruit fly control methods outlined above are practiced on individual farms and are targeted at the protection of individual fruit orchards. Such an approach would have little effect on the breeding population of flies inhabiting the general area. If many fruit farms are concentrated in a particular area it would certainly be highly advantageous if efforts could be coordinated to suppress fly populations over a large area to the benefit of all growers. Area-wide control, however, cannot be carried out by growers alone and such a program would require institutional planning and support. In Mauritius, it has been demonstrated that populations of four economically important species of fruit flies (peach fruit fly *Bactrocera zonata*, Natal fly *Ceratitis rosa*, medfly *Ceratitis capitata* and Ber fruit fly *Carpomya vesuviana*) can be effectively controlled over an area of 600 km^2 by using a combination of protein bait spraying and male lure trapping to the extent of achieving close to zero infestation in both wild and cultivated fruits (Soonnoo et al. 1996). So far no area-wide control programs have been attempted or implemented in the Southeast Asian region. It would be worthwhile and highly beneficial to the tropical fruit industries in the region if area-wide control programs were implemented. In addition, area-wide control would also support and strengthen the effectiveness of preharvest quarantine systems that may be in place and ensure even better quality of tropical fruits.

Preharvest quarantine system

A quarantine system as defined by Armstrong (1991) is a systems approach utilising various individual actions or treatments sequentially so that their combined effects will provide acceptable statistical probability of quarantine security. A sound quarantine system is indeed very useful as it can preclude the need for or modify the severity of postharvest disinfestation treatments. In Southeast Asia, however, the concept of developing a quarantine system has yet to be seriously considered, possibly because it is generally viewed as being quite impractical and too difficult to implement in the Southeast Asian context. However, the concept should be pursued and developed further because some of the fundamentals that are required to support such a system already seem to be in operation.

For example, both carambola (var. B10) and papaya (var. Eksotika) are hosts of fruit flies but a lucrative industry has been developed by growers of these fruit types who now export these fruits to several countries in Europe, as well as to Hong Kong and Singapore. In these countries, imports of tropical fruit are allowed without the need for postharvest disinfestation treatments or other quarantine measures because fruit flies are not considered pests of quarantine importance. It does not mean, however, that a shipment containing fruit fly infested fruits are accepted or tolerated. On the contrary, all fruit meant for the export market has to meet very rigid quality requirements with regard to the correct size, weight, colour, shape and being free from insect pests and diseases. To meet these requirements, several control practices for pests and diseases (cover sprays of insecticides and protein bait spraying during the early fruiting phase followed by fruit bagging which provides protection until harvest) are implemented to ensure that harvested fruits are practically free of pests and diseases. Harvested fruits are subject to manual sorting and grading during which each fruit is carefully inspected and infested fruit if any, are culled. These various procedures have enabled Malaysia to be the top carambola exporter in the world even though carambola is grown in areas where fruit fly populations are high. Thus, good opportunities exist to build upon the present carambola production system and to introduce further measures that may provide the components to meet the requirements of a preharvest quarantine system or even reduce the severity of postharvest quarantine treatments.

Similarly, papaya cultivated for the export market has also to meet rigid quality requirements. Fruits free of fruit fly infestation are produced by a combination of sound field control measures and careful harvesting of mature green fruits just before colour break. Mature-green papaya is resistant to fruit fly infestation because it contains linalool and benzyl isothiocyanate (Seo et al. 1983), the former compound being quite toxic to the eggs and larvae (Greany 1989).

Conclusion

The Southeast Asian region possesses a rich diversity of native and introduced fruits which have an international appeal and most countries have the potential to further develop the tropical fruit industry into a major income earner. In order to fully realize this potential, however, the fruit fly problem must be addressed. In particular, existing quarantine procedures must be reviewed and strengthened to ensure that spread of damaging species does not occur both

within and from outside the region. Despite several endemic species of fruit flies being present, production of quality fruit that meets with stringent export market requirements is made possible by implementing good field control measures and postharvest grading and selection operations. The potential exists to improve upon the existing production mechanisms to develop systems that approach a preharvest quarantine system. Coupled with institutionally supported programs targeted at area-wide population control or suppression, the fruit fly problem may be effectively managed and cease to be an obstacle to the further development of tropical fruit industries in the region.

Acknowledgments

The author acknowledges with thanks the Director-General of MARDI for permission to participate in this symposium, ACIAR and the Regional Fruit Fly Project in the South Pacific for providing financial assistance.

References

Agrawal, N. and Mathur, Y.K. 1991. The fruit fly problem associated with cultivated crops in India and its control. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 140–151.

Armstrong, J.W. 1991. Postharvest quarantine treatments in the tropics. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First international Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 49–59.

Bess, H.W., van den Bosch, R. and Haramoto, F.H. 1961. Fruit fly parasites and their activities in Hawaii. Proc. Haw. Entomological Soc. 17: 367–78.

Cheng, C.C. and Lee, W.Y. 1991. Fruit flies in Taiwan. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 152–160.

Department of Statistics, Malaysia. 1989. Annual Statistical Bulletin, 1989.

Drew, R.A.I., Courtice, A.C., and Teakle, D.S. 1983. Bacteria as a natural source of food for adult fruit flies (Diptera: Tephritidae). Oecologia (Berlin) 60: 279–284.

Drew, R.A.I. and Fay, H.A.C. 1988. Comparison of the roles of ammonia and bacteria in the attraction of *Dacus tryoni* (Froggatt) (Queensland fruit fly) to proteinaceous suspensions. J. Plant Prot. Trop. 5: 127–130.

Drew, R.A.I. and Hancock, D.L. 1994. The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. Bulletin of Entomological Research (1994) Supplement No. 2, 68 p.

FAO 1986. Report of the expert consultation on progress and problems in controlling fruit fly infestation. RAPA Publication No. 1986/28.

Georghiou G.P. 1986. Insecticide resistance: the Tephritidae next? Proceedings of the Second International Symposium on Fruit Flies, September, 1986, Crete, Greece, 27–40. Elsevier Science Publishers, Amsterdam.

Greany, P. 1989. Host plant resistance to tephritids: an under-exploited control strategy. In: Robinson, A.S. and Hooper, G., ed., World Crop Pests: Fruit Flies, Vol. 3A, Elsevier, 353–362.

Hapitan, J.C. Jr. and Castillo, B.S. 1976. Commercial mango production in the Philippines. Agric. Publishing Corporation, 35 p.

Hooper, G.H.S. 1991. Fruit fly control strategies and their implementation in the tropics. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First international Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 30–43.

Isnadi, S. 1991. The distribution of *Dacus* spp. in the Indonesian Archipelagos. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 99–107

Meksongsee, B., Liewvanich, A., and Jirasuratana, M. 1991. Fruit flies in Thailand. Proceedings of the First International Symposium on Fruit Flies in the Tropics, March 1988, Kuala Lumpur, Malaysia.

Newell, I.M. and Haramoto, F.H. 1968. Biotic factors influencing populations of *Dacus dorsalis* in Hawaii. Proc. Hawaiian. Entomol. Soc. 20: 81–138.

Palacio, I.P. 1990. Bioecology of Opiine parasitoids of Oriental fruit fly, *Bactrocera dorsalis* (Hendel). PhD Thesis, Universiti Pertanian Malaysia.

Rejesus, R.S., Baltazar, C.R. and Manoto, E.C. 1991. Fruit flies in the Philippines: Current status and future prospects. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 108–124.

Seo, S.T., Tang, C.S., Sanidad, S. and Takenaka, T.H. 1983. Hawaiian fruit flies (Diptera: Tephritidae): Variation of index of infestation with benzyl isothiocyanate concentration and colour of maturing papaya. J. Econ. Entomol., 76: 535–538.

Serit, M., Jaal, Z. and Tan, K.H. 1986. Parasitism of *Dacus dorsalis* Hendel in a village ecosystem in Tanjung Bunga, Penang, Malaysia. Proceedings of the Second International Symposium on Fruit Flies, September, 1986, Crete, Greece, 441–448.

Soonnoo, A.R., Smith, E.S.C., Joomaye, A., Permalloo, S. and Gungah, B. 1996. A large scale fruit fly control programme in Mauritius. In: Chua, T.H. and Khoo, S.G., ed., Problems and management of tropical fruit flies. Universiti Malaya. 52–60.

Steiner, L.F. 1952. Fruit fly control in Hawaii with poison bait sprays containing protein hydrolysates. J. Econ. Ent. 45: 838–843.

Sultantawong, M. 1991. Control of fruit flies *Dacus dorsalis* Hendel and *Dacus correctus* (Bezzi) by sterile insect technique at Antkhang, Chiang Mai. Report of the Office of Atomic Energy for Peace, Thailand.

van Sauers-Muller, A. 1991. An overview of the carambola fruit fly *Bactrocera species* (Diptera: Tephritidae) found recently in Suriname. Florida Entomologist 74, 432–440.

Vijaysegaran, S. 1983. The occurrence of Oriental fruit fly on starfruit in Serdang and the status of its parasitoids. J. Plant Protection in the Tropics, 1(2): 93–98.

Vijaysegaran, S. 1985. Management of fruit flies. In: Lee, B.S. and Heong, K.L., ed., Proc. Seminar on Integrated Pest Management in Malaysia, 1984. Malaysian Plant Proc. Soc., Kuala Lumpur, 231–254.

Vijaysegaran, S. 1989. An improved technique for fruit fly control in carambola cultivation using spot sprays of protein baits. National Seminar on Carambola: Developments and Prospects, 18–19 July 1989, Kuala Lumpur, Malaysia.

Vijaysegaran, S. 1994. Preharvest fruit fly control: strategies for the tropics. In: Champ, B.R., Highley, E. and Johnson, G.I., ed., Postharvest handling of tropical fruits, ACIAR Proceedings No. 50, ACIAR, Canberra, 228–303.

Vijaysegaran, S., Lum, K.Y., Drew, R.A.I., and Allwood, A.J. 1990. Attractancy of microorganisms isolated from the crop and mid-gut of fruit flies (Tephritidae: Diptera) to fruit flies in the field. Third International Conference on Plant Protection in the Tropics, March, 1990, Genting Highlands, Malaysia.

White, I.M. and Elson-Harris, M.M. 1992. Fruit flies of economic significance; their identification and bionomics. Wallingford, United Kingdom, C.A.B. International, 601 p.

Yang, Ping-Jun. 1991. Status of fruit fly research in China. In: Vijaysegaran, S. and Ibrahim, A.G., ed., Proceedings of the First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, 1988. MARDI, 161–168.

An Overview of Present and Future Fruit Fly Research in Hawaii and the US Mainland

J.W. Armstrong[1] and E.B. Jang[1]

Abstract

Fruit fly research in Hawaii and the US mainland is an important priority of the USDA Agricultural Research Service (ARS), with active research programs at several ARS laboratories that directly impact state, federal and foreign regulatory agencies, cooperators in universities and in domestic, import, and export fresh fruit industries. The research programs cover established species found in Florida and Hawaii, incursive species, such as Mexican fruit fly, *Anastrepha ludens* Loew, in the Rio Grande Valley of Texas, and species that present a threat of incursion through imported fresh fruits and vegetables, which include many different species of *Anastrepha* from Mexico, Central America, and South America. Presented here is an overview of fruit fly research in the US, including the research areas of fruit fly biology, ecology, parasites, rearing, trapping for detection and monitoring, containment and eradication technologies, and the development of quarantine treatments to open new or maintain existing export markets.

WORLD trade in fresh tropical fruits is expanding rapidly to meet increasing demands on existing markets and to supply new markets resulting from international trade agreements, such as the World Trade Agreement (General Agreement on Tariffs and Trade), European Union, North America Free Trade Agreement, ASEAN Free Trade Agreement, and others. The world market for fresh fruit, per se, increased 1.9% between October 1995 and February 1996 over the 12-month period preceding October 1995 and was valued at US$771 750 million (Anon. 1996). Evidence of the global expansion in fresh fruit markets is reflected by the market increases for US fruit exports during the October 1995 to February 1996 period, which included the Republics of the former USSR (64.5% increase), the non-European Union countries of West Europe (54.9% increase), the countries of North Africa (44.5% increase), the countries of Central America (33.2% increase), the combined four ASEAN countries of Indonesia, Malaysia, Philippines, and Thailand (27.6% increase), and the combined 15 countries of the European Union (20.5% increase) (Anon. 1996). Moreover, the US market for imported tropical fruits increased. During 1994, for example, imports of bananas (*Musa acuminata* Colla and hybrids of *M. acuminata* and *M. balbisiana* Colla), mangoes (*Mangifera indica* L.), papayas (*Carica papaya* L.), and pineapples (*Ananas comosus* Merr.) increased approximately 5%, 11%, 32%, and 3%, respectively, over the previous year (Klotzback 1995). Other tropical/subtropical fruits in the global marketing system include avocado (*Persea americana* Mill.), carambola or starfruit, (*Averrhoa carambola* L.), *Citrus* spp. and cultivars, durian (*Durio zibethinus* L.), guava (*Psidium guajava* L.), litchi (*Litchi chinensis* Sonn.), longan (*Euphoria longana* L.), mangosteen (*Garcinia mangostana* L.), and rambutan (*Nephelium lappaceum* L.).

Accompanying increased international trade in tropical fruits is the increased risk for inadvertently transporting quarantine pests to countries or regions where they do not already occur. Although quarantine pests include plant pathogens, insects, and nematodes, this discussion primarily concerns quarantine insect pests that may be on or in tropical fruits. Tropical fruits are hosts or vehicles of transport for a wide variety of quarantine insect pests that include, but are not limited to, many species of

[1] US Department of Agriculture, Agricultural Research Service, Tropical Fruit and Vegetable Research Laboratory, PO Box 4459, Hilo, Hawaii 96720

aphids, boring, souring or seed beetles, scales and mealybugs, moths, thrips, and tephritid fruit flies. Because the tephritid fruit flies as a group (1) comprise the most economically important of all the quarantine insect pests of tropical fruit, (2) are the largest number of economic species found in tropical fruit hosts, and (3) are distributed throughout all tropical fruit growing areas of the world (White and Elson-Harris 1992), most of the discussion and examples provided herein relate to them.

The introduction and potential establishment of new, exotic quarantine pests in agricultural areas can produce devastating economic results. Therefore, regulatory measures, such as post-harvest quarantine treatments (usually applied before export), are required to kill insects on or in tropical fruits. Post-harvest quarantine treatments include fumigation with toxic compounds, heat treatments, cold treatments, irradiation, non-host status and regulatory inspection protocols, and other technologies for ensuring quarantine security. Treatment monitoring and/or inspection by regulatory personnel are required to ensure quarantine treatment procedures and regulations, including handling requirements to preclude reinfestation after treatment, are followed. While simple exclusion of potentially infested fruit is an unsatisfactory response to quarantine requirements, failure to control the spread of insect pests can result in expensive quarantine and eradication procedures (Carey 1991), product losses due to infestation, and costly new quarantine treatment requirements (Dowell 1983). Therefore, exclusion becomes the only available quarantine tool in the absence of adequate quarantine treatments.

Quarantine problems are compounded not only by the rapid expansion of international trade in fresh fruits but also by international passenger traffic, along with shorter transit times. There may actually be more risk for introductions of exotic pest species from contraband fruit smuggled by airline passengers than commercial shipments of fresh fruits. For example, a special inspection effort by regulatory personnel of all passenger baggage coming through Los Angeles International Airport from selected Central and South American countries during one week in 1990 resulted in 677 interceptions of contraband fruits with a total weight of almost one ton. The intercepted fruit contained 61 live fruit fly larvae (Anon. 1990). These special inspection results contrast with an average interception rate of 434 contraband fruits for one week of random baggage inspections for all international arrivals. Increasing travel and trade means that quarantine barriers are becoming increasingly more difficult to maintain and new fruit fly introductions occur at an alarming rate (Carey and Dowell 1989).

The presence of four fruit fly species in Hawaii, the so-called Malaysian fruit fly (*Bactrocera latifrons* Hendel), Mediterranean fruit fly (*Ceratitis capitata* Wiedemann), melon fly (*B. cucurbitae* Coquillett), and Oriental fruit fly (*B. dorsalis* Hendel), serves as a reservoir for introductions into the subtropical areas of the US mainland regardless of quarantine barriers. Mediterranean fruit fly and Oriental fruit fly introductions into California have occurred annually since 1980, and such incipient introductions require expensive monitoring, containment, and eradication procedures that have exceeded US$350 million (Jackson and Lee 1985, R.V. Dowell, pers. comm.). The 1982–1983 establishment of the Mediterranean fruit fly in California also required quarantine treatment of host fruits before they could be shipped to other states or foreign markets.

Quarantined insect pests, especially tephritid fruit flies, have seriously disrupted fresh fruit marketing not only between countries, but also between geographical areas within countries (e.g. Florida to California, Hawaii to the Mainland US, Queensland to Victoria in Australia, Okinawa to Japan) unless accepted quarantine treatments are available. Without treatments to provide quarantine security, quarantine restrictions limit available markets for fresh tropical fruits. Therefore, effective post-harvest quarantine treatments that are not harmful to either the fruit or people coming in contact with or consuming the fruit are essential to the unrestricted trade of fresh tropical fruit through domestic and international marketing channels (Paull and Armstrong 1994).

Equally important to the research and development of quarantine treatments is the development of technologies, methods and strategies for eradicating incursive populations of exotic fruit flies. Specifically, the development of containment and eradication technologies, methods and strategies are predicated on an overall fruit fly research program that includes systematics; biology; ecology; physiological studies; trapping, detection, and population monitoring; bait and insecticidal formulations and applications; and field control measures.

Discussion

Many disinfestation procedures using chemical or physical treatments, or combinations thereof, are accepted by the regulatory agencies of most importing countries. However, prohibitions on the use of ethylene dibromide starting in the US (Anon. 1984, Ruckleshaus 1984) and effective almost internationally today, and potential impending restrictions on the use of methyl bromide (United Nations

Environmental Programme 1992, Watson et al. 1992) as post-harvest quarantine fumigants require the development and use of alternative treatments to toxic fumigants (Armstrong 1992). Current research efforts are directed to the use of physical disinfestation treatments, such as heat or cold, that may be more costly and difficult to apply than chemical treatments. Furthermore, many commercially important tropical fruits that are hosts of or vehicles of transport for quarantined pests have no approved disinfestation treatments. Therefore, it is obvious from a research perspective that the most immediate need is for quarantine treatments or systems to open and/or maintain the export and marketing of tropical fruits through quarantine barriers.

Before proceeding, some basic concepts of quarantine need to be defined:

1. *Quarantine host* is any tropical fruit that, at one or more of its growth stages, can be naturally infested in the field and support development of the pest.
2. *Quarantine treatment* is any individual (or multiple) action(s) or treatment(s) that can be used to disinfest host tropical fruits to ensure quarantine security.
3. *Quarantine system* is a systems approach that uses various individual operational components, each reducing the amount of infested fruit or infestation in the fruit until quarantine security is achieved.
4. *Quarantine security* is that degree of statistical probability needed by quarantine treatments or systems to disinfest host tropical fruits so that, upon transport or shipment of the treated fruits, the targeted pests cannot become established in any area where they do not already exist.

The last concept, quarantine security, is the most difficult to deal with because the 'degree' of statistical probability is not predicated on an internationally accepted statistical design. The US uses the Probit 9 concept (Baker 1939) corresponding to a mortality rate of 99.997% from which it can be inferred that no more than three individuals from a population of 100 000 will survive a quarantine treatment at the 95% confidence limit (Couey and Chew 1986). Japan often uses a variation of the Probit 9 concept that requires no survivors from a treated population of 30 000 target pests. The Probit 9 concept has come under increased scrutiny because it does not consider several factors that directly impact quarantine situations, such as the actual level of infestation of the host by the pest at harvest, the actual infestation per volume of treated fruit, the potential for culling infested fruits during processing, the infestation variability between good hosts and poor hosts, or the probability of a potential normal mating pair occurring at the same time at the market destination. Alternative quarantine statistics that challenge the Probit 9 concept have appeared in the literature (Landolt et al. 1984; Robertson et al. 1994), but few changes in quarantine statistics have occurred, except in New Zealand which developed the concept of maximum pest limits for pests in imported produce (Baker et al. 1990). Maximum pest limit statistics include a sampling model for the accurate assessment of infestation levels in the host fruit and a limit on the number of immature fruit flies that may be present in consignments imported during a specified time to a specified location (Baker et al. 1990). Application of a treatment of known efficacy ensures that the limit is not exceeded if the infestation, determined by the sampling model, is below a predetermined value (Baker et al. 1990).

It is more difficult to develop quarantine treatments or systems for pest organisms when more than one life stage is present on or in the host fruit because the stage that is most difficult to kill must be determined. For example, the egg and pupal stages may be more tolerant to fumigants than larval or adult stages because of lower metabolic and respiration rates. The location of the pest organism also affects the type and severity of quarantine treatment or system required to disinfest the fruit because the different life stages can be on the surface or inside the host fruit in the pulp, seed cavity, or seed. Pests with life stage(s) only on the surface of the host fruit are generally more susceptible to treatments because they are more exposed. Insects with life stage(s) inside the host fruit require more severe treatments because penetration by the treatment into the fruit is needed to cause insect mortality (Paull and Armstrong 1994).

Quarantine treatment technologies available today that are alternatives to fumigation with toxic compounds include the application of heat to increase the temperature of the host fruit above the thermal limits of the target pest, the application of cold to decrease the temperature of the host fruit below the thermal limits of the target pest, or irradiation to kill or sterilise the target pest. Although some insecticides, such as dimethoate or fenthion incorporated in fruit immersions or sprays, were used as post-harvest disinfestation treatments (Saunders and Elder 1966; Smith 1977; Swaine et al. 1984; Heather et al. 1987) against banana fruit fly, *B. musae* (Tryon), or Queensland fruit fly, *B. tryoni* (Froggatt), the practice has not gained widespread acceptance. Even 'relatively safe,' narrow-spectrum compounds, such as the insect growth regulator methoprene that when incorporated into waxes and applied to fruit provided substantial fruit fly mortality (Saul et al. 1985, 1987; Saul and Siefert 1990), have not found commercial

use as disinfestation treatments. The future of pesticides as post-harvest disinfestation treatments is limited by both the lack of available, 'safe,' and acceptable compounds, the prohibitive costs involved in developing, testing, and registering new pesticides, and the consumer-driven trend toward reducing chemical residues in foods and new laws governing food safety and additives. The following is a brief review of available and potential quarantine treatment technologies and methods for tropical fruits. Although the majority of quarantine treatments development for fruit fly hosts of export importance is done in Hawaii and the US mainland, important contributions have been made by other countries, primarily Australia, Japan, and New Zealand. Credit is given herein for this research effort because it should not be overlooked.

Heat treatments

Heat disinfestation treatment methods consist of forced hot-air (Animal and Plant Health Inspection Service 1996a; Armstrong et al. 1989a, b, 1995; Gaffney and Armstrong 1990; Mangan and Ingle 1992, 1994; Sharp 1992, 1993; Sharp et al. 1991; Sharp and Gould 1994; Sharp and Hallman 1992; Shellie et al. 1993; Williamson et al. 1991; Williamson and Winkelman 1989; Winkelman and Williamson 1990), vapor heat (Animal and Plant Health Inspection Service 1996b; Hallman G.J. 1990; Heard et al. 1992; Sunagawa and Iwaizumi 1987, 1988), and hot-water immersion (Animal and Plant Health Inspection Service 1994; Gould and Sharp 1990b; Hallman and Sharp 1990; Nascimento et al. 1992; Segarra-Carmona et al. 1990; Sharp et al. 1988, 1989a, b, c; Sharp and Picho-Martinez 1990). Heat treatments are relatively easy to apply, have potential for both fungicidal and insecticidal activity, and leave no chemical residues. The disadvantages are the potential for fruit damage, that must be researched on a fruit-by-fruit basis (Armstrong and Couey 1989; Paull 1990). Forced hot-air and vapor heat treatment methods are essentially the same, except that water condenses on the fruit surfaces during vapor heat treatment and the fruit surfaces remain dry during forced hot-air treatment (Armstrong 1994a; Williamson and Winkelman 1989; Winkelman 1990). Forced hot-air quarantine treatments were developed for carambola (Sharp and Hallman 1992), citrus (Mangan and Ingle 1994; Sharp and Gould 1994; Shellie et al. 1993), mango (Animal and Plant Health Inspection Service 1996a; Mangan and Ingle 1992), and papaya (Armstrong et al. 1989a, b, 1995). Hot-water immersion quarantine treatments were developed to disinfest fruit flies from bananas (Armstrong 1982), papayas (Couey and Hayes 1986; Hayes 1994), guavas (Gould and Sharp 1990b), and mangoes (Animal and Plant Health Inspection Service 1994; Naciemento et al. 1992; Segarra-Carmona et al. 1990; Sharp 1986, 1989; Sharp and Spalding 1984; Sharp et al. 1988, 1989a, b, c; Sharp and Picho-Martinez 1990).

Cold treatments

Cold disinfestation treatments (Animal and Plant Health Inspection Service 1996c; Armstrong et al. 1985b; Chan 1994; Gould and Sharp 1990a; Jessup, 1991, 1994; Jessup and Baheer 1990; Lee 1991; Nishijima et al. 1995; Sanxter et al. 1994) have the same advantages as heat treatments in that they are easy to apply and they leave no chemical residues. Cold treatments were recommended for many years following the observations that refrigeration was an effective quarantine treatment against Mediterranean fruit fly (Hooper 1907; Lounsbury 1907; Back and Pemberton 1916). Cold disinfestation treatments are used today against many fruit fly species in a wide range of fruits (Animal and Plant Health Inspection Service 1996c; Rippon and Smith 1979; Benschoter 1984, 1988; Hill et al. 1988). The eggs and larval stages of fruit flies are killed by exposure to temperatures below 10 °C. However, only temperatures below 3 °C are practical because of the long exposure times involved (10 days or longer at 0 °C) (Burditt and Balock 1985; Armstrong and Couey 1989). The lengthy treatment periods required for quarantine cold disinfestation are disadvantageous because of the large volume of treatment facilities that must be dedicated for that purpose alone. However, quarantine cold treatments are used successfully and have the advantage that, with the proper equipment, they may be applied in transit (Animal and Plant Health Inspection Service 1996c; Armstrong and Couey 1989).

Washing

The simple technique of washing may be used as a quarantine treatment for pest organisms found on the surface of host fruits. The addition of a detergent (insecticidal soaps) increases the effectiveness of washing by dissolving the waxy epicuticle of insect pests and causing rapid drowning (Waller 1990; Hata et al. 1992). Additionally, the use of hot-water washing may kill surface pest organisms if the thermal limits of the target pest are exceeded. Combinations of soapy water and wax to disinfest mites from cherimoya (*Annona cherimola* Mill.), or of warm, soapy water and brushing to disinfest mealybugs, scales and other insects from the surface of durian are accepted quarantine treatments by the US (Animal and Plant Health Inspection Service 1994).

Irradiation

Irradiation of fresh fruit up to a maximum dosage of 1.0 kilogray (kGy) for insect disinfestation was approved by the US Food and Drug Administration (FDA 1987). Although there are some disadvantages in using irradiation (Maxie et al. 1971; Paull and Armstrong 1994), it is a viable quarantine treatment technology against many quarantine insects in tropical fruits, such as disinfesting fruit flies from avocado, banana, citrus, litchi, mango, papaya, and others (Burditt et al. 1971; Burditt and Seo 1971; Heather 1986), or mango weevil (*Chryptorhynchus mangiferae* F.) from mango (Seo et al. 1970). Excellent overviews of irradiation disinfestation treatments for fresh horticultural crops, and the efficacy of irradiation against quarantine pests, were provided by Burditt (1994), Morris and Jessup (1994), and Nation and Burditt (1994).

Controlled or modified atmospheres

Controlled atmospheres (reduced O_2 elevated CO_2, and/or added CO_2) were evaluated as possible insect control treatments in a number of stored grains, dried fruits, and tree nuts with positive results (Carpenter and Potter 1994; Hallman 1994). Unfortunately, most fresh tropical fruits do not tolerate those controlled atmosphere treatments found effective for insect control in dry stored products. Although there is also very little information on the responses of quarantine pests of tropical fruit to controlled atmospheres, controlled atmospheres usually do not penetrate fruit surfaces very well and, therefore, may not directly affect such pests as fruit flies or mango weevil that are found in the fruit flesh or inside the seed, respectively. Kader and Ke (1994) reported their work and the studies of others that showed fresh fruits tolerate longer storage periods at lower temperatures under controlled atmosphere conditions (< 0.5% O_2 vol/vol and 1.1 °C) than under normal storage atmospheres. Decreasing temperatures may further limit any disinfestation value of controlled atmospheres because the metabolism and respiration of the target pests would decrease in the cold environment. However, the controlled atmospheres are potentially useful in protecting cold-sensitive fruits at low temperatures for times required to complete quarantine cold treatments against the target pests.

Microwaves and ultrasound

Microwaves, or dielectric heating, is limited because heating is non-uniform and from the centre of the fruit outward. Although pulsed microwave treatments showed potential for inducing mortality in mango weevil (Seo et al. 1970), the available technology has not been applicable for use in quarantine treatments (Armstrong 1992). An excellent overview of the history, application, and potential use in quarantine treatments for microwave technology was provided by Hallman and Sharp (1994).

Ultrasound was shown to cause mortality of fruit fly eggs and larvae (Horner 1979), but this treatment method was limited by its inability to penetrate fruit, such as papaya, to depths where fruit fly eggs and larvae could be found (Hayes 1982; Hayes et al. 1983). Although ultrasound may have some potential for removing insects from fruit surfaces, possibly in combination with washing treatments, the available technology does not appear applicable for use in quarantine treatments against target pests found below the fruit surface (Armstrong 1992).

Commodity resistance and nonhosts

Nonhost or infestation-resistant fruits and cultivars, stages of maturity of hosts, and growing periods have received little attention as alternate approaches to quarantine, perhaps because of the difficulty in developing supporting data and the necessary reliance on inspection to maintain quarantine security. A nonhost for a given quarantine pest is a fruit which is not attacked during any stage of growth or maturity by that pest. For example, commercially grown 'Smooth Cayenne' pineapple in Hawaii is a nonhost for melon fly and Oriental fruit fly (Flitters et al. 1953), and pineapple cultivars with 50% or more 'Smooth Cayenne' parentage also appear to be nonhost for these fruit fly species (Armstrong et al. 1979; Armstrong and Vargas 1982; Seo et al. 1973). The fruit may have some chemical attribute(s) that either preclude attack or cause mortality to the eggs or larvae of attacking pests (Armstrong 1994b).

Fruits may have a nonhost stage of maturity. Some fruits that are hosts for fruit flies are not infested at early stages of maturity. Harvesting a host at the noninfested stage of maturity can be used to avoid the need for a quarantine treatment (Armstrong 1994b). Heather (1985) reported that green tomatoes are not a host for Queensland fruit fly and are therefore exported from Queensland to Victoria without a quarantine treatment. This is probably not a good example as green tomatoes have been recorded as hosts of *B. tryoni* by R. Drew and A. Allwood (pers comm.). Another example is banana, which can be infested by Mediterranean fruit fly, melon fly or Oriental fruit fly when mature, but is not infested at the mature green stage of ripeness (Back and Pemberton 1916; Armstrong 1983).

Many fruits that have partial resistance to infestation by quarantine pests fall into the often misused

category of 'poor' hosts. Generally, poor hosts are fruits that have high titres of specific chemical and/or physical deterrents. These deterrents are found in abundance during early stages of maturity and dissipate as the fruit senesces. Greany (1989) and Seo et al. (1983) correlated chemical components in citrus and papaya, respectively, that were deterrents to fruit fly oviposition and deleterious to larval development. Many different fruits are relatively resistant to fruit fly infestation and considered poor hosts (Armstrong 1994b). Unfortunately, a relatively resistant fruit is still a host, albeit a poor one. Other measures must be taken to ensure quarantine security if no quarantine treatment is used. For example, grapefruit and other citrus are poor hosts for Caribbean fruit fly, especially at early harvest maturity (Calkins and Webb 1988). A quarantine protocol was developed to permit the shipment of early-season grapefruit from Florida to California without quarantine treatment. The protocol consists of harvesting grapefruit or other citrus during a specified time period from areas certified free of Caribbean fruit fly based on trapping or bait spray procedures (Armstrong 1994b).

Infestation-resistant or nonhost fruits, cultivars, stages of maturity, and growing periods offer alternatives to classical quarantine treatment technologies. Sorting or culling operations for fruits that are poor hosts also may be useful. Developing these strategies may require much more biological data from field and laboratory studies and more complex statistical approaches to ensure quarantine security than used for classical quarantine treatments, and inspection may be the essential element to successful application (Armstrong 1994b). The most probable use of resistance to infestation will be in the development of quarantine systems approaches that incorporate risk assessment, maximum pest limits, fruit sampling, trapping, and other population and infestation estimation methods, and that may or may not include a quarantine treatment (Jang and Moffitt 1994).

Systems approaches

According to Jang and Moffitt (1994), systems approaches differ from classical quarantine treatments because they attempt to integrate biological and operational factors into a 'model' that ensures quarantine security. Unlike fruit that are considered nonhosts, systems approaches begin with the fruit as a known host, with the level of infestation in the host as the key component in the design of the overall system. Systems approaches rely on knowledge of the infestation level of the host and measure the impact of the various operational procedures on removing infested hosts, thereby reducing the risk that infested fruits will be shipped. Systems approaches can be differentiated from single, direct quarantine treatments in which the treatment alone is sufficient to provide quarantine security. Systems approaches should also be separated from the concept of combination and multiple treatments comprised of two or more direct treatments which, if used alone, would not be sufficient to achieve quarantine security. However, a direct treatment can be a component of a systems approach if the treatment cannot provide quarantine security unless it is combined with other operational parts of the system.

The operational factors that may be incorporated into systems approaches include, but are not limited to, production practices that reduce or limit the pest population in the field (e.g. integrated pest management), infestation indices during the production season for all stages of maturity or growth, field populations of pests, defined levels of economic thresholds or economic injury, fruit sampling methods, harvesting practices, sorting and culling procedures, packing and holding conditions, efficacy of any direct treatments used to reduce infestation, prevention of reinfestation, inspection and certification procedures, and shipping and distribution conditions, (Jang and Moffitt 1994). For example, Cowley et al. (1991) described a systems approach that included a direct methyl bromide fumigation treatment to disinfest potential infestations of *B. xanthodes* (Broun) from watermelons (*Cucumis melo* L.) exported from Tonga to New Zealand. Their system incorporated a bilateral agreement with the exporting country, biological information on the infestation levels in export quality melons, and a treatment sufficient to meet the maximum pest limit (Baker et al. 1990) established for the fruit.

Fruit quality

The development of quarantine disinfestation treatments is often complicated by fruit sensitivity to available treatment technologies, and commercial quarantine treatments often involve a compromise between meeting regulatory requirements while accepting some reduction in fruit quality. However, disinfestation treatments should have minimal deleterious effects on the fruit undergoing treatment because a quarantine treatment that reduces the value of the fruit is not fully efficacious.

An excellent overview of quality maintenance in the development and application of quarantine treatments was provided by McDonald and Miller (1994). Specific reviews of physiological and biochemical responses were provided by Forney and Houck (1994) for chemical treatments, by Morris and Jessup

(1994) for irradiation treatments, by Paull and McDonald (1994) for heat and cold treatments, and by Kader and Ke (1994) for controlled atmospheres.

A thorough understanding of the effects of quarantine treatments on both the target pest and the host fruit can result in unique methods to ameliorate fruit damage caused by the treatments. For example, Jessup (1991), Nishijima et al. (1995) and Sanxter et al. (1994) described preconditioning methods using heat to increase the tolerance of avocados to quarantine cold treatments. Chan and Linse (1989a, b) described preconditioning cucumbers with heat to tolerate quarantine heat treatments at much higher temperatures.

Entomologists and post-harvest physiologists must work together to develop insect dosage-mortality information following standardised protocols to determine the treatment levels required to ensure quarantine security without loss of fruit quality aspects, such as appearance, texture, flavor, shelf life, odor, and nutritive value (Paull and Armstrong 1994).

Other Fruit Fly Research Areas

In addition to the research and development of quarantine treatments is the equally important development of technologies, methods and strategies for eradicating incursive populations of exotic fruit flies. Specifically, the development of containment and eradication technologies, methods and strategies are predicated on an overall fruit fly research program that includes systematics; biology; ecology; physiological studies; trapping, detection, and population monitoring; bait and insecticidal formulations and applications; and field control measures. The following outlines the work in progress in Hawaii and the US mainland.

Biology, ecology and physiology studies

Studies on the biology, ecology and physiology of tephritid species in the US has been the basis for most of the subsequent applied work done for control of these pests. Early ecological research conducted on tephritids established in Hawaii has been applied to many other tropical species of tephritids. Studies on host finding, dispersal, and various aspects of behavior such as the role of 'learning' and host acceptance has resulted in numerous studies in the laboratory, field cages and in the natural environment. Mating behavior for most of the tropical tephritid species in Hawaii and Florida has been extensively studied. Many of *Anastrepha* species have also been looked at. All flies are thought to have a complex and varied behavioral repetoire which is dependent on environment as well as inherent genetic differences. Some species of flies mate in the morning (medfly) while others prefer to mate at dusk (*Bactrocera* sp.).

Feeding and nutritional research on tephritids has been largely empirical with many species raised on holitic diets which contain crude mixtures of yeast, sugar, and either wheat, corn cobs, sugar cane bagasse or soy flour. Methods for mass-rearing of these tephritids have followed historical lines with incremental improvements being made along the way. Even so, the ability to rear several species of flies for Sterile Insect Technology (SIT) has been impressive. Reproductive studies have been carried out primarily to identify the optimum times needed to rear flies and collect eggs from females. Many species have benefited from the presence of olfactory (or gustatory) stimuli to help in the egging process. For example, certain of the *Bactrocera* prefer to lay eggs in artificial devices containing extracts of host plants.

Demographic and spatial models have been well researched for many species such as the medfly and very little for other species. Currently there is a lot of interest in understanding demographics as it relates to invasion biology of many tephritid species into areas such as California where the flies do not normally occur.

Detection and delimitation

One of the most studied areas of tephritid fruit fly biology in the US is the application of attractant 'traps' and 'baits' for use in detection and delimitation of fruit fly populations. The idea is to develop technology to be able to detect introductions of fruit flies when they occur and develop improved methods for control and eradication where flies exist. The research in the US ranges from highly sophisticated electrophysiological studies in the sensory system of fruit flies, to screening programs where candidate chemicals are tested without much regard to their origin. While both methods have their strengths and weaknesses, many of the male attractants developed in the 1950s are still in use today. Attractants other than the proteinaceous food baits are not available for some tephritids in the *Anastrepha* group.

The basis for most census and detection of fruit flies are the male lure or parapheromones and the proteinaceous baits. The male lures represent a powerful group of semiochemicals, some of which have been found to have a biological link in nature while for others the precise role of these compounds to the chemical ecology of these species is largely unknown. For the many species of fruit flies which

are not attracted to male lures, such as much of the *Anastrepha* sp., proteinaceous baits are the only semiochemical tools available.

Proteinaceous food baits remain as one of the few attractants which attract both males and females of most tropical tephritid species. Research aimed at identifying the active components in the protein have uncovered a large number of nitrogenous compounds, many of which are thought to be secondary components of microorganism metabolism. For example, several species of bacteria are thought to play a role in breakdown of proteins to secondary compounds. Among the classes of compounds have been pyrazines, putrescine and delta-1-pyroline. Bird faeces, hydrolysed chicken feathers and bacteria identified from tephritids have all been reported to be attractive to tephritid fruit flies.

Perhaps the most obvious need in this area is the development of female attractants for all species which will complement the currently available male lures. Central to this research is the need to understand the differences between male's and female's need for food, mating and oviposition (females). Recent research in Hawaii has shown that females are different in their behavior from males and that female behavior is closely linked to the physiological state that she is in. For example, newly emerged female may be more attracted to proteinaceous food attractants in search for 'food' for which to develop her eggs. This behavior may then change as she becomes sexually mature and she becomes more responsive to pheromone. Lastly, after mating the female is focused on finding suitable oviposition sites and thus will respond to fruit odors from ripening fruit.

Traps and formulations

In addition to a wealth of new studies on putative attractants for tephritid flies, have been studies to improve the traps used to capture flies in detection and census programs. Historically, the Jackson or delta trap has been the 'dry' trap of choice for action programs based primarily on its ease of use. More recent studies have shown that other designs are superior to the Jackson trap for several fruit flies. These include the Lynfield trap developed in New Zealand, the yellow sticky panel trap, the cylinder trap and the C&C trap all developed in the US. These traps combine visual clues and/or shapes with insecticides or stickum to kill or capture the attracted flies. These traps have also incorporated new 'slow-release' technology to ensure constant release rates over weeks to months periods. Such technology greatly relieves the need to service traps on a daily or weekly basis thus reducing labor costs.

New designs for liquid traps have not been forthcoming, due primarily to the difficulty in servicing such traps in detection programs. Improvements have however been made in the material used to build the classic 'McPhail' trap which now includes high-impact plastics.

Systematics

Several groups are actively involved in the use of molecular techniques to try to identifiy the origin of exotic fruit fly introduction into the US. Using techniques such as mitochondrial and nuclear DNA fingerprinting, they are hoping to determine if trapped flies originated from particular areas of the world. Work on Medfly is of course most active due to the widespread establishment of this fly in areas from Europe to Brazil to Hawaii and Australia.

Control and eradication

Two control technologies, the sterile insect technique (SIT) and male annihilation trapping continue to have high research priority for tephritids in the US. In both cases, the technologies are not new but several improvements have been made to improve the effectiveness of the control strategies. Male annihilation refers primarily to the use of the male attractant methyl eugenol with a toxicant which kills the flies. Male attractants for other species are either not powerful enough or not available for other fruit fly species. Reseach in the Hawaii has centred on finding more powerful analogs to methyl eugenol through synthetic modifications of the benzene ring. Similar work is being done to find more effective attractants for Medfly (Trimedlure) and melon fly (Cue-lure). Ceralure, a iodo-analog of the trimedlure molecule and alpha-copaene, a natural product, are improved medfly male lures. Alpha-ionol, the active ingredient of the male attractant for the Malaysian fruit fly (*B. latifrons*), has also been looked at.

Xanthene dyes have recently been rediscovered as an apparent 'insecticide' having neglegible mammalian toxicity. These dyes which are used in the cosmetic industry have the unique property of being photoactive and thus able to adversely affect the insect's digestive system when the animals are exposed to light. The mode of action of the xanthene dyes are thought to involve the formation of monomolecular oxygen radicals which bind to the gut. Intensive research is currently being carried out on both Medfly and Mexican fruit fly with very promising results. The effectiveness of the dyes are related to the amount of dye ingested by the flies. The use of xanthene dyes as replacements for conventional insecticides promises to be a major

technology to be used with fly attractants and feeding stimulants.

SIT is the method of choice for control of flies which are not attracted to methyl eugenol and for which mass-rearing and sterilisation protocols have been worked out. Most research in the US has centred on the use of SIT to control medfly. Research has centred on improved mass-rearing of medfly, and the development of all male strains for use in SIT. Dietary improvements include a better understanding of the physiochemical characteristics of the medfly diet, control of pH in the diet, identification of pathogens in the diet and reduction of dietary sugar levels.

All male strain development has included the earlier work on a pupal color strain as well as the more recently studied temperature sensitive lethal (TSL) strain. The pupal color mutant was a strain in which the male pupae were brown and the female pupae white. This difference could be sorted out using a machine. The more recent TSL strain has a conditional lethal attached to the female chromosone which kills the female embryo at a lethal temperature. Males remain unaffected.

Biological control of fruit flies has been another research area which has had high visability in the US. Both classical and augmentative biocontrol programs are active in Hawaii and Florida. In Hawaii, an opiine egg parasitoid of the tephritid fruit flies (*Fopius arisanus*) is being mass-reared in the laboratory. Biological studies in anticipation of the field testing of this parasitoid are currently underway. Another parasitoid (*Psyttalia fletcheri*) has been found to be a good parasitoid for melon fly in Hawaii. Researchers continue to be on the lookout for parasitoids found in nature which could complement the existing species in Hawaii. The use of bacteria, fungi and pathogenic viruses have not kept pace with research on parasitoids.

Future Research Plans

The ARS research plans for all aspects of fruit fly research are clearly identified in the *USDA-ARS Action Plan for Fruit Flies Research* (USDA 1992) and the *Fruit Fly Research: 1993 Supplement to the USDA-ARS Action Plan* (USDA 1993). The 1992 Action Plan, a five-year plan, is the operating mechanism committing ARS to specific areas of research over a five-year period. The 1993 Supplement added components that needed to be addressed to complete the original Action Plan. The present research plan, developed in 1992, will be updated again in 1997. The updating of the Action Plan will include a review of accomplishments and the setting of new goals for the subsequent five-year period. The primary thrust of ARS research now and for the immediate future will be the development of alternative quarantine treatments to methyl bromide fumigation.

Conclusion

Increasing world trade in tropical fruits requires disinfestation treatments to open and maintain marketing channels through quarantine barriers while ensuring that quarantine pests are not transported along with the fruit. No single quarantine treatment or system can be expected to work equally against all quarantine pests of tropical fruits, and the response of both fruit and pest to any treatment can vary greatly. With the loss of or potential restrictions on the use of toxic fumigants, and the trend toward reducing toxic residues from insecticide in foods, industry will depend increasingly on physical treatments using heat, cold, or washes, irradiation, controlled or modified atmospheres, quarantine protocols based on nonhost status or systems approaches, and other technologies and methods to ensure quarantine security while maintaining fruit quality.

References

Animal and Plant Health Inspection Service. 1994. T102—Water treatment. In: Plant Protection and Quarantine Treatment Manual. 5.45–5.50. US Dept. Ag., Hyattsville, Maryland, USA.

Animal and Plant Health Inspection Service. 1996a. T103—High temperature forced air. In: Plant Protection and Quarantine Treatment Manual. 5.51–5.53. US Dept. Ag., Hyattsville, Maryland, USA.

— 1996b. T106—Vapor Heat. In: Plant Protection and Quarantine Treatment Manual. 5.57–5.58. US Dept. Ag., Hyattsville, Maryland, USA.

— 1996c. T107—Cold Treatment. In: Plant Protection and Quarantine Treatment Manual. 5.59–5.65. US Dept. Ag., Hyattsville, Maryland, USA.

Anon. 1984. Ethylene dibromide: amendment of notice to cancel registration of pesticide products containing ethylene dibromide. Congressional Federal Register 49: 14182–14185. US Govt. Printing Office, Washington, DC, USA.

Anon. 1990. Fruit flies found in luggage in inspection of LA airport. The Packer, June 9, 1990, page 17A.

Anon. 1996. US exports of fresh fruit, FY1991–1995 and year-to-date comparisons. US export/import statistics for bulk, intermediate, and consumber oriented foods and beverages (BICO Report). US Bureau of the Census Trade Data, Trade and Marketing Analysis Branch, Foreign Agric. Service, US Department of Agriculture, Washington, DC, USA.

Armstrong, J.W. 1982. The development of a hot water immersion quarantine treatment for Hawaii-grown Brazilian bananas. J. Econ. Entomol. 75: 787–790.

Armstrong, J.W. 1983. Infestation biology of three fruit fly (Diptera: Tephritidae) species on 'Brazilian,' 'Valery,' and 'William's' cultivars of banana in hawaii. J. Econ. Entomol. 76: 539–543.

Armstrong, J.W. 1992. Fruit fly disinfestation strategies beyond methyl bromide. New Zealand J. Crop and Hort. Sci. 20: 181–193.

Armstrong, J.W. 1994a. Cold and heat disinfestation treatments. In: Paull, R.E. and Armstrong, J.W. eds., Insect Pests and Fresh Horticultural Products: Treatments and Responses. 103–119. C.A.B. International, Wallingford, Oxon., UK.

— 1994b. Commodity resistance to infestation by quarantine pests. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants. 199–211. Westview Press, Boulder, Colorado, USA.

Armstrong, J.W. and Couey, H.M. 1989. Fumigation, heat, and cold. In: Robinson, A. S. and Hooper, G., eds., World Crop Pests, Vol. 3A, Fruit Flies, Their Biology, Natural Enemies, and Control. 411–424. Elsevier, Netherlands.

Armstrong, J.W. and Vargas, R.I. 1982. Resistance of pineapple variety '59-656' to field populations of oriental fruit flies and melon flies (Diptera: Tephritidae). J. Econ. Entomol. 75: 781–782.

Armstrong, J.W., Hansen, J.D., Hu, B.K.S. and Brown, S.A. 1989a. High-temperature forced-air quarantine treatment for papayas infested with tephritid fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 82: 1667–1674.

— 1989b. Hot air disinfestation of fruits and vegetables. Patent serial No. 07/270/608, issued March 11, 1989.

Armstrong, J.W., Silva, S.T. and Shishido, V.M. 1995. Quarantine cold treatment for Hawaiian carambola fruit infested with Mediterranean fruit fly, melon fly, or Oriental fruit fly (Diptera: Tephritidae) eggs and larvae. J. Econ. Entomol. 88: 683–687.

Armstrong, J.W., Silva, S.T. and Shishido, V.M. 1995b. Quarantine cold treatment for Hawaiian carambola fruit infested with Mediterranean fruit fly, melon fly, or oriental fruit fly (Diptera: Tephritidae) eggs and larvae. J. Econ. Entomol. 88: 683–687.

Armstrong, J.W., Vriesenga, J.D. and Lee, C.Y.L. 1979. Resistance of pineapple varieties 'D-10' and 'D-20' to field populations of Oriental fruit flies and melon flies (Diptera: Tephritidae). J. Econ. Entomol. 72: 6–7.

Back, E.A. and Pemberton, C.E. 1916. Effect of cold-storage temperatures on the Mediterranean fruit fly. J. Agric. Research 5: 657–666.

Baker, A.C. 1939. The basis for treatment of products where fruit flies are involved as a condition of entry into the United States. US Dept. Agric. Circ. 551. 8 p.

Baker, R.T., Cowley, J.M., Harte, D.S. and Frampton, E.R. 1990. Development of a maximum pest limit for fruit flies (Diptera: Tephritidae) in produce imported into New Zealand. J. Econ. Entomol. 83: 13–17.

Benschoter, C.A. 1984. Low-temperature storage as a quarantine treatment for the Caribbean fruit fly (Diptera: Tephritidae) in Florida citrus. J. Econ. Entomol. 77: 1233–1235.

Benschoter, C.A. 1988. Methyl bromide fumigation and cold storage as treatments for California stone fruits and pears infested with the Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 81: 1665–1667.

Burditt, A.K., Jr. 1994. Irradiation. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants, 101–118. Westview Press, Boulder, Colorado, USA.

Burditt, A.K., Jr. and Balock, J.W. 1985. Refrigeration as a quarantine treatment for fruits and vegetables infested with eggs and larvae of *Dacus dorsalis* and *Dacus cucurbitae* (Diptera: Tephritidae). J. Econ. Entomol. 78: 885–887.

Burditt, A.K., Jr., and Seo, S.T. 1971. Dose requirements for quarantine treatment of fruit flies with gamma irradiation. In: Disinfestation of fruit by irradiation. 33–41. International Atomic Energy Agency, Vienna, Austria. 177 p.

Burditt, A.K., Jr., Seo, S.T. and Balock, J.W. 1971. Basis for developing quarantine treatments for fruit flies. In: Disinfestation of fruit by irradiation, 27–31. International Atomic Energy Agency, Vienna, Austria. 177 p.

Calkins, C.O. and Webb, J.C. 1988. Temporal and seasonal differences in movement of Caribbean fruit fly larvae in grapefruit and the relationship to detection by acoustics. Florida Entomol. 71: 409–416.

Carey, J.R. 1991. Establishment of the Mediterranean fruit fly in California. Science, 253: 1369–1373.

Carey, J.R. and Dowell, R.V. 1989. Exotic fruit fly pests and California agriculture. Californian Ag. 43: 38–40.

Carpenter, A. and Potter, M.A. 1994. Controlled atmospheres. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants, 171–198. Westview Press, Boulder, Colorado, USA.

Chan, H.T., Jr. 1994. Strategies for overcoming tissue damage caused by quarantine heat and cold treatments (Plenary Lecture). Proc. Australasian Postharvest Conf., Univ. Queensland, Gatton College, Sept. 20-24, 1993, 283–287.

Chan, H.T., Jr. and Linse, E.S. 1989a. Conditioning cucumbers for quarantine heat treatments. HortSci. 24: 985.

— 1989b. Conditioning cucumbers to increase heat resistance in the EFE system. J. Food Sci. 54: 1375–1376.

Couey, H.M. and Chew, V. 1986. Confidence limits and sample size in quarantine research. J. Econ. Entomol. 79: 887–890.

Couey, H.M. and Hayes, C.F. 1986. Quarantine procedure for Hawaiian papaya using fruit selection and a two-stage hot-water immersion. J. Econ. Entomol. 79: 1307–1314.

Cowley, J.M., Baker, R.T., Englberger, K.G. and Lang, T.G. 1991. Methyl bromide fumigation of Tongan watermelons against *Bactrocera xanthodes* (Diptera: Tephritidae) and analysis of quarantine security. J. Econ. Entomol. 84: 1763–1767.

Dowell, R.V. 1983. The Medfly in California: the threat. HortSci. 18: 40.

FDA — US Food and Drug Administration. 1987. Irradiation in the production, processing and handling of food; Final rules. Congressional Federal Register 51: 13375–13399. US Govt. Printing Office, Washington, DC, USA.

Flitters, N.E., Miyabara, F., Nakagawa, S. and Dresner, E. 1953. The status of commercial pineapples as hosts of the oriental fruit fly in Hawaii. Special Report Ho-1, Fruit Fly Investigations in Hawaii. US Dept. Ag., Entomol. Research Branch, Honolulu, Hawaii, USA.

Forney, C.F. and Houck, L.G. 1994. Chemical treatments. In: Paull, R.E. and Armstrong, J.W., eds., Insect pests and fresh horticultural products: treatments and responses, 139–162. C.A.B. International, Wallingford, UK.

Gaffney, J.J. and Armstrong, J.W. 1990. High-temperature forced-air research facility for heating fruits for insect quarantine treatments. J. Econ. Entomol. 83: 1959–1964.

Gould, W.P. and Sharp, J.L. 1990a. Cold-storage quarantine treatment for carambolas infested with the Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 83: 458–460.

— 1990b. Hot-water immersion treatment for guavas infested with Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 85: 1235–1239.

Greaney, P.D. 1989. Host plant resistance to tephritids: an under-exploited control strategy. In: Robinson, A.S. and Hooper, G., eds., World Crop Pests, Vol. 3A, Fruit Flies, Their Biology, Natural Enemies and Control. 353–362. Elsevier, Amsterdam.

Hallman, G.J. 1990. Vapor-heat treatment of carambolas infested with Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 83: 2340–2342.

— 1994. Controlled atmospheres. In: R.E. Paull and Armstrong, J.W., eds., Insect Pests and Fresh Horticultural Products: Treatments and Responses. 121–136. C.A.B. International, Wallingford, Oxon, UK.

Hallman, G.J. and Sharp, J.L. 1990. Mortality of Caribbean fruit fly (Diptera: Tephritidae) larvae infesting mangoes subjected to hot-water treatment, then immersion cooling. J. Econ. Entomol. 83: 2320–2323.

Hallman, G.J. and Sharp, J.L. 1994. Radio frequency heat treatments. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants. 165–170. Westview Press, Boulder, Colorado, USA.

Hata, T.Y., Hara, A.H., Jang, E.B., Imaino, L.S., Hu, B.K.S. and Tenbrink, V.L. 1992. Pest management before harvest and insecticidal dip after harvest as a systems approach to quarantine security for red ginger. J. Econ. Entomol. 85: 2310–2316.

Hayes, C.F. 1982. A study of ultrasound and microwaves for the control of fruit flies in papaya postharvest. Hawaii Institute of Tropical Ag. and Human Resources, Honolulu, Research Ext. No. 20., 51 p.

Hayes, C.F. 1994. Modeling heat and cold transfer. In: Paull, R.E. and Armstrong, J.W., eds., Insect Pests and Fresh Horticultural Products: Treatments and Responses. 237–248. C.A.B. International, Wallingford, Oxon, UK.

Hayes, C.F., Chingon, H.T.G., McMurdo, M.B., Ikeda, M.B., Sanderson, S.L. and Deaver, J. 1983. Ultrasonic effects on *Dacus dorsalis*. Ultrasound in Medicine and Biol. 9: 186–189.

Heard, T.A., Heather, N.W. and Peterson, P.M. 1992. Relative tolerance to vapor heat treatment of eggs and larvae of *Bactrocera tryoni* (Diptera: Tephritidae) in mangoes. J. Econ. Entomol. 85: 461–463.

Heather, N.W. 1985. Alternatives to EDB fumigation as post-harvest treatment for fruit and vegetables. Queensland Agric. J. 111: 321–323.

Heather, N.W. 1986. Irradiation of fruit and vegetables. Queensland Agric. J. (March–April), 85–88.

Hill, A.R., Rigney, C.J. and Sproul, A.N. 1988. Cold storage of oranges as a disinfestation treatment against the fruit flies *Dacus tryoni* (Froggatt) and *Ceratitis capitata* (Wiedermann) (Diptera: Tephritidae). J. Econ. Entomol. 81: 257–260.

Hooper, T. 1907. Cold storage and fruit fly. J. Dept. Agric. Western Australia 15: 252–153.

Horner, M.E. 1979. An investigation into the potential use of ultrasonic irradiation as a means of disinfestation of Hawaiian *Carica papaya* L., M.S. Thesis, Dept. Entomol., Univ. Hawaii, Honolulu, Hawaii, USA. 62 p.

Jackson, D.S. and Lee, B.G. 1985. Medfly in California, 1980-82. Bull. Entomol. Soc. 31: 29–37.

Jang, E.B. and Moffitt, H.R. 1994. Systems approaches to achieving quarantine. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants. 225–238. Westview Press, Boulder, Colorado, USA.

Jessup, A.J. 1991. High-temperature dip and low temperatures for storage and disinfestation of avocados. HortSci. 26: 1420.

Jessup, A.J. 1994. Quarantine disinfestation of 'Haas' avocados against *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) with a hot fungicide dip followed by cold storage. J. Econ. Entomol. 87: 127–130.

Jessup, A.J. and Baheer, A. 1990. Low-temperature storage as a quarantine treatment for kiwifruit infested with *Dacus Tryoni* (Diptera: Tephritidae). J. Econ. Entomol. 83: 2317–2319.

Kader, A.A. and Ke, D. 1994. Controlled atmospheres. In: Paull, R.E. and Armstrong, J.W., eds., Insect pests and fresh horticultural products: treatments and responses, 223–236. C.A.B. International, Wallingford, UK.

Klotzbach, T. 1995. U.S. imports of fresh fruits, vegetables and cut flowers. Tropical Produce Marketing News, Spring 1995, accessed from Global Agribusiness Information Network, Fintrac, Inc. (http:\\www.milcom.com/fintrac/fintrac.html).

Landolt, P.J., Chambers, D.L. and Chew, V. 1984. Alternative to the use of probit 9 mortality as a criterion for quarantine treatments of fruit fly (Diptera: Tephritidae)-infested fruit. J. Econ. Entomol. 77: 285–287.

Lee, R.E. 1991. Principles of insect low temperature tolerance. In: Lee, R.E. and Denlinger, D.L., eds., Insects at Low Temperature, 17–46. Chapman and Hill, New York, USA.

Lounsbury, C.P. 1907. The fruit fly (*Ceratitis capitata*). Agric. J. Cape of Good Hope 31: 186–187.

Mangan, R.L. and Ingle, S.J. 1992. Forced hot-air quarantine treatment for mangoes infested with West Indian fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 85: 1859–1864.

Mangan, R.L. and Ingle, S.J. 1994. Forced hot-air quarantine treatment for grapefruit infested with Mexican fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 87: 1574–1579.

Maxie, E.C., Sommer, N.F. and Mitchell, F.G. 1971. Infeasibility of irradiating fresh fruits and vegetables. HortSci. 6: 202–204.

McDonald, R.E. and Miller, W.R. 1994. Quality and condition maintenance. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants. Westview Press, Boulder, Colorado, USA.

Morris, S.C. and Jessup, A.J. 1994. Irradiation. In: Paull, R.E. and Armstrong, J.W., eds., Insect Pests and Fresh Horticultural Products: Treatments and Responses. 163–190. C.A.B. International, Wallingford, Oxon, UK.

Nascimento, A.S., Malavasi, A., Morgante, J.S. and Duarte, A.L.A. 1992. Hot-water immersion treatment for mangoes infested with *Anastrepha fraterculus*, *A. obliqua*, and *Ceratitis capitata* (Diptera: Tephritidae) in Brazil. J. Econ. Entomol. 85: 456–460.

Nation, J.L. and Burditt, A.K., Jr. 1994. Irradiation. In: Paull, R.E. and Armstrong, J.W., eds., Insect Pests and Fresh Horticultural Products: Treatments and Responses, 85–102. C.A.B. International, Wallingford, Oxon., UK.

Nishijima, K.A., Chan, H.T., Jr., Sanxter, S.S. and Linse, E.S. 1995. Reduced heat shock period of 'Sharwil' avocado for cold tolerance in quarantine cold treatment. HortSci. 30: 1052–1053.

Paull, R.E. 1990. Post-harvest heat treatments and fruit ripening. Post-harvest news and information 1: 355–363.

Paull, R.E. and Armstrong, J.W. 1994. Introduction. In: Paull, R.E. and Armstrong, J.W., eds., Insect pests and fresh horticultural products: treatments and responses, 1–33. C.A.B. International, Wallingford, UK.

Paull, R.E. and McDonald, R.E. 1994. Heat and cold treatments. In: Paull, R.E. and Armstrong, J.W., eds., Insect pests and fresh horticultural products: treatments and responses, 191–222. C.A.B. International, Wallingford, UK.

Robertson, J.L., Preisler, H.K, Frampton, E.R. and Armstrong, J.W. 1994. Statistical analyses to estimate efficacy of disinfestation treatments. In: Sharp, J.L. and Hallman, G.J., eds., Quarantine Treatments for Pests of Food Plants, 47–66. Westview Press, Boulder, Colorado.

Rippon, L.E. and Smith, R.J. 1979. Postharvest treatment of Chinese gooseberries (kiwifruit) for the control of Queensland fruit fly. Rural News 73: 34–35.

Ruckleshaus, W.D. 1984. Ethylene dibromide, amendment of notice of intent to cancel registration of pesticide products containing ethylene dibromide. Congressional Federal Register 49: 14182–14185. US Govt. Printing Office, Washington, DC, USA.

Sanxter, S.S., Nishijima, K.A. and Chan, H.T., Jr. 1994. Heat treating 'Sharwil' avocado for cold tolerance in quarantine cold treatments. HortSci. 29: 1166–1168.

Saul, S. and Seifert, J. 1990. Methoprene on papaya: persistence and toxicity to different developmental stages of fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 83: 901–904.

Saul, S.H., Mau, R.F.L. and Oi, D. 1985. Laboratory trials of methoprene-impregnated waxes for disinfesting papayas and peaches of the Mediterranean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 78: 652-655.

Saul, S.H., Mau, R.F., Kobayashi, R.M., Tsuda, D.M. and Nishina, M.S. 1987. Laboratory trials of methoprene-impregnated waxes for preventing survival of adult Oriental fruit flies (Diptera: Tephritidae) from infested papayas. J. Econ. Entomol. 80: 494–496.

Saunders, G.W. and Elder, R.J. 1966. Sterilization of banana fruit infested with banana fruit fly. Queensland J. Agric. Sci. 23: 81–85.

Segarra-Carmona, A.E., Franqui, R.A., Ramirez-Ramos, L.V., Santiago, L.R. and Torres-Rivera, C.N. 1990. Hot water dip treatments to destroy *Anastrepha obliqua* larvae in mangoes from Puerto Rico. J. Ag., Univ. Puerto Rico 74: 441–447.

Seo, S.T., Chambers, D.L., Kobayashi, R.M., Lee, C.Y.L. and Komura, M. 1970. Mortality of mango weevils in mangoes treated with dielectric heating. J. Econ. Entomol. 63: 1977–1978.

Seo, S.T., Chambers, D.L., Lee, C.Y.L., Komura, M., Fujimoto, M. and Kamakahi, D. 1973. Resistance of pineapple variety '59-443' to field populations of Oriental fruit flies and melon flies (Diptera: Tephritidae). J. Econ. Entomol. 66: 522–523.

Seo, S.T., Tang, C.S., Sanidad, S. and Takenaka, T.H. 1983. Hawaiian fruit flies (Diptera: Tephritidae) variation of index of infestation with benzyl isothiocyanate concentration and color of maturing papayas. J. Econ. Entomol. 76: 535–538.

Sharp, J.L. 1986. Hot-water treatment for control of *Anastrepha suspensa* (Diptera: Tephritidae) in mangoes. J. Econ. Entomol. 79: 706–708.

Sharp, J.L. 1989. Hot-water immersion appliance for quarantine research. J. Econ. Entomol. 82: 189–192.

Sharp, J.L. 1992. Hot-air quarantine treatment for mango infested with Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 85: 2302–2304.

Sharp, J.L. 1993. Hot-air treatment for 'Marsh White' grapefruit infested with Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 86: 462–464.

Sharp, J.L. and Gould, W.P. 1994. Control of Caribbean fruit fly (Diptera: Tephritidae) in grapefruit by forced hot-air and hydrocooling. J. Econ. Entomol. 87: 31–133.

Sharp, J.L. and Hallman, G.J. 1992. Hot-air quarantine treatment for carambolas infested with Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 85: 168–171.

Sharp, J.L. and Picho-Martinez, H. 1990. Hot-water quarantine treatment to control fruit flies (Diptera: Tephritidae) in mangoes imported into the United States from Peru. J. Econ. Entomol. 83: 1940–1943.

Sharp, J.L., Gaffney, J.J., Moss, J.I. and Gould, W.P. 1991. Hot-air treatment device for quarantine research. J. Econ. Entomol. 84: 520–527.

Sharp, J.L., Ouye, M.T., Hart, W., Ingle, S. and Chew, V. 1988. Submersion of Francis mango in hot water as a quarantine treatment for the West Indian fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 81: 1431–1436.

Sharp, J.L., Ouye, M.T., Hart, W., Ingle, S., Hallman, G., Gould, W.P. and Chew, V. 1989a. Immersion of Florida mangoes in hot water as a quarantine treatment for Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 82: 186–188.

Sharp, J.L., Ouye, M.T., Ingle, S.J. and Hart, W.G. 1989b. Hot-water quarantine treatment for mangoes from Mexico infested with Mexican fruit fly and West Indian fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 82: 1657–1662.

Sharp, J.L., Ouye, M.T., Ingle, S.J., Hart, W.G., Enkerlin, H., Celedonio, H., Toledo, A.J., Stevens, L., Quintero, E., Reyes, F. and Schwarz, A. 1989c. Hot water quarantine treatment for mangoes from the State of Chiapas, Mexico infested with *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae). J. Econ. Entomol. 82: 1663–1666.

Sharp, J.L. and Spalding, D.H. 1984. Hot water as a quarantine treatment for Florida mangoes infested with Caribbean fruit fly. Proc. Florida State Hort. Soc. 97: 355–357.

Shellie, K.C., Firko, M.J. and Mangan, R.L. 1993. Phytotoxic response of 'Dancy' tangerine to high-temperature moist forced-air treatment for fruit fly disinfestation. J. American Soc. Hortic. Sci. 118: 481–485.

Smith, E.S.C. 1977. Studies on the biology and commodity control of the banana fruit fly, *Dacus musae* (Tryon) in Papua New Guinea. Papua New Guinea Agric. J. 28: 47–56.

Sunagawa, K. and Iwaizumi, R. 1987. The effectiveness of vapor heat against the melon fly, *Dacus cucurbitae* Coquillett, in mango and fruit tolerance to the treatment. Research Bull. Plant Prot. Japan 23: 13–20.

Sunagawa, K. and Iwaizumi, R. 1988. Sterilization of melon fly and thermal injuries to bitter momordica fruit. Research Bull. Plant Prot. Japan 24: 1–5.

Swaine, G., Melksham, K.J. and Corcoran, R.J. 1984a. Dimethoate dipping of 'Kensington' mango against Queensland fruit fly. Australian J. Exp. Ag. & Animal Husbandry 24: 620–623.

Swaine, G., Hargreaves, P.A., Jackson, D.E. and Corcoran, R.J. 1984b. Dimethoate dipping of tomatoes against Queensland fruit fly, *Dacus tryoni* (Froggatt). Australian J. Exp. Ag. & Animal Husbandry 24: 447–449.

United Nations Environmental Programme. 1992. Methyl bromide: Its atmospheric science, technology and economics. Montreal Protocol Assessment Supplement. United Nations Headquarters, Ozone Secretariat, PO Box 30552, Nairobi, Kenya. 41 p.

USDA. 1992. USDA-ARS Action Plan for Fruit Flies Research. Faust, R.M. and Coppedge, J.R., eds., US Department of Agriculture, Agriculture Research Service, Beltsville, Maryland. 190 p.

USDA. 1993. Fruit Fly Research: 1993 Supplement to the USDA-ARS Action Plan. Faust, R.M. and Coppedge, J.R. eds., US Department of Agriculture, Agriculture Research Service, Beltsville, Maryland. 109 p.

Waller, J.B. 1990. Insecticidal soaps for postharvest control of thrips in asparagus. Pp. 60–62, *In* Proc. 43rd New Zealand Weed & Pest Control Conf. Auckland, New Zealand.

Watson, R.T., Albritton, D.L., Anderson, S.O. and Lee-Bapty, S. 1992. Montreal Protocol. Assessment Supplement. Synthesis Report of the Methyl Bromide Interim Scientific Assessment and Methyl Bromide Interim Technology and Economic Assessment. Requested by: United Nations Environment Programme on Behalf of the Contracting Parties to the Montreal Protocol. June, 1992. 33 p.

White, I.M. and Elson-Harris, M.M. 1992. Distribution of fruit pest Tephritidae. In: Fruit Flies of Economic Significance: Their Identification and Bionomics. 424–432. C.A.B. International, Wallingford, Oxon., UK. 601 p.

Williamson, M.R. and Winkelman, P.M. 1989. Commercial scale heat treatment for disinfestation of papaya. 1989 International Winter Meeting, American Soc. Agric. Engineers at Quebec, Canada. ASAE, St. Joseph, Missouri, USA.

Williamson, M.R., Winkelman, P.M. and Armstrong, J.W. 1991. Certification of fruit fly disinfestation chambers, paper No. 91-6569. In: Proceedings, Am. Soc. Agric. Eng., Winter meeting, December 17-20, 1991. Chicago, Illinois, USA.

Winkelman, P.M. and Williamson, M.R. 1990. Advances in commercial dry heat disinfestation of papaya, ASAE Paper No. 90-6016. 1990 International Summer Meeting, American Soc. Agric. Engineers, Columbus, Ohio. ASAE, St. Joseph, Missouri, USA.

Fruit Fly Research and Development in the South Pacific

P. Ferrar[1]

Abstract

The South Pacific region has seen many activities in research and development into fruit flies during the past six years. Other than continuing research in Australia and work on quarantine preparedness and pest risk analysis by New Zealand, the most important has been the activities associated with the Regional Fruit Fly Project (RFFP).

The project, in cooperation with the Australian Centre for International Agricultural Research (ACIAR), has elucidated the species of fruit flies in the project countries, their host ranges and seasonal abundances and assessed losses attributable to fruit flies and the parasitoid fauna of each country. To enhance production and export of fresh commodities, the project has developed protein bait spray technology to control fruit flies in the field (with ACIAR) and adopted technology transferred from Hawaii on quarantine treatments based on hot forced air.

Australia's current research focuses very much on problems of exotic fruit flies that have entered Australia recently, mainly papaya fruit fly. Work includes surveys of distribution of these exotic species within Australia, development of strategies to prevent further spread and to reduce numbers of infested areas, and investigation of the possibility of eradication of papaya fruit fly from Australia.

New Zealand has also been active in the area, particularly in relation to post-harvest disinfestation and the development of secure quarantine protocols, e.g., standards for quarantine treatments and surveillance.

During the RFFP it has become increasingly apparent that countries cannot consider their fruit fly problems in isolation from those of other countries. Inter-country movements of fruit flies are increasing, and fruit fly quarantine and control strategies must be considered on a whole-region basis. It may even be desirable for Southeast Asia and the Pacific to be considered together for overall fruit fly management.

UNTIL relatively recently, fruit fly research and development was very fragmentary. Individual Departments of Agriculture conducted a little research on methods of controlling fruit flies, usually by means of sprays; occasionally there were also quarantine operations as when melon fly (*Bactrocera cucurbitae*) entered the western islands of Solomon Islands but not the other islands; and a limited amount of taxonomic identification of Pacific fruit flies was conducted, mainly by experts in Australia and Hawaii.

In the past ten years there has been a slowly but steadily increasing awareness of the importance of fruit flies to a number of South Pacific nations, partly as a result of their impact on exports of fresh fruits and vegetables from the Pacific to countries such as New Zealand and Australia that are concerned about fruit flies, and partly because of incursions of new species into areas where they were not present before. As a result of this concern, several initiatives involving regional collaboration were started. These have included:

- the Regional Fruit Fly Project;
- three ACIAR South Pacific fruit fly projects;
- New Zealand collaboration with the South Pacific;
- US collaboration with the South Pacific (especially from Hawaii);
- increasing Australian research relevant to the South Pacific.

These operations all integrate with the national country programs that are now increasing in size and activity in various South Pacific nations.

[1] Crop Sciences, ACIAR, GPO Box 1571, Canberra, ACT, 2601 Australia

Regional Fruit Fly Project

The largest and most significant fruit fly project in the South Pacific is the Regional Fruit Fly Project (RFFP), around which much of the other work is also focused. The first phase of the RFFP involved Cook Islands, Fiji, Tonga and Western Samoa, chosen particularly because they were countries with export trades in fresh fruits and vegetables that had problems with fruit flies. This first project made excellent progress, and a review recommended an extension with the previous four countries and addition of a further three also concerned about fruit flies and exports — Federated States of Micronesia (FSM), Solomon Islands and Vanuatu. Support to the RFFP came from United Nations Development Program (UNDP), Food and Agriculture Organisation of the United Nations (FAO), Australian Agency for International Development (AusAID), South Pacific Commission (SPC) and the New Zealand and United States Governments, and the fact that so many agencies were interested to band together in work on this subject is an indication of the importance with which it is regarded.

The RFFP has included work on:

- inventories of species present in each project country, and which host fruits each species breeds in;
- estimates of losses caused by fruit flies at all stages of the production chain (an important subject for countries wishing to approach donors for further assistance, since most donors require evidence of the size and scope of the problem before committing funds);
- quarantine aspects of fruit flies, within the project countries and between the project countries and those with which they trade;
- development of export protocols with countries proposing to import fresh produce from the project countries — what will be permitted and under what circumstances and conditions;
- pre-harvest control, including bait spraying and orchard hygiene — how to minimise infestation and damage before the fruit is even harvested;
- post-harvest disinfestation — how to eliminate any residual infestation after harvest and assure importing countries that the produce is safe.

Most importantly, the RFFP has also included comprehensive training for national staff, which has included techniques for identification of fruit flies, methods of field control, quarantine treatments, fruit fly surveillance and emergency response strategies to be used in case of new incursions.

ACIAR South Pacific Fruit Fly Projects

ACIAR has recently conducted two fruit fly projects in the South Pacific which were specifically designed to run alongside and complement the RFFP. The first project was with the first four countries of the RFFP (Cook Islands, Fiji, Tonga and Western Samoa) and the second, which is still under way, is with the remaining three countries (FSM, Solomon Islands and Vanuatu). These two projects are particularly helping with surveys of which fruit fly species occur within each of the countries concerned (including sorting out taxonomic difficulties and anomalies), and what is the full host fruit range of each species. They have also involved collection and identification of parasitoids of fruit flies, as part of a wider study of the role (if any) of these natural enemies in regulating fruit fly populations.

The two projects have also been helping with implementation of bait spraying as a means of pre-harvest control of fruit flies. This is an alternative to the less environmentally friendly cover spraying of orchards, which also affects bees (important for pollination and fruit set) and natural enemies of other orchard pests. The technique is based on the fact that fruit flies are strongly attracted to baits of hydrolysed protein, but other insects are not. Insecticide is mixed with bait and small splashes of the mixture are applied to leaves of the trees at scattered points in the orchard. The fruit flies are attracted to feed on the bait, ingest the insecticide as well and are killed.

Suitable bait materials are available commercially, but it is also possible to use brewery waste to produce bait. The waste contains yeast cells which can be hydrolysed to yield material which is very attractive to fruit flies, and is cheap because the source material is waste. ACIAR has also supported (together with USAID) a small project to install pilot processing equipment in the Royal Tongan Brewery in Nuku'alofa, to process the waste into bait on a semi-commercial scale. If successful the technology will be transferable to any brewery in any country with a fruit fly problem, yielding cheap and easily accessible bait (and in some cases preventing environmental contamination from the waste which otherwise flows out into streams or coastal marine waters).

Post-harvest disinfestation research

Various methods of disinfestation are known, including vapour heat treatment, forced hot-air treatment (which involves drier air than the vapour heat treatment), dipping in chemicals or hot water, cooling and irradiation. Forced hot-air treatment was considered to be the most appropriate for the South Pacific, on grounds of cost of equipment and

environmental aspects. It is this treatment on which research has concentrated, and around which quarantine protocols are being developed.

New Zealand involvement

New Zealand has perhaps been the most constructive of the countries importing Pacific produce in trying to develop protocols that will allow the trade to continue and even increase, but without significant risk to New Zealand's own fruit fly-free status. Work has focused on a combination of factors that will lead to zero fruit fly infestation in produce reaching New Zealand, including acceptance of area freedoms, acceptance of some host status factors (e.g. that pawpaw is not a host of certain species if picked before a defined stage of ripening), and particular specifications in relation to disinfestation procedures. This has involved careful risk analysis, and thorough evaluation of the results of much of the research recently carried out by the RFFP.

Trade Pressures: Why the Problems may Become Worse

An indisputable development in world trade is that pressures will increase for trade in fresh horticultural produce, particularly in high value tropical, subtropical and temperate fruits. These are seen as excellent earners of export income by the producers and their countries, and are also of great appeal to buyers with good incomes in developed countries. Pressures are growing on countries at both ends of the export chain to facilitate and increase this trade, and under the new World Trade Agreement quarantine considerations cannot be used as an unreasonable barrier to such trade. Thus quarantine authorities and plant protection personnel will have to make increasing efforts to make risk analyses and conduct research to find ways (as New Zealand has done) to permit this trade safely.

The Need for Regional Cooperation

There are two reasons why international collaboration is vital if progress is to be made in managing or controlling fruit flies in our region.

The first is that for reasons of quarantine no country can look at its fruit fly problems and risks in isolation. Even if produce coming in as imports is carefully monitored from when it is grown, and carefully inspected on arrival, there is always the other problem of travellers coming in from overseas with fruit smuggled in through their luggage. No matter how good customs inspections and passenger profiling are, there will eventually be one important infestation that slips through. Countries that collaborate to help their neighbours, or to help those who are at the other end of airline routes, to reduce their numbers of fruit flies, will also be helping themselves by reducing the risks of accidental introductions.

To this end, countries are urged to be open with information about what fly species they have, what measures are being taken to control them, and what information is available about thermal death points and other means of disinfestation. Information about species distributions is required to be divulged under regional plant protection agreements, but information about disinfestation is often kept secret on grounds of commercial confidentiality. Countries should look hard at how much commercial value they can gain from the information (often not very great), balanced against how much they stand to lose if new fruit flies come in from other areas.

The second reason for collaboration is shrinking resources everywhere for research and development to do with agriculture. ACIAR suffered a cut to its budget this year, after a number of years of sustained growth, and the problem is worldwide. The major international research centres are looking at cuts of the order of 20% to their programs, and donors are contributing less than before to international aid generally.

In Australia the cuts are biting deep, and whole sections that ACIAR used to commission for research are now disappearing, along with the expertise that resided in them. These resources will not easily be replaced. However, through collaboration limited resources can be pooled thereby creating something that is still very worthwhile and productive. If this is not done, the fruit flies may yet win.

Overview — Tephritidae in the Pacific and Southeast Asia

R.A.I. Drew[1] and M.C. Romig[1]

Abstract

There are approximately 4500 known species of the family Tephritidae worldwide. They occupy habitats in extremes of climates from cold temperate latitudes to tropical equatorial regions. Further, there are species of 'fruit flies' that attack different parts of plants e.g. stems, growing tips, leaves, flowers, fruits, bamboo shoots, to name some. Consequently, almost all above-ground parts of plants are susceptible to attack from fruit flies. All regions of the world contain major pest species of fruit flies that are devastating to horticultural industries. However, the Southeast Asian and Pacific regions have considerably more pest species than any other and therefore have proportionately more economic problems. Primarily, researchers are concerned with the subfamily Dacinae in Asia and the Pacific region, when the major pest species are considered. The most recent taxonomic revisions have been Drew (1989), Drew and Hancock (1994a, b) and Drew et al. (in press).

Distribution of Species of Dacinae within Southeast Asia and the Pacific

DISTRIBUTION of Dacinae species throughout Southeast Asia and the Pacific region is such that Papua New Guinea, Malaysia and West Indonesia have the majority, while East Indonesia, Vanuatu and New Caledonia the least (Table 1).

Table 1. The number of known species of Dacinae in zones within Southeast Asia and the Pacific region.

Zone	No. of species[a]
Vanuatu/New Caledonia	20
East Indonesia	25
Solomon Islands	27
India	42
Philippines	47
South China/Southern Japan/Taiwan	48
Myanmar/Thailand to Vietnam	64
Australia	90
Malaysia/West Indonesia	106
Papua New Guinea	173

[a] Data extracted from Cabikey

[1] Faculty of Environmental Sciences, Griffith University, Nathan Campus, Qld, 4111

An analysis of these data indicate that the centre of evolution of species is probably the area covering Papua New Guinea, northern Australia and Malaysia.

Distribution of Pest Species in Southeast Asia and the Pacific Region

In Southeast Asia the major fruit fly pest species are *Bactrocera albistrigata* de Meijere, the *Bactrocera dorsalis* complex (*B. carambolae* Drew and Hancock, *B. dorsalis* Hendel, *B. occipitalis* Bezzi, *B. papayae* Drew and Hancock, *B. philippinensis* Drew and Hancock, *B. pyrifoliae* Drew and Hancock, *B. caryeae* Kapoor, *B. kandiensis* Drew and Hancock), *Bactrocera correcta* Bezzi, *Bactrocera latifrons* Hendel, *Bactrocera zonata* Saunders, *Bactrocera cucurbitae* Coquillett, *Bactrocera tau* Walker. In addition there is a significant group of species of the subfamily Ceratitinae that infest bamboo shoots throughout Southeast Asia.

These pest species account for damage to most fruit crops and many vegetable crops. Some species have a number of specific host fruits while also overlapping with other species in the same hosts. For example, *B. carambolae* is the primary fruit fly pest in carambola, *B. papayae* is the main pest in mangoes and papaya, and both infest guavas.

B. albistrigata

A member of the *frauenfeldi*-complex with sibling species in northern Australia, Papua New Guinea and some Pacific islands. Co-exists with species such as *B. papayae* in *Terminalia catappa*. A pest of mangoes, guava and some edible *Syzygium* species.

B. carambolae (Carambola Fly)

A major pest in the *dorsalis* complex. Occurs in the Andaman Islands, southern Thailand, Malaysia (Peninsular and East), the Indonesian islands including Kalimantan and Singapore. Introduced into tropical South America and now occurs in Surinam, Guyana, French Guiana and northern Brazil. Occurs in very large populations in areas producing commercial carambola, its major host fruit. Recorded from 75 host fruits in Southeast Asia.

B. dorsalis (Oriental Fruit Fly) (Fig. 1)

First encountered in the 18th century and recognised as a major fruit fly pest for the past century. Other *dorsalis*-complex pest species have been mistakenly called *B. dorsalis*, e.g. *B. carambolae, B. papayae, B. occipitalis* and *B. philippinensis*. Occurs from Sri Lanka, India through to southern China, Taiwan, northern Thailand, parts of Indo-China. Has been introduced into the Hawaiian islands, Nauru, Tahiti, Mauritius, Palau. Recorded from 117 host fruits in Southeast Asia.

B. occipitalis

A significant pest species in the Philippines. Has also been recorded in Sabah, East Malaysia. Previously called *B. dorsalis* by many authors but now known to be a distinct pest species (Drew and Hancock 1994).

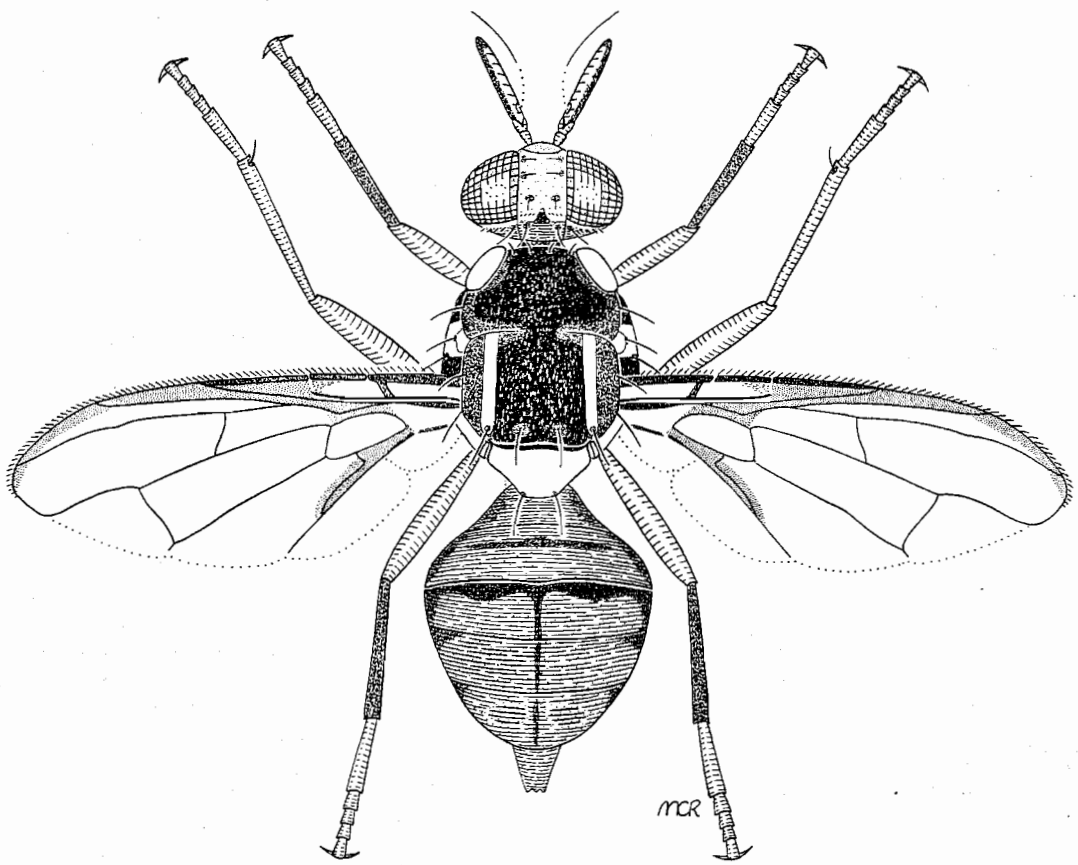


Figure 1. *Bactrocera dorsalis* (Hendel), female.

Extensive trapping and host fruit surveys are required in order to define its geographic distribution and host pest status and particularly its infestation levels in commercial/edible fruits in relation to *B. philippinensis.*

B. papayae (Asian Papaya Fruit Fly)

Previously called *B. dorsalis* in Indonesia and Malaysia by most authors before being described as a distinct species in 1994 by Drew and Hancock. Now recognised as the most destructive of all *dorsalis* complex pest species, having been recorded from 209 host fruit species in Southeast Asia. Endemic to southern Thailand, Malaysia (Peninsular and East), the Indonesian islands, Kalimantan and Singapore. More recently introduced into Irian Jaya, Papua New Guinea and north Queensland.

B. philippinensis

The major *dorsalis* complex pest species in the Philippines. Probably as destructive as *B. dorsalis* but trapping and host fruit survey work in the Philippines is urgently needed in order to understand its host plant biology, pest status and geographic distribution.

B. pyrifoliae

A serious *dorsalis* complex pest of pome and stone fruits in northern Thailand. Needs research, as very little is known about this species, its geographic distribution, biology and host records.

B. caryeae

A significant pest species in the *dorsalis* complex in southern India. Probably more important than *B. dorsalis* in most high altitude areas.

B. kandiensis

Another *dorsalis* complex pest species in Sri Lanka. Little is known about its pest status and distribution.

B. correcta

A major pest species from Sri Lanka and India through to Thailand. Has been recorded from 58 host fruits in Southeast Asia.

B. zonata

A major pest species in India. Also known from Sri Lanka, Myanmar, Pakistan, Thailand and parts of Indo-China where it is only of minor pest status, being recorded from 20 host fruits. Has been introduced into Mauritius.

B. cucurbitae (Melon Fly)

The world's major fruit fly pest of cucurbit crops. Widespread from northern Arabia to Southeast Asia. Has been introduced into northeast and east Africa, Mauritius and Reunion. Also introduced into Papua New Guinea, probably during World War II. More recently introduced into Solomon Islands (probably early 1980s) and now widespread over most of that country. Also introduced into the Hawaiian Islands, Mauritius and Nauru. Has been recorded from 41 hosts in Southeast Asia and attacks fruit crops such as guava and vegetable crops such as tomato. It is known to attack vegetative parts of plants such as the growing tips of cucurbits, *Brassica* species and legumes such as beans and cow peas (USDA Hawaii host records).

B. tau

Another major pest of cucurbit crops in Southeast Asia and widespread throughout the region. There is a large complex of sibling species in Southeast Asia called the *tau*-complex. This complex requires intensive taxonomic and biological research in order to define the pest species and understand their geographic distributions and pest status in commercial/edible fruit crops. Has been recorded from 34 hosts in Southeast Asia.

Recent research in Thailand and Malaysia, funded by ACIAR, has revealed previously unknown major pest species such as *B. carambolae, B. papayae, B. philippinensis* and *B. pyrifoliae*. This emphasises the great importance of taxonomic and biological research in defining pest species, their distributions, host ranges and pest status. This knowledge has a direct impact on the successful development of field control strategies, market access technologies and international trade.

In the South Pacific region, including Papua New Guinea, Australia and islands to the East and Southeast, there are 20 known major pest species of fruit flies. Five of these have been introduced, at least to some of these countries. The introduced species are *B. cucurbitae, B. dorsalis, B. papayae, B. tryoni* and *Ceratitis capitata*, although *B. tryoni* is endemic to Australia. Three of these have been introduced from Southeast Asia, indicating the enormous quarantine importance of that region to the Pacific area. Because of a paucity of fruit fly research in Papua New Guinea, very little is known about the pest species in that country. There are almost certainly more than those presently known, i.e. *B. atrisetosa*

Perkins, *B. frauenfeldi* Schiner and *B. trivialis* Drew. Also, the geographic distribution of these three species and their pest status is unclear.

The major fruit fly pest species in the South Pacific region are discussed below.

B. atrisetosa (Perkins)

Probably will become a major pest species in Papua New Guinea when horticultural industries expand. Has been recorded from higher altitudes in PNG and infesting vegetable crops particularly cucurbits and tomatoes.

B. cucumis (French) (Cucumber Fly)

This species is endemic to eastern Australia north from northern New South Wales. It is a major pest of cucurbit crops and also infests some Solanaceae and Papaya. It has been recorded from the Darwin area of northern Australia but as it has never been reared from commercial/edible fruits in that locality the population there may represent an undescribed sibling species.

B. distincta (Malloch)

Known from Fiji, Futuna, Tonga, Western Samoa and Niue. Its pest status is not fully understood but has been recorded from some edible/ commercial fruits.

B. frauenfeldi (Schiner) (Mango Fly) (Fig. 2)

A significant pest species endemic to Papua New Guinea, including New Britain, New Ireland, Lihir Island, Bougainville and Solomon Islands. It also occurs in Nauru, Kiribati, Marshall Islands and Federated States of Micronesia (Allwood, pers. comm.). Introduced into Cape York, Queensland about 1974. In 1994 it was recorded for the first time in Cairns, north Queensland. It is now spreading south and has been recorded at Innisfail, north Queensland in November 1996. Recorded from fruits such as banana, citrus, guava and mango. *Terminalia catappa* is a major wild host as it is also for the sibling

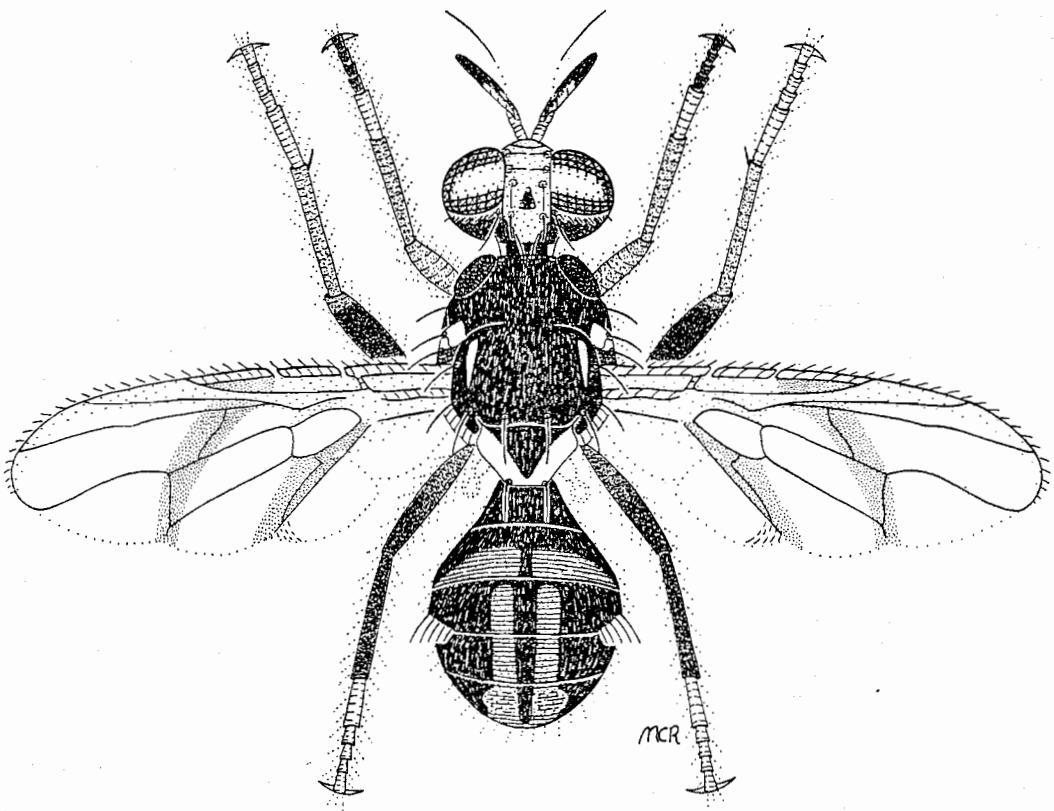


Figure 2. *Bactrocera frauenfeldi* (Schiner), male.

species, *B. albistrigata,* in Southeast Asia. Other *frauenfeldi*-complex sibling species occur in northern Australia and Vanuatu.

B. facialis (Coquillett)

Endemic to Tonga where it is a major pest species. To date, has not been spread to other countries. It is a species of great quarantine importance.

B. jarvisi (Tryon)

A significant pest species endemic to northern and eastern Australia. Capable of infesting fruits such as mango, guava and ripe banana. Some specimens have been recorded as responding to Cue-lure while the major part of the population does not. Perhaps a complex of sibling species exists.

B. kirki (Froggatt)

A major pest species occurring in American Samoa, Western Samoa, Niue, Tonga, French Polynesia, Wallis and Futuna. Undoubtedly introduced to French Polynesia where it has become widespread. Probably one of the most serious of all South Pacific pest species.

B. melonotus (Coquillett)

Endemic to the Cook Islands and has never spread from there. A major pest species of definite quarantine significance.

B. musae (Tryon) (Banana Fruit Fly)

A fruit fly almost specific to *Musa* species (bananas). Capable of attacking green fruit and distributed from north-eastern Australia, Papua New Guinea, around the Bismarck Archipelago to the Solomon Islands. The record of *B. musae* in Solomon Islands needs to be confirmed.

B. neohumeralis (Hardy)

A sister-species to *B. tryoni* and of equal ability to infest most edible/commercial fruit crops. Common along the east coast of Australia and in Papua New Guinea.

B. passiflorae (Froggatt)

A major pest species occurring throughout Fiji, Niue, Tuvalu, Wallis and Futuna. A population with a pale abdomen occurs in Fiji, Tuvalu, Tokelau and the Niuas group in Tonga and this is probably an undescribed sibling species. Will always require major field control programs and market access technologies for export trade.

B. psidii (Froggatt)

Known only from New Caledonia. A significant pest species but probably outcompeted by the introduced *B. tryoni* in most commercial host fruits.

B. trilineola Drew

The major pest species in Vanuatu and one of the *frauenfeldi*-complex of species. Will require effective field control programs and the development of market access technologies for most international trade.

B. trivialis (Drew)

A species in Papua New Guinea with potential to become a major economic pest if horticultural production is expanded. Requires extensive research in PNG in order to clarify its pest status but already known to attack a range of commercial fruits.

B. tryoni (Froggatt) (Queensland Fruit Fly) (Fig. 3)

The major Australian fruit fly pest species. It is distributed across northern Australia and along eastern Australia from Cape York to Melbourne. It is responsible for extremely large crop losses, both at subsistence and commercial levels and has been recorded from 113 fruit species (wild and edible/cultivated combined). *B. tryoni* has also prevented a considerable amount of export trade from Australia and within Australia to fruit fly free areas. It was introduced to New Caledonia and then to French Polynesia over the past two decades. Its spread throughout French Polynesia, from the original outbreak in Tahiti, is proof of the way fruit flies are spread internationally by travellers, not by commercial trade.

B. xanthodes (Broun) (Fig. 4)

A major South Pacific region pest species responsible for crop losses and trade restrictions. It is now clear that there is a *xanthodes*-complex of sibling species in the South Pacific, that *B. xanthodes* is the only one that is a pest species and that it does not occur in all countries. This is an example of the importance of taxonomic research and its application to the establishment of international trade.

The Economic Impact of Fruit Flies

Within Southeast Asia and the Pacific region, fruit flies are regarded as the major insect pests of fruit and vegetable crops. Indeed, very few people in subsistence, village or larger area commercial production escape their ravages. Losses due to fruit flies can be categorised as follows:

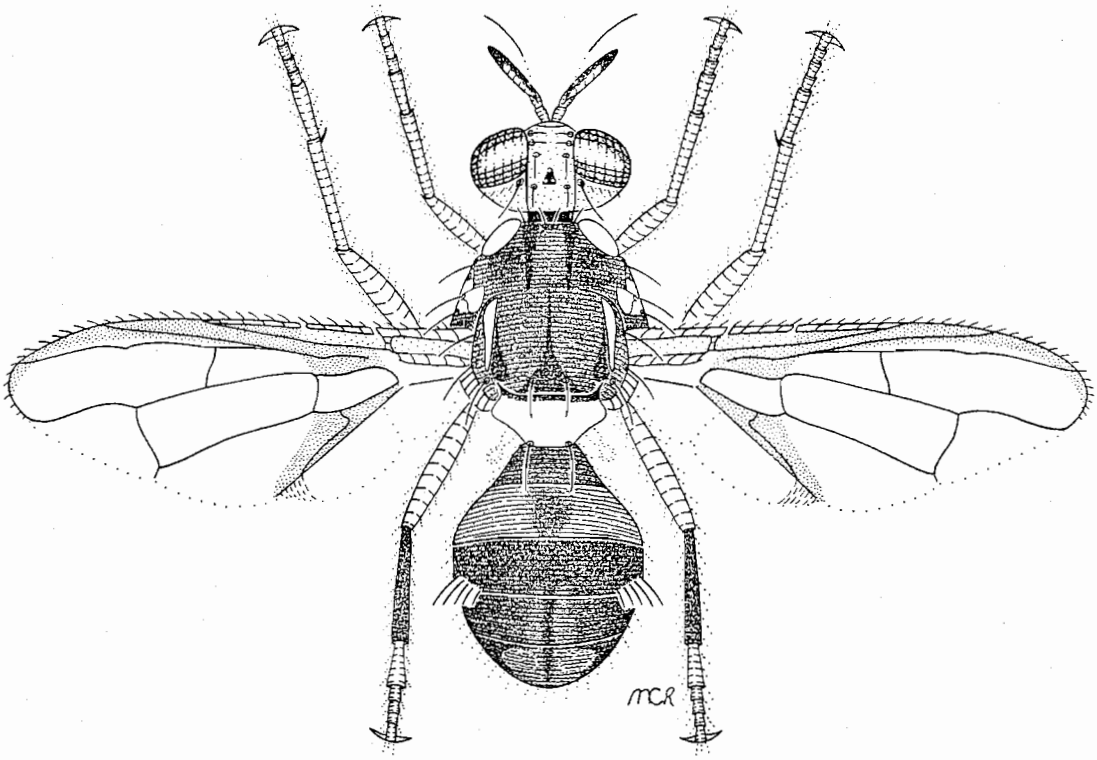


Figure 3. *Bactrocera tryoni* (Froggatt), male.

(a) loss of crop production;
(b) decrease in export trade;
(c) increased pressure and cost on quarantine services

Loss of crop production can only be prevented if specific control treatments are applied. These vary from physical barriers to applications of protein baits or insecticide cover sprays. It is important to recognise that there are efficient fruit fly control strategies available for most, if not all, production situations. What is now needed are education programs to communicate these strategies to producers. Training and education programs should be high on the agenda for future fruit fly project work.

In developing countries of Southeast Asia and the Pacific region, loss of fruit and vegetable crops is a major concern as it causes serious reductions in the availability of essential food-based nutrients. However, the major economic losses due to fruit flies are those related to loss of export trade. Some countries have the potential to produce and export valuable horticultural crops which enhance their GNP. Export of pumpkin squash from Tonga to Japan is one example. Again, the basic market access technologies are available and can be used, subject to the prerequisite experimental data being provided to prove post-harvest treatment efficacy that guarantees quarantine security. Experimental work in this area plus intensive training programs are urgently needed.

The outbreak of *B. papayae* (Asian Papaya Fruit Fly) in north Queensland has highlighted another economic impact due to fruit flies, i.e., the increased pressure and cost on national quarantine services. The very real threat posed to countries by fruit flies breaking quarantine barriers forces nations to spend more on quarantine security, especially border quarantine and early warning systems.

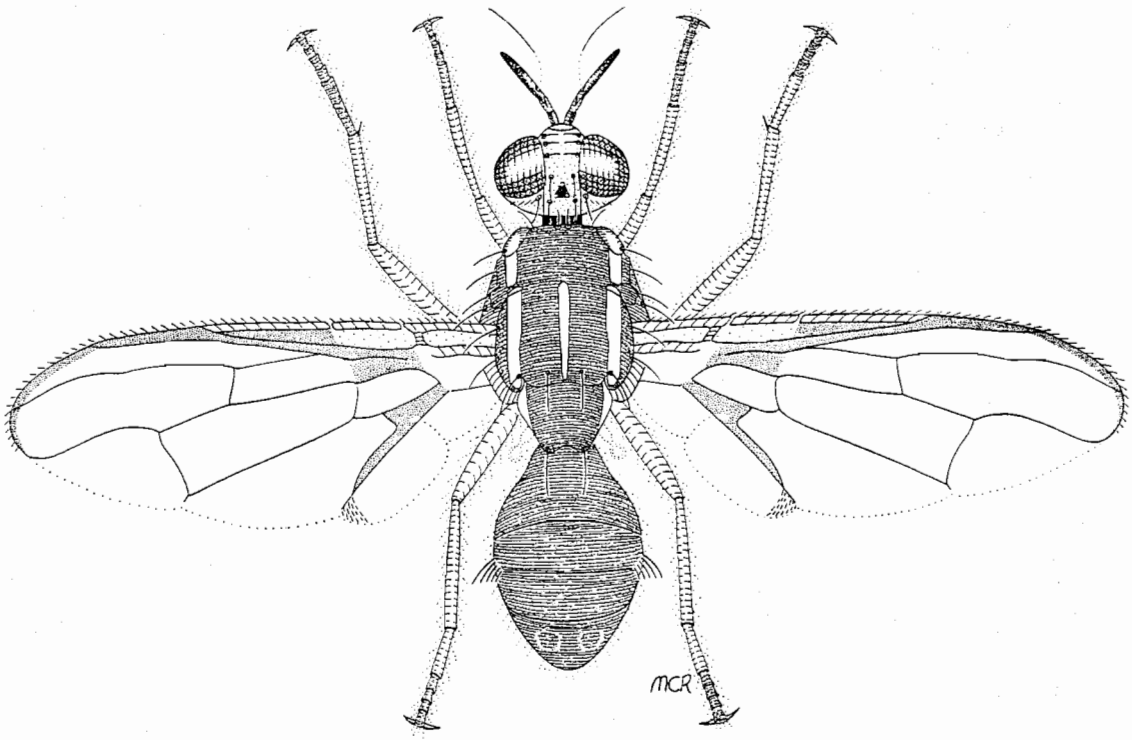


Figure 4. *Bactrocera xanthodes* (Broun), male.

A major problem that must be addressed in future Regional Fruit Fly Projects (both ACIAR and extensions of the RFFP) is the research and development of strategies required to prevent further geographic spread of major fruit fly pest species. Again, the *B. papayae* story highlights this problem.

This species is endemic to southern Thailand, Malaysia, Borneo and the chain of Indonesian islands. It was taken into Irian Jaya, probably from the Indonesian area. The lack of border quarantine security in Irian Jaya virtually allows free passage of pest and disease organisms into that country from Southeast Asia. From Irian Jaya there was subsequently the normal overland spread to Papua New Guinea and then across quarantine barriers into northern Australia.

The *B. papayae* incursion was first detected within Papua New Guinea in the Western Province in late 1992 and in the Torres Strait islands early in 1993. Although the first detection in Queensland was near Cairns in October 1995, it must have been introduced 2 to 2½ years earlier (about mid-1993). This means that the spread of *B. papayae* from PNG to Queensland was rapid, an indication of the virulence of the species. This story also highlights the fact that PNG is a quarantine timebomb for other South Pacific countries both to the east and south. It will undoubtedly receive other fruit fly pest species from Southeast Asia via Irian Jaya which will in turn threaten other countries such as Australia, Solomon Islands, Vanuatu etc.

Consequently there is an urgent need to carry out fruit fly research, associated quarantine surveillance and training programs on the PNG mainland and associated islands. If well planned and executed correctly, effective fruit fly surveillance, education and quarantine will prevent the further spread of major pest species from PNG.

Research — Past, Present and Future

In reviewing the history of fruit fly research worldwide, it is seen that long-term intensive fruit fly research has been carried out in the following countries:

- USA (mainland and Hawaii);
- Central America;
- United Kingdom;
- Southern Africa;
- Europe;
- Mediterranean area;
- Australia.

This research has covered taxonomy, biology, ecology, control, large-area eradication strategies and market access technology development, to name but a few important aspects. Much of this work has provided valuable information that can be applied to other countries.

Short-term research, carried out in recent years (approximately from the mid-1980s to the mid-1990s) has been undertaken in Southeast Asia (Taiwan, Japan, Thailand, Malaysia, Philippines) and in the Pacific region (Cook Islands, Fiji, Federated States of Micronesia, Solomon Islands, Tonga, Vanuatu, Western Samoa). This has been, to a point, more preliminary in that there has not been enough time to carry out intensive investigations. However, a considerable amount of basic information has been gathered upon which major progress can be made in crop production, trade and additional research and development. Above all, enough data are now available to carry out effective training and education programs for quarantine and agriculture officers.

Future research efforts should also include countries that hitherto have had little or no fruit fly investigations. The most important are Southeast Asia (India, Sri Lanka, Myanmar, China, Vietnam, Laos, Cambodia, Philippines, Indonesia) and Pacific region (PNG, Nauru, Niue, parts of Micronesia).

Conclusions

Fruit flies will increase in economic importance, particularly in the area of quarantine and international trade. There will be further spread and introductions of major pest species into new areas or countries, but research and training efforts must be expanded to meet this danger. A major effort in this area is urgently needed in PNG. Also, a major expansion of fruit fly research efforts into a genuine regional approach is now required. Such efforts must include research in Southeast Asia and Pacific island nations. This broad regional approach will guarantee shared results, knowledge and technology applications that will have long-term benefits in crop production and international trade.

Besides research in specific geographic locations, as noted above, another area of urgent need is the definition of species within sibling species complexes. Most species complexes contain at least one major pest species and a larger number of non-pest species. International trade restrictions, in some situations, are applied as a result of non-pest species misidentified as pest species, e.g. *Bactrocera* sp. near *paraxanthodes* in Vanuatu previously called the pest species *B. xanthodes*. Research to define the species and their host plant biology in complexes such as those represented by *B. dorsalis* (Fig. 1), *B. frauenfeldi* (Fig. 2), *B. tryoni* (Fig. 3) and *B. xanthodes* (Fig. 4) will be richly rewarded in terms of increased international trade without the need for expensive market access technologies.

References

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanian Regions. Memoirs of the Queensland Museum 26: 1–521.

Drew, R.A.I. and Hancock, D.L. 1994a. The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. Bulletin of Entomological Research, Supplement No. 2.

— 1994b. Revision of the tropical fruit flies (Diptera: Tephritidae: Dacinae) of South-East Asia. I. *Ichneumonopsis* Hardy and *Monacrostichus* Bezzi. Invertebrate Taxonomy 8: 829–838.

Drew, R.A.I., Hancock, D.L. and White, I.M. In press. Revision of the tropical fruit flies (Diptera: Tephritidae: Dacinae) of South-East Asia. II. *Dacus* Fabricius. Invertebrate Taxonomy.

Fauna of Fruit Flies in the Cook Islands and French Polynesia

M. Purea[1], R. Putoa[2] and E. Munro[1]

Abstract

Fruit flies in Cook Islands (*Bactrocera xanthodes* and *B. melanotus*) and French Polynesia (*B. kirki*, *B. tryoni* and *B. dorsalis*) are unique both in distribution and host specificity.

In Cook Islands, *B. melanotus* is predominantly found inland among the native forests but rather sparsely distributed on the coastal areas of Rarotonga. *B. xanthodes*, on the other hand, seems to associate around villages where fruit trees such as breadfruit are abundant. These two species generally show distinct host preference. They are not present in the northern atoll islands of Cook Islands.

Within the fauna of fruit flies in Cook Islands, there is a parasitoid, *Fopius arisanus*, but it is weakly developed.

Previously in French Polynesia, there were two major fruit fly species of economic importance. In July 1996, *B. dorsalis* was detected on Tahiti and it later spread onto the nearby island of Moorea. The rest of the islands in French Polynesia are free from *B. dorsalis*. Current data show that *B. dorsalis* is predominantly found along the coastal areas of Moorea and Tahiti islands. The host fruits are: *Carica papaya*, *Citrus grandis*, *Mangifera indica* and *Psidium guajava*.

B. kirki seems to have more host fruits than *B. dorsalis*, including several native species such as *Spondias*, *Syzygium jambos* and *Terminalia catappa*. *B. kirki* was first recorded in Tahiti in 1928. Data from Cue-lure traps laid around the islands showed only 3% of the catch was *B. kirki*, but 97% collected was *B. tryoni*.

B. tryoni has a broader host range than *B. kirki*. It attacks crops such as annona, tomatoes, avocados, papaya, oranges and many more. It was first recorded in 1970. None of the three fruit fly species are found in the Marquesas Islands of French Polynesia.

FRUIT flies of the Family Tephritidae are some of the most destructive and important pests in the Pacific Islands region. Their presence results in trade restrictions between countries that export horticultural crops, including some processed fruit chunks such as mangoes and papaya.

Cook Islands in the 1800s (according to a New Zealand horticulturist duty report in 1805) was said to have only one species of fruit fly *Dacus melanotus* Coquillett, now renamed *Bactrocera melanotus* (Coquillett). This species was of major economic importance and has been ever since. It is known to occur only in Cook Islands and nowhere else in the world. There was no record to indicate when *B. melanotus* was first introduced to other islands of the Southern Cook Group.

The second species, *Bactrocera xanthodes* (Broun), was thought to have been introduced in Cook Islands during the early 1970s. It occurred also in other Pacific Islands: Fiji, Western Samoa, Tonga and Vanuatu (Drew 1989). Trapping work carried out in the early 1970s by Joseph and Purea using Cue-lure in Dak-Pot trapping systems did not capture *B. xanthodes* as Cue-lure does not attract *B. xanthodes* males.

In the early 1980s P. Dale from the New Zealand Ministry of Agriculture and Fisheries (MAF) worked with M. Purea on the use of cordilitos dipped in Cue-lure and the use of protein bait spray to further study the seasonal distribution pattern of *B. melanotus* on the island of Rarotonga. As expected, the seasonal abundance was then found to be related to wild host

[1] Cook Islands Ministry of Agriculture, Totokoitu Research Station, PO Box 57, Rarotonga, Cook Islands
[2] Ministry of Agriculture and Livestock, Papeete, Tahiti

availability and commercial fruits in season. The movement of *B. xanthodes* to other islands in the Southern Cook Group may have occurred in the 1980s when no internal inter-island quarantine was implemented.

There is a better understanding of the fauna of the two fruit fly species in Cook Islands due mainly to the combined efforts of the Regional Fruit Fly Project, DSIR New Zealand and the Research Plant Protection staff of the Ministry of Agriculture, Cook Islands.

Host Ranges

Agricultural production is one of the major avenues of earning foreign exchange in Cook Islands. Horticultural commercial crops such as papaya, oranges, mangoes, grapefruit, guava, etc are target crops of the two species of fruit flies in Cook Islands (see trap data Tables 1 to 4). It is not unusual to find both species developing in the same fruit host.

Trapping studies for *B. melanotus* indicated a general trend of greater populations from traps located inland than traps along the coastal areas. On the other islands in the Southern Cook Islands (Aitutaki, Mangaia, Atiu, Mauke and Mitiaro), this trend was not obvious, perhaps due to the smallness of these islands.

The sustainability of *B. melanotus* in Cook Islands has been attributed to the biodiversity of host plants and the continuous availability of wild fruits in the forests on these islands. Some of these host plants are: Polynesian chestnuts, *Pometia pinnata*, wild cherry guava, *Terminalia catappa*, *Spondias*, Puapua fruits and mountain cherries. Understanding the range of host plants and their fruiting cycles is a key factor and of great importance in explaining population fluctuations of these two fruit fly species. *B. xanthodes* associate with fruits such as breadfruit,

Table 1. Trapping data — *B. melanotus* (inland).

	1993										1994		
Months	M	A	M	J	J	A	S	O	N	D	J	F	M
No. of flies	40	55	83	110	211	810	400	382	720	821	1523	1050	

Table 2. Trapping data — *B. xanthodes* (coastal).

	1993										1994		
Months	M	A	M	J	J	A	S	O	N	D	J	F	M
No. of flies	8	17	22	9	14	16	9	8	6	4	3	2	4

Table 3. Trapping data — *B. melanotus* (Mauke).

	1993										1994		
Months	M	A	M	J	J	A	S	O	N	D	J	F	M
No. of flies	50	45	600	450	300	200	245	180	210	752	820	934	756

Table 4. Trapping data — *B. xanthodes* (Mauke).

	1993										1994		
Months	M	A	M	J	J	A	S	O	N	D	J	F	M
No. of flies	5	8	12	16	20	57	170	78	23	10	8	19	36

guavas, jackfruit, papaya and some varieties of mangoes. Its population (based on trapping data, Tables 2 and 4) was low when compared to that of *B. melanotus*.

Within the fauna of fruit flies in the Cook Islands, parasitoid *Fopius arisanus* is fairly active but weakly developed.

Fruit Flies in French Polynesia

Currently there are three fruit fly species of economic importance:

B. kirki and *B. tryoni*, introduced since 1970, with *B. tryoni* being introduced probably from New Caledonia and *B. dorsalis*, collected in July 1996.

The host plants of *B. kirki* include *Inocarpus fagifer*, *Mangifera indica*, *Psidium* spp., *Spondias dulcis*, *Spondias mombin*, *Syzygium jambos* and *Terminalia catappa*.

The host plants of *B. tryoni* include *Annona* spp., *Carica papaya*, *Citrus sinensis*, *Inocarpus fagifer*, *Lycopersicon esculentum*, *Persea americana*, *Psidium* spp. and *Terminalia catappa*.

The host plants of *B. dorsalis* include *Carica papaya*, *Citrus grandis*, *Mangifera indica* and *Psidium guajava*.

The Marquesas are the only islands in French Polynesia where fruit flies are absent. *B. kirki* and *B. tryoni* are found in most of the other islands in French Polynesia.

The presence of *B. kirki* was recorded in Tahiti in 1928. According to observations made in the past, it does not seem to have been a very serious pest. For example in the Cue-lure traps, 97% of the collected flies were *B. tryoni* and only 3% were *B. kirki*.

Since the detection of *B. dorsalis* in July 1996, trapping with methyl eugenol was intensified and traps were set up in the main islands of every achipelago: 107 traps in Tahiti, Moorea and the other Society Islands, 51 traps in the Tuamotu Islands, 30 traps in the Austral Islands, 47 traps in the Marquesas Islands and 26 traps in the Gambler Islands. Tahiti and Moorea were the only islands where Oriental fruit flies were found in the traps.

The Government of Tahiti has agreed to allocate a budget of US$340 000 for an eradication program of the Oriental fruit fly. The program will begin as soon as money is available, perhaps in early October 1996. According to Putoa (1996), the plan is to use coconut husk blocks impregnated with methyl eugenol and Malathion for male fruit fly annihilation. Protein bait sprays will also be used in some areas.

At the same time, host fruit surveys are continuing. Currently Oriental fruit flies are found on papaya and pummelo.

Fruit and vegetables exported to other islands from Tahiti and Moorea are being treated with methyl bromide.

Reference

Drew, R.A.I. 1989. Tropical Fruit Flies (Diptera: Tephritidae: Dacinae) of Australia and Oceania Regions. Memoirs of the Queensland Museum 26: 1–521.

Putoa, R. 1996. Report. Ministry of Agriculture: Tahiti.

The Fruit Fly Fauna of Tonga, Western Samoa, American Samoa and Niue

V. Heimoana[1], F. Tunupopo[2], E. Toleafoa[3], C. Fakanaiki[4]

Abstract

Surveys for fruit flies (family Tephritidae), commenced by the Regional Fruit Fly Project in 1991, confirmed that Tonga has five species in the main islands of Tongatapu, Vava'u, Ha'apai and 'Eua. These are *Bactrocera facialis* (Coquillett), *B. xanthodes* (Broun), *B. kirki* (Froggatt), *B. distincta* (Malloch) and *B. obscura* (Malloch). Also, *B. passiflorae* (Froggatt), a species that is endemic to Fiji, occurs in the Niuas, a group of northern islands in Tonga. *B. distincta, B. kirki, B. obscura* and *B. xanthodes* are common to Western Samoa and American Samoa. However, Western Samoa has three other species — *B. aenigmatica* (Malloch), *B.* sp.n. (near *xanthodes*) and *B. samoae* Drew, which are not attracted to male lures. There are three species in Niue (*B. kirki, B. passiflorae* and *B. obscura*). The presence of *B. xanthodes* is uncertain as no methyl eugenol trapping has been done recently. The distribution, abundance and economic importance of these species are discussed in this paper.

FRUIT flies are of major economic importance throughout the world. They attack and destroy a wide range of fruits and vegetables. Since the beginning of this century, studies have been focused on their distribution and habits. These characteristics need to be known as bases for measures to control them. A fruit fly project implemented in 1990 throughout the South Pacific includes documentation of the fruit fly fauna of the region. Trapping with lures, host collections and host surveys have been used to collate this information.

The region now has a substantial database on its fruit fly species. Western Samoa has the highest number of species: seven compared to Tonga with six, American Samoa with four and Niue with three. *B. kirki* and *B. xanthodes* are major pests in all four countries. *B. facialis* in Tonga is by far the most destructive pest and, with 64 plant species recorded as being hosts, has the largest host list. Other authors have discussed fruit fly species in other South Pacific countries in these Proceedings.

[1]Ministry of Agriculture and Forestry Research Division, Nuku'alofa, Kingdom of Tonga
[2]Ministry of Agriculture, Fisheries, Forests and Meteorology, Apia, Western Samoa
[3]Department of Agriculture, Pago Pago, American Samoa
[4]Department of Agriculture, Forestry and Fisheries, Alofi, Niue

Fauna in Tonga

Distribution and abundance

Situated east of Fiji, south of the Samoas and west of Niue, Tonga is divided into four island groups: the largest consists of the islands of Tongatapu and 'Eua in the south, Ha'apai and Vava'u with their many small islands in the centre and the two small Niuas (Niuatoputapu and Niuafo'ou) in the north. *B. xanthodes, B. kirki,* and *B. distincta* occur on all these island groups. *B. facialis*, the major pest of Tongatapu, is absent in the Niuas; *B. passiflorae* is confined only to the Niuas. *B. obscura* is present in all groups except on the island of 'Eua (Table 1). Distributions were determined as a result of host surveys and a trapping system of modified Steiner traps. Attractants used in traps were either methyl eugenol (for *B. xanthodes*) or Cue-lure (for all other Tongan species).

Between 1991 and 1996, pairs of traps (one with methyl eugenol and one with Cue-lure) were set up in various locations throughout Tongatapu and Vava'u and at locations each in Ha'apai, 'Eua, Niuatoputapu

and Niuafo'ou. None of the local species responds to Trimedlure, but traps have been set up for quarantine surveillance of *Ceratitis capitata* at entry ports in Tongatapu, Vava'u and on Niuatoputapu. Since 1996, the number of traps in each island group has been increased, primarily for quarantine surveillance. Nemeye (1995) estimated abundance of each species in the different island groups (Table 1).

The information collated to 1994 shows *B. xanthodes* and *B. facialis* to be the most abundant species in Tongatapu, followed by *B. distincta* and *B. kirki. B. obscura* is extremely rare in Tongatapu. In Vava'u the predominant species are *B. xanthodes, B. kirki* and *B. distincta,* while *B. obscura* occurs in low numbers, and *B. facialis* is rare. In some years, the rare species have not even been detected in traps. *B. facialis* is seen in sizeable numbers in host species such as *Inocarpus fagifer* in Vava'u but these numbers are not reflected in trap catches. Further investigation into this taxonomic status anomaly is required.

Annual fruit fly population peaks occur between September and December, the region's spring and summer months; the cooler season between May and August supports the lowest number of flies. The October–December period coincides with abundant vegetable production as well as with fruiting of many native hosts.

Several factors, apart from temperature, influence the frequency of flies. Moisture directly affects the fruiting of plants, and droughts consequently produce lower fruit volumes. Mango is a major host of the three main species *B. facialis, B. xanthodes* and *B. kirki.* Mango volume varies due to irregular bearing of trees. Nemeye (1995) speculated that mango is a key host species that influences total number of flies as well as their peaks. In years when mango fruits abundantly, numbers peak during summer, followed by a smaller peak in February to March. This period is followed by the fruiting of guava (*Psidium guajava*), tropical almond (*Terminalia catappa*) and *Syzygium* spp. which are major hosts of *B. kirki.* Out-of-season fruiting due to climatic irregularities also influences fruit fly abundance.

Economic importance

The three most damaging species in Tonga are *B. facialis, B. xanthodes* and *B. kirki. B. facialis* attacks a very wide range of fruits and out-competes *B. kirki* in plants such as citrus, capsicum, Pacific chestnut, feta'u, and Pacific lychee, but it still occurs together with *B. kirki* in plants such as guava and tropical almond. *B. facialis* and *B. xanthodes* are the most aggressive species occurring in Tonga.

The parasitoids *Psyttalia fijiensis* and *Fopius arisanus* (Fam. Braconidae) have been reared from both *B. facialis* and *B. kirki.* They seem to be reared from tropical almond in larger numbers than from guava, possibly because the pulp depth in guava makes it harder for the wasp to lay its eggs into developing larvae in the case of *P. fijiensis.* The parasitoids have been reared much less frequently from *B. xanthodes* and *B. distincta.* The level of parasitism is too low to contribute a significant component to the control of fruit flies. Nevertheless, parasitoids are still of benefit in combination with other control methods.

Fauna in American Samoa

Distribution and abundance

Fruit fly surveys in American Samoa have only been carried out since June 1996, using Cue-lure and methyl eugenol in modified Steiner traps. American Samoa, situated north-east of Tonga, consists of four islands: Tutuila, the largest, with the capital Pago Pago; and Ofu, Olosega and Ta'u of the Manu'a group to the north and east. Four fruit fly species have so far been detected: *B. xanthodes, B. kirki, B. distincta* and *B. obscura.* Data on their exact distribution and abundance are not yet available, as host surveys have not been carried out.

Fauna in Western Samoa

Distribution and abundance

Western Samoa is situated north of Tonga. The northern-most Tongan islands, the Niuas, are

Table 1. Distribution and abundance of fruit fly species in Tonga (Nemeye 1995).

Species	Tongatapu	'Eua	Ha'apai	Vava'u	Niuatoputapu	Niuafo'ou
B. facialis	+++	+++	+++	++	0	0
B. xanthodes	+++	+++	+++	+++	+	+
B. kirki	+++	+++	+++	+++	+++	+++
B. distincta	+++	+++	+++	+++	+	+
B. obscura	+?	0	+?	+?	+++	+++
B. passiflorae	0	0	0	0	+++	+++

actually closer to Western Samoa than to the main islands of Tonga. The countries share four species of fruit fly, namely *B. xanthodes, B. kirki, B. distincta and B. obscura*. In addition, Western Samoa has three other species, *B. samoae, B.* sp. n. (near *xanthodes*) and *B. aenigmatica*, the three occurring in that country only. None of these three species are attracted to male lures and so have been recorded from host surveys.

Trapping has been carried out since the commencement of the project in April 1991. Originally, Lynfield traps were used which since have been replaced by modified Steiner traps. Traps are baited with methyl eugenol and Cue-lure and 20 traps are set up on Upolu while Savaii is covered with 12 traps. Trapping has shown a dominance of different species at different locations:

- *B. distincta*: Puapua, Safune, Salelologa, Togitogiga;
- *B. kirki*: Mt. Vaea, Nafanua, Atele, Aleisa;
- *B. obscura*: Aleisa, Togitogiga, Faleolo.

Economic importance

B. xanthodes and *B. kirki* are the species that are of economic importance in Western Samoa. The other species attack native hosts which would not be considered for export.

Fauna in Niue

Distribution and abundance

Niue is situated to the east of Tonga and to the south of American Samoa. It consists of a single, small island, relatively isolated from its neighbouring countries. Three fruit fly species have been confirmed in Niue: *B. kirki, B. passiflorae* and *B. obscura*. It has been suggested in some literature that *B. xanthodes* is also present in Niue. However, this report has not been confirmed. Niue's trapping system utilises Cue-lure traps only, while *B. xanthodes* is attracted to methyl eugenol.

Observations have shown that the three major species are distributed over the island and occur in high numbers, especially during the fruiting seasons of host plants. Recent surveillance has shown that fruit flies are abundant between August and March, during which time most species of fruit trees are bearing. Even wild host species such as *Syzygium richii, S. inophylloides, S. malaccense* and *Pometia pinnata* are infested between those months. The placement of traps and host collections in forest areas around the island has confirmed this observation. The number of fruit flies collected from traps between April and July is regularly low.

Economic importance

The relative economic significance of each species in Niue has not been determined. From the roles that *B. kirki* and *B. passiflorae* play in other islands, it can be assumed that they would be the major damaging species.

Future Needs

As Pacific Island countries endeavour to develop fresh produce export industries to strengthen their economic situations, the importance of fruit flies is highlighted. Because of their importance as quarantine pests they pose a primary constraint to the export of fresh fruit and vegetables to countries such as New Zealand, Australia, Japan and the United States. Quarantine negotiations, protocols and disinfestation schedules are based on knowledge about an exporting country's fruit fly fauna. The main methods used to determine fruit fly status in the Pacific are trapping and host collections. It is therefore essential to maintain fruit fly surveillance to monitor changes in frequency and abundance, host status and the introduction of exotic species.

In most island countries, fruit fly work has been carried out under the auspices of the Regional Fruit Fly Project. As the project draws to an end, some very well trained and capable staff will face the problem of maintaining their activity level without adequate funding. In many cases, the budget allocated by the local government is insufficient to continue surveys and complete data collection, especially on outer islands. Limitations, such as fuel shortages, lack of funds for consumable resources and travel expenses, usually occur particularly towards the end of the financial year.

In addition, the region will be left without a co-ordinator to facilitate dialogue and the exchange of information between the participating countries. It is essential that each party is aware of its responsibility to maintain contact and to share knowledge. It may be necessary to nominate a new co-ordinator from the remaining staff and continue with the satellite 'Fly Net' sessions, at least on a bi-monthly basis.

Reference

Nemeye, P.S. 1995. Progress Report; South Pacific Regional Fruit Fly Project. Ministry of Agriculture, Vaini Research Station, Nuku'alofa, Kingdom of Tonga.

Fruit Fly Fauna in Fiji, Tuvalu, Wallis and Futuna, Tokelau and Nauru

E. Tora Vueti[1], A.J. Allwood[2], L. Leweniqila[1], L. Ralulu[1], A. Balawakula[1], A. Malau[3], F. Sales[4] and K. Peleti[5]

Abstract

Trapping and host fruit surveys in Fiji, Nauru, Tokelau, Tuvalu and Wallis and Futuna have helped identify the fruit fly fauna in each country. The species of fruit flies (Diptera: Tephritidae: Dacinae) in Fiji are *Bactrocera passiflorae* (Froggatt), *B. xanthodes* (Broun), *B. distincta* (Malloch), and *B. gnetum* (Drew and Hancock), a new subgenus. In Nauru, *B. xanthodes* and *B. frauenfeldi* (Schiner) are typically South Pacific species, while *B. dorsalis* (Hendel) and *B. cucurbitae* (Coquillett) have been introduced, possibly from Taiwan. Only *B.* sp.n. (near *passiflorae*) occurs in Tokelau, determined by limited trapping during 1996. In Tuvalu, the light form of *B. passiflorae* (now referred to as *B.* sp.n. (near *passiflorae*)) was recorded during 1993 (Drew, pers. commun.). The fruit fly fauna in Wallis and Futuna demonstrates the social and cultural linkages between these islands and Tonga, Western Samoa and Fiji. Wallis Island hosts *B. passiflorae*, *B. kirki* and *B. xanthodes* while *B. passiflorae*, *B. distincta*, *B. xanthodes*, *B. obscura* and *B. kirki* occur on Futuna. The relationships between geographical and floristic diversity and the distribution of fruit fly species are discussed. The influence of cultural ties between countries and the movement of people between island countries also determines the fruit fly fauna of the islands.

THE distribution of fruit fly species in the South Pacific shows that movements of both endemic and exotic species have occurred within the region. The presence of similar fruit fly species in different Pacific Island countries confirms the direct relationship between the fruit fly fauna and movement of people and horticultural produce. Most of the fruit fly species in the South Pacific region belong to the Dacini, a tribe of tropical species (Drew 1989). Dacinae are further classified into 2 genera, *Bactrocera* and *Dacus* Fabricius (Drew 1989). All the species in Fiji, Nauru, Tuvalu, Tokelau and Wallis and Futuna belong to the genus *Bactrocera*. All but two species present in Nauru are endemic to rainforest areas in the South Pacific region.

The faunal relationship between fruit fly species in the west of the region, particularly Papua New Guinea, and the central and eastern Pacific islands indicates that diverse speciation of related species has occurred (Drew 1975). Endemic fruit fly species have the ability to shift to introduced hosts (Hooper et al. 1978). The similarity in the geographical characteristics of the islands has also contributed to the ability of endemic species from one island country to become established in a similar habitat in another country. Records of fruit fly species from all of the islands in the South Pacific are not totally known. However, there has been tremendous progress on the knowledge of the fruit fly fauna in the region in the past six years. Records of the fruit fly fauna in Fiji, Nauru, Tokelau, Tuvalu and Wallis and Futuna have been taken from literature as early as the 1930s to the latest fruit fly work conducted in

[1] Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2] Regional Fruit Fly Project, South Pacific Commission, Private Mailbag, Nabua, Fiji
[3] Service de l'Economie rurale et de la Pêche, BP 19, Mata 'Utu, Iles Wallis
[4] Centre de coopération internationale en recherche agronomique pour le développement, de Recherches Fruitières de Pocquereux, BP 32 98880, LA FOA, Nouvelle-Calédonie
[5] Tokelau Apia Liaison Office, PO Box 865, Apia, Western Samoa

the South Pacific by national agricultural staff, by the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project (RFFP), and by projects run by the Australian Centre for International Agricultural Research (ACIAR) and the Centre for International Research and Agricultural Development (CIRAD).

Fauna in Fiji, Nauru, Tokelau, Tuvalu and Wallis and Futuna

Table 1 shows the known distribution of fruit fly species in Fiji, Nauru, Tokelau, Tuvalu and Wallis and Futuna, determined by trapping and host surveys.

Table 1. Fruit fly species in Fiji, Nauru, Tuvalu, Tokelau and Wallis and Futuna.

Species	Fiji	Rotuma	Nauru	Tokelau	Tuvalu	Wallis	Futuna
B. cucurbitae	—	—	+	—	—	—	—
B. distincta	+	+	—	—	—	—	+
B. dorsalis	—	—	+	—	—	—	—
B. frauenfeldi	—	—	+	—	—	—	—
B. gnetum	+	—	—	—	—	—	—
B. kirki	—	+	—	—	—	+	+
B. obscura	—	+	—	—	—	+	+
B. passiflorae	+	—	—	—	—	+	+
B. sp.n. near *passiflorae*	+	—	—	+	+	—	—
B. xanthodes	+	+	+	—	—	+	+

Fiji

Simmonds (1936) recorded *Bactrocera passiflorae* (Froggatt), *B. xanthodes* (Broun) and *B. distincta* (Malloch) in traps and host fruit collections in Fiji. Recent host fruit collections have confirmed a fourth species, *Bactrocera (Bulladacus) gnetum* (Drew and Hancock) (Drew and Hancock 1995). *B. passiflorae* and *B. xanthodes* are economically important fruit fly species because of the damage caused to fresh fruits and vegetables. *B. passiflorae* is recorded in Cue-lure traps throughout the year and has been recorded in 48 species of host fruits and vegetables (RFFP, unpublished data). *B. xanthodes* is attracted to methyl eugenol and has been reared from eight host fruit species. *B. distincta* is an anomaly in Fiji because it occurs in quite large numbers at all times of the year in Cue-lure traps, but has been recorded in *Manilkara zapota* (sapodilla) only. The known distribution of sapodilla does not account for the persistently large numbers in traps. There must be more widely distributed wild host fruits that have not been recorded as yet.

In 1995, Drew and Hancock identified a lighter coloured form of *B. passiflorae* from Fiji. This strain is conspicuous because of the pale coloration of terga III-V. Initial identifications were carried out on flies that were reared from *Ochrosia oppositifolia* collected on Viti Levu. This *B. passiflorae* strain is also trapped in Cue-lure traps that are located in Nadarivatu, in the northern interior of Viti Levu, Fiji.

As mentioned above, Drew and Hancock (1995) described a new species, *Bactrocera (Bulladacus) gnetum* which was reared from *Gnetum gnemon* (Gnetaceae) on Vanua Levu. This endemic species belongs to a new subgenus and possesses a bulla or air bubble on the wing of the male. Consistent with other species that possess a bulla, it is not attracted to synthetic male attractants.

Fruit fly trapping records for Rotuma, an island north east of Viti Levu and Vanua Levu, Fiji, have shown the presence of *B. distincta, B. kirki* (Froggatt), *B. obscura* (Malloch) and *B. xanthodes*. Host fruit surveys have not been carried out to confirm the host fruit ranges of these species in Rotuma and also the presence of other fruit fly species that are not attracted to male attractants. *B. kirki* is a major fruit fly pest in Tonga having 15 host fruits, 3 wild and 12 commercial (Nemeye, et al. unpublished data). Its occurrence in Rotuma probably reflects the cultural ties between Rotumans and Western Samoans.

Tuvalu

Waterhouse (1993) listed the occurrence of *B. passiflorae* in Tuvalu, but temporary fruit fly traps that were set on the island of Tuvalu in 1993 by the RFFP recorded the presence of *B.* sp.n. (near *passiflorae*) (Allwood, pers. commun.). Specimens collected in October, 1996 confirmed this species' being present. No host records are available at this stage.

Wallis and Futuna

Fruit fly trapping carried out prior to1995 and since have recorded *B. passiflorae, B. obscura* and *B. kirki* from Cue-lure traps and *B. xanthodes* from methyl eugenol traps on the Island of Wallis. Trapping on Futuna has recorded *B. passiflorae, B. distincta, B. kirki* and *B. obscura* in Cue-lure traps and *B. xanthodes* in methyl eugenol traps. Host fruit collections have yet to be done to show the presence of species that are non-attracted to male lures.

Nauru

B. cucurbitae (Coquillett) was first recorded on the Island of Nauru in 1982 from ribbed gourd (*Luffa acutangula*) (Muniappan, pers. commun., cited Waterhouse 1993). Other fruit fly species identified during short-term trapping by Fletcher in 1992 were *B. frauenfeldi* (Schiner) which was abundant and *B. xanthodes* and *B. dorsalis* (Hendel) (Fletcher, pers. commun., cited in Waterhouse 1993).

Tokelau

Fruit fly trapping commenced in Tokelau in 1996 and to date the identification of fruit flies trapped from Cue-lure traps has yet to be confirmed but has been tentatively identified as *B.* sp.n. (near *passiflorae*). It is expected that the species of fruit flies in Tokelau may be similar to that of Western Samoa because of their proximity, cultural ties and inhabitant movements.

Faunal Relationship

In 1975, Drew produced a possible pathway of dispersal of Dacinae along the Melanesian arc, from Papua New Guinea (PNG) to central and south-eastern Polynesia. Apart from the pathway, an attempt was made to relate the species in PNG (having the largest number of endemic fruit fly species in the region) with species in the Melanesian arc and central and south-eastern Polynesia (Drew 1975). The faunal relationships of fruit flies occurring in the island countries mentioned in this paper have shown links with fruit flies of the western region and the central and eastern Pacific. The islands located in the west (e.g. PNG and Solomon Islands) show enormous diversity in geography and vegetation, which explains the large numbers of endemic fruit fly species. In contrast, the small island or coral atoll geography and the less diverse rainforest vegetation of the islands on the central and eastern Pacific explains the fewer endemic species in these islands.

Fruit fly species that are related (morphologically similar) to the species present in Fiji, Nauru, Tokelau, Tuvalu and Wallis and Futuna occur in PNG, Bismarck Archipelago and Solomon Islands (Drew 1975). *B. passiflorae* from Fiji is related to *B. exspoliata* (Hering) that occurs in PNG and *B. perfusca* (Aubertin) that occurs in Marquesas Islands of French Polynesia. *B. kirki* is related to *B. trifaria* (Drew) which occurs in New Britain, while *B. unifasciata* (Malloch) in the Solomon Islands is related to *B. distincta* (Drew 1975, 1989).

Discussion

Table 1 shows that *B. passiflorae, B. distincta, B. kirki* and *B. xanthodes* are the most common species in the countries mentioned in this paper. Rotuma and Wallis and Futuna have fruit fly species that are common and, with the exception of *B. passiflorae*, these species occur in Western Samoa and Tonga. The approximate distance of Rotuma and Wallis and Futuna from Western Samoa is 880 km and 600 km, respectively. Rotuma is marginally closer to Wallis and Futuna (420 km) than it is to Fiji (440 km). These distances preclude natural spread of fruit fly species. Because *B. kirki* and *B. obscura* occur in Wallis and Futuna, Rotuma, Tonga and Western Samoa, there obviously has been exchange of host fruits between the countries. This relates to the cultural ties and custom of bearing gifts by visitors and travellers. Similarly, explanations along these lines can be made with respect to species common to Wallis and Futuna and Fiji. This custom persists today and presents one of the most serious quarantine threats related to assisted movements of fruit fly species around the Pacific region.

B. xanthodes is common to all countries except for Tuvalu and Tokelau. The presence of *B. xanthodes* in the central and south-eastern Polynesia demonstrates its ability to adapt in small island situations with a limited host fruit range. However, most of the islands in the central and south-eastern Polynesia region have breadfruit (*Artocarpus artilis*) in abundance. The availability of breadfruit in most these islands has made the islands a suitable breeding ground for *B. xanthodes.*

This study has also shown the correlation of the distribution of species and the vegetation of the islands. All of these islands are either small volcanic islands or coral atolls with very similar vegetation. It is also evident that the number of endemic species of fruit flies in these countries are fewer because of their small physical geographies and less diverse rainforest vegetation compared to that of the island countries to the west.

This study has highlighted the presence of major pest species in Nauru which pose a threat to the fresh fruit and vegetable production in other island countries. Further work needs to carried out in Nauru, Rotuma, Tuvalu, and Tokelau to determine the host fruit range and the presence of species that are not attracted to synthetic male attractants. Strict quarantine passenger inspection measures should be carried out on air and sea ports to reduce the possible incursion of the exotic pest species in Nauru or other countries that have pest fruit fly species. There is also an urgent need to impose strict quarantine measures on the movement of fresh fruits and vegetables from Rotuma to Viti Levu, Vanua Levu and other islands in the Fiji group to prevent the introduction of *B. kirki*. Pacific islanders should also be educated on the detrimental effects that are caused to agricultural produce if an exotic pest species is introduced into the country. They should be discouraged from moving fresh produce from one country to the other, without appropriate quarantine clearances.

References

Drew, R.A.I. 1975. Zoogeography of Dacini (Diptera: Tephritidae) in the South Pacific area. Pacific Insects, 16: 4: 441–454.

Drew, R.A.I. 1989. Memoirs of the Queensland Museum. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanic regions. Vol. 26: 521 p.

Drew, R.A.I. and Hancock, D.L. 1995. New species, subgenus and records of *Bactrocera* Macquart from the South Pacific (Diptera: Tephritidae: Dacinae). Journal of Australian Entomological Society, 34: 7–11.

Hooper, G.H.S, Drew, R.A.I and Bateman, M.A. 1978. Economic Fruit Flies of the South Pacific Region. Queensland Dept. of Primary Industries, 2nd Edition, 139 p.

Simmonds, H.W. 1936. Fruit fly investigations, 1935. Department of Agriculture, Fiji. Bulletin No. 19: 1–18.

Waterhouse, D.F. 1993. Biological control, Pacific prospects. Publ. Australian Centre of International Agricultural Research, Canberra, Supplement 2, 4–47.

Fruit Fly Fauna in Federated States of Micronesia, Guam, Palau, Kiribati, Northern Marianas and Marshall Islands

L. Leblanc[1]

Abstract

The Dacine fruit fly fauna (Tephritidae: Dacinae) present in Palau, Federated States of Micronesia (FSM), Guam, Commonwealth of Northern Marianas Islands (CNMI), Marshall Islands and Kiribati is reviewed. Two species are native to these countries. Mango fruit fly, *Bactrocera frauenfeldi* (Schiner), is a widespread pest species but is absent from Guam and CNMI. *B. ochrosiae* (Malloch), a non-economic species, is endemic to Guam and CNMI. Melon fly, *B. cucurbitae* (Coquillet), a major pest of Cucurbitaceae, has been present on Guam since 1936 and CNMI since 1943. It was eradicated from CNMI by the sterile insect technique (SIT) in 1962–63, but was re-introduced from Guam in 1981. It was also discovered on Christmas Island in Kiribati in 1987, but presumably eradicated by a two year interruption of cucurbit cropping. Oriental fruit fly (*B. dorsalis* Hendel) was also introduced to CNMI before 1935 and Guam in 1948. Male annihilation, protein bait spraying and SIT resulted in eradication of the species. It has been absent from Guam and CNMI since 1965. Oriental fruit fly has recently been discovered in Palau. It has probably been present there since 1995. Breadfruit fly, *B. umbrosa* (Fabricius), is a pest of *Artocarpus* spp present in Palau. Quarantine surveillance, to detect incursions of exotic fruit fly species by trapping, is operational in CNMI, Guam, FSM and Gilbert Islands of Kiribati.

THE Dacine fruit fly fauna (Tephritidae: Dacinae) present in Micronesia, including islands in the countries and territories of Palau, Guam, Commonwealth of Northern Marianas Islands (CNMI), Federated States of Micronesia (FSM), Marshall Islands and Gilbert Islands of Kiribati, but excluding Nauru, is essentially composed of two native and three introduced species. Published literature on fruit flies of Micronesia, especially about the native species, is very poor. The only comprehensive but preliminary monograph of fruit flies in Micronesia was published by Hardy and Adachi (1956), mostly based on examination of dead flies in museum collections. Active research on biology and control of pest fruit flies has recently been initiated in the FSM and on Guam. The present status of knowledge on distribution and occurrence of fruit flies in Micronesia is reviewed here with up-to-date information on the fruit fly trapping system in place in each country.

[1] Regional Fruit Fly Project in the South Pacific. South Pacific Commission, Private Mail Bag, Suva, Fiji

Native Species

The diversity of the native Dacine fruit fly fauna in Micronesia is extremely poor, as would be expected for small isolated oceanic islands. It is composed of two species, with mutually exclusive distributions.

Mango fruit fly (*Bactrocera frauenfeldi* (Schiner)) is the most widespread species in Micronesia. Its range is Palau, FSM, Nauru, Marshall and Gilbert Islands, Solomon Islands, Papua New Guinea and, since 1974, Northern Queensland in Australia. It is very common throughout its range, even on the most remote atolls. Recent host surveying in FSM identified 31 species of hosts in 22 genera and 16 families. Damage assessment on economic crops have revealed that it infests, in FSM, up to 91% of guavas, 37% of breadfruits, 20% of tangerines, 8% of mangoes and 4% of oranges. Trapping has shown that it is extremely abundant on Pohnpei and Kosrae Islands, in FSM. Its presence was recorded in Saipan, based on a museum specimen collected in 1946 (Hardy and Adachi 1956), but more than three decades of intense trapping on Guam and CNMI has never revealed its presence, even in present times (R. Campbell, pers.

comm.). For this reason, host fruits from other Micronesian countries are not allowed into Guam or CNMI.

Bactrocera ochrosiae (Malloch) is a non- economic species endemic to Guam and CNMI. It is commonly collected in Cue-lure traps. Very little is known about its biology and detailed host range, but it has been reared from *Aglaia mariannensis*, *Ochrosia mariannensis*, *Ximenia americana* and *Eugenia uniflora*.

Hardy and Adachi have recorded the presence of *Bactrocera calophylli* (Perkins and May) in Palau, based on the examination of a museum specimen collected in 1954. It occurs in Malaysia and Northern Queensland. Its presence on Palau can only be confirmed by collecting and incubating samples of *Calophyllum inophyllum*, its main host, since it is not attracted to male lures.

Introduced Species

The non-native fauna, *Bactrocera cucurbitae* (Coquillett), *B. umbrosa* (Fabricius) and *B. dorsalis* Hendel, have a strong Asian affinity. Movements of infested fruits by humans was responsible for their accidental introductions.

Melon fly, *B. cucurbitae*, is very common on Guam, Rota, Saipan, Tinian and Agiguan (CNMI). Its native range is Tropical Asia, from Pakistan to Taiwan and down to South-east Asia. It is a major pest of Cucurbitaceae. It was first recorded in Guam in 1936, and subsequently in Rota, Tinian and Saipan in 1943. It was probably introduced by importing contaminated hosts from Asia.

Melon fly on Rota, CNMI was the target for the first case of successful fruit fly eradication by the sterile insect technique (SIT) in 1962–63 (Steiner et al. 1965b). Similarly, it was eradicated from Saipan, Tinian and Agiguan, and the last fly was collected in 1963 (Mitchell 1980). An intensive survey in 1976–77 to verify the absence of melon fly and Oriental fruit fly from CNMI by setting Cue-lure and methyl eugenol traps failed to collect either species (Mitchell 1980). Melon fly was nevertheless reintroduced from Guam to Rota in 1981 and Saipan in 1986 and is now also equally widespread on Tinian and Agiguan.

Melon fly was discovered in 1987 on Christmas Island in Kiribati, imported from Hawaii in infested cucumbers. An interruption of cucurbit cropping for two years was sufficient to eradicate the fly, according to G.S. Sandhu (Waterhouse 1993). The island has however not been recently surveyed.

A melon fly control program has been implemented by the Guam Department of Agriculture and is being widely adopted by farmers (R. Campbell, pers. comm.). It consists in using yellow sticky traps and yeast baits to attract and kill female flies in cucurbit crops. They claim that damage levels have been reduced by up to 90%.

Oriental fruit fly, *B. dorsalis*, a major pest with native range similar to melon fly, was also introduced to Guam and CNMI. It was first recorded on Saipan in 1935 and Guam in 1948. Male annihilation and protein bait spraying and release of sterile flies, from 1962 to 1965, were used to eradicate Oriental fruit fly from Guam, Rota, Saipan, Tinian and Agiguan (Steiner et al. 1965a, 1970). The last flies were trapped in 1965. In the survey carried in CNMI in 1976–77, no Oriental fruit flies were trapped (Mitchell 1980). It has not been collected by the five methyl eugenol traps presently maintained on Guam (R. Campbell, pers. comm.).

Oriental fruit fly was recently discovered in Palau. One methyl eugenol trap set up in September 1996 collected 291 male flies in five days. It had apparently been present since 1995, when very high damage levels, nearly 100%, were suddenly observed on carambolas at the Agriculture Station on Koror (D. Otobed, pers. commun.). Its presence on Palau is a serious concern for all Micronesia.

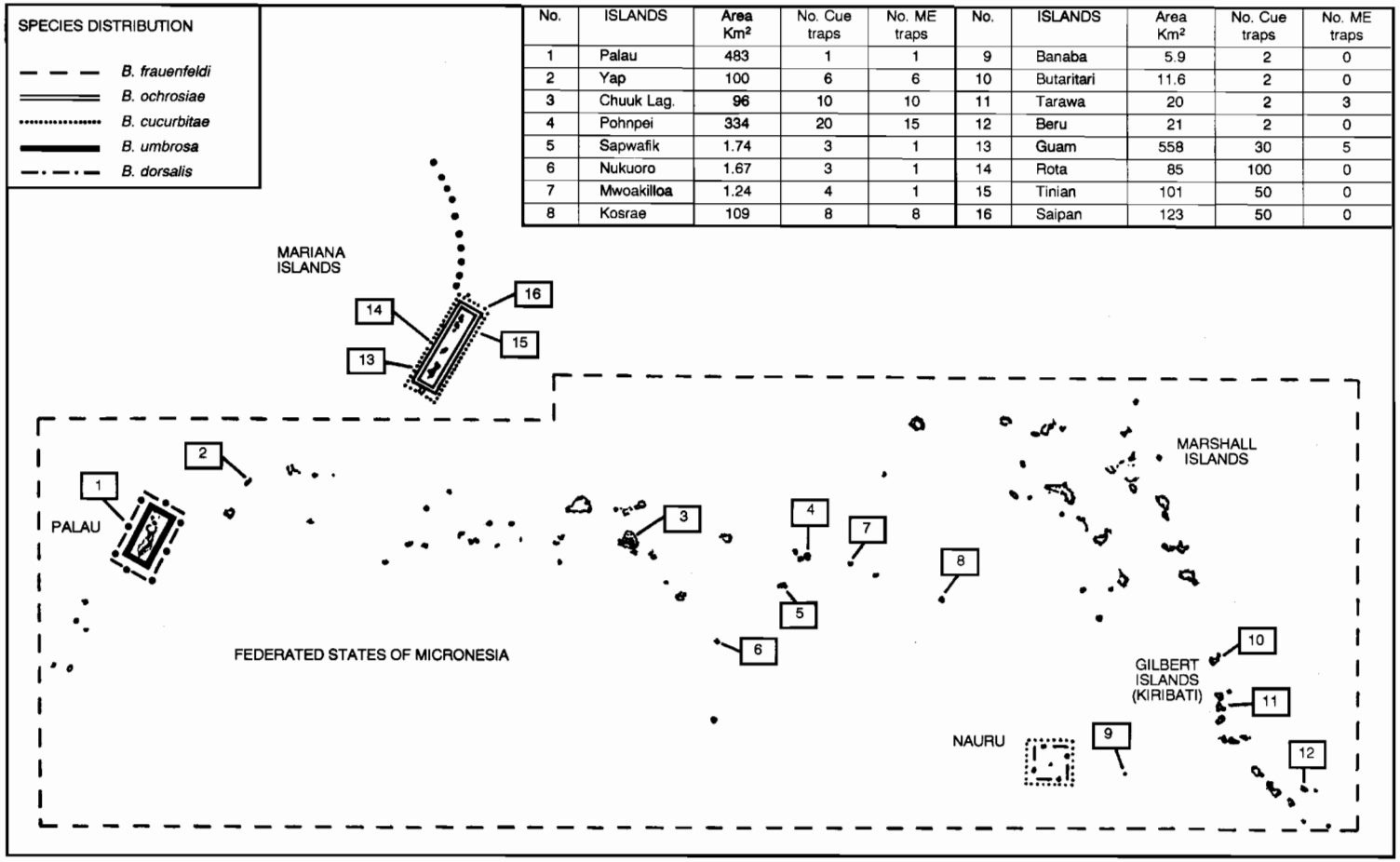
Breadfruit fruit fly, *B. umbrosa*, is another introduced species present in Palau. Its range is South-east Asia, Papua New Guinea, Solomon Islands, Vanuatu and New Caledonia. It is a pest of breadfruit, jackfruit and other *Artocarpus* spp.

Quarantine Surveillance

Quarantine surveillance through permanent trapping stations and regular sampling of high risk commodities is the best way to rapidly detect newly introduced exotic fruit flies. Figure 1 shows fruit fly distribution in Micronesia and the extent of quarantine surveillance by the number of traps in place in each country in 1996. Trapping has already been carried out on a permanent basis for several decades in Guam and CNMI. It was started in early 1995 in FSM and in middle 1996 in Kiribati. Palau has just initiated an embryonic surveillance system with two traps, with a strong wish for quick expansion to evaluate the Oriental fruit fly situation. There is no known trapping in Marshall Islands. Some high risk commodities are regularly sampled only on Pohnpei, in FSM, by the Regional Fruit Fly Project.

Acknowledgments

The author thanks Russell Campbell (Guam Department of Agriculture), Nakabuta Teuriaria (Kiribati Division of Agriculture), Demei Otobed (Palau Department of Agriculture) and Diana Greenough (College of Northern Marianas) for contributing precious information about the quarantine surveillance and field control systems in place in their respective countries.



No.	ISLANDS	Area Km²	No. Cue traps	No. ME traps	No.	ISLANDS	Area Km²	No. Cue traps	No. ME traps
1	Palau	483	1	1	9	Banaba	5.9	2	0
2	Yap	100	6	6	10	Butaritari	11.6	2	0
3	Chuuk Lag.	96	10	10	11	Tarawa	20	2	3
4	Pohnpei	334	20	15	12	Beru	21	2	0
5	Sapwafik	1.74	3	1	13	Guam	558	30	5
6	Nukuoro	1.67	3	1	14	Rota	85	100	0
7	Mwoakilloa	1.24	4	1	15	Tinian	101	50	0
8	Kosrae	109	8	8	16	Saipan	123	50	0

Figure 1. Present fruit fly distribution in Micronesia and trapping systems in place in 1996 in Palau, Guam, FSM and Kiribati.

References

Hardy, D.E. and Adachi, M. 1956. Insects of Micronesia. Vol. 14, No. 1. Diptera: Tephritidae. Bishop Museum. 28 p.

Mitchell, W.C. 1980. Verification of the absence of Oriental fruit and melon fruit fly following an eradication program in the Mariana Islands. Proceedings, Hawaiian Entomological Society. 23(2): 239–243.

Steiner, L.F., Hart, W.G., Harris, E.J., Cunningham, R.T., Ohinata, K. and Kamakahi, D.C. 1970. Eradication of the Oriental fruit fly from the Mariana Islands by the methods of male annihilation and sterile insect release. Journal of Economic Entomology. 63(1): 131–135.

Steiner, L.F., Mitchell, W.C., Harris, E.J., Kozuma, T.T. and Fujimoto, M.S. 1965a. Oriental fruit fly eradication by male annihilation. Journal of Economic Entomology. 58(5): 961–964.

Steiner, L.F., Harris, E.J., Mitchell, W.C., Fujimoto, M.S. and Christenson, L.D. 1965b. Melon fly eradication by overflooding with sterile flies. Journal of Economic Entomology. 58(3): 519–522.

Waterhouse, D.F. 1993. Biological control. Pacific prospects. Supplement 2. Australian Centre for International Agricultural Research. vii+138 p.

Fruit Fly Fauna in New Caledonia

R. Amice[1] and F. Sales[2]

Abstract

Thirteen species of fruit flies have been recorded in New Caledonia. Eight species are endemic to the country. Queensland fruit fly *Bactrocera tryoni* (Froggatt) was introduced in 1969.

The host range of New Caledonian fruit flies has been studied at different periods but mainly in the past few years through the research program funded by the Territory and conducted by CIRAD.

Three species, *B. tryoni, B. psidii* (Froggatt) and *B. curvipennis* (Froggatt), have an extensive host range comprising several important fruit families. Other species are related to wild hosts and two species still have unknown hosts. A new species, *B. grandistylus* Drew and Hancock, has been discovered by host fruit surveys.

B. tryoni is the most important economic species and has also international quarantine significance. The geographic distribution has been established through trapping data but also fruit surveys. The two major species, *B. tryoni* and *B. psidii*, present a complementary distribution. *B. tryoni* is dominant in urban and village areas while *B. psidii* favours more natural habitats. *B. umbrosa* which depends on breadfruit and jackfruit is common in the North East. *B. caledoniensis* (Drew) and *B. ebenea* (Drew) are common in the Loyalty Islands. The introduced *B. tryoni* has replaced *B. curvipennis* which has probably similar requirements but is much less competitive.

A surveillance system aims to detect any incursions of an exotic fruit fly. Its importance is enhanced by the presence of *B. dorsalis* (Hendel) in Tahiti.

THE fruit fly fauna in New Caledonia comprises 13 species of which 10 are endemic (E) to the country. Only one species, the Queensland Fruit Fly, has been introduced in recent years (probably in 1969). These species and their classification are the following:

Family *Tephritidae*	
Subfamily *Dacinae,* Tribe *Dacini*	
— Genus *Bactrocera*	Attractant:
+ Subgenus *Afrodacus*	
grandistylus (E)	Unknown
+ Subgenus *Bactrocera*	
• *frauenfeldi* complex	Cue-lure
caledoniensis (E)	
• *tryoni* complex	Cue-lure
tryoni	
• Species not placed in complexes	
curvipennis (E)	Cue-lure
ebenea (E)	Methyl eugenol
mucronis (E)	Cue-lure
psidii (E)	Cue-lure
umbrosa	Methyl eugenol
+ Subgenus *Notodacus*	
paraxanthodes (E)	Methyl eugenol
+ Subgenus *Sinodacus*	
aneuvittata (E)	Cue-lure
perpusilla (E)	Cue-lure
+ Subgenus *Zeugodacus*	
fulvifacies (E)	Cue-lure
Subfamily *Trypetinae,* Tribe *Acanthonevrini*	
— Genus *Dirioxa*	
— *pornia*	

It is likely that another species known only from a specimen has not been described.

The high proportion of endemism is probably due to the long isolation of the New Caledonia islands.

[1] Direction de l'Agriculture et de la Foret, B.P. 256, Noumea Cedex, New Caledonia
[2] CIRAD-FLHOR, Station de Recherches Fruitieres de Pocquereux, B.P. 32, La Foa, New Caledonia

Most endemic species have no relationship with any other species although three are closely related to other species found in the South Pacific: *B. mucronis* and *B. facialis* in Tonga, *B. caledoniensis* part of the *B. frauenfeldi* complex, *B. paraxanthodes* and *B. xanthodes*.

Host Plants

Plant hosts of New Caledonia fruit fly species have been studied through commercial and wild fruit surveys. While significant work was done by P. Cochereau (Orstom) between 1965–1970 and C. Pinson (CIRAD) in 1990–91 the most important surveys have been realized during the past few years as part the fruit fly research program conducted by CIRAD-FLHOR and funded by the Territory.

From October 1994 to now, approximately 900 samples have been collected. These recent surveys have lead to a better knowledge of the host range of the common species and also have given information on the less known endemic species.

The table in Appendix I gives the known host records for New Caledonia fruit fly species. These data are taken from the 1995 CIRAD Report on Fruit Fly Research Program (Anon. 1996).

There is still no host record for two endemic species: *Bactrocera ebenea* and *B. perpusilla*.

Host surveys have been the means of the discovery of a completely new species: fruits of an Ebenaceae plant collected in Maré in 1993 gave emergence to an unknown species which has recently been described by Drew and Hancock (1995) as *Bactrocera grandistylus*, which has not yet been caught in any lure trap.

Three species have an extensive host range including several fruit hosts of economic importance. These species comprise *Bactrocera tryoni* and two endemic species *B. curvipennis* and *B. psidii*. Other species are only found on forest species apart from *B. mucronis* which can infest guava and *B. umbrosa* on breadfruit and jackfruit.

Economic Importance

Three species commonly infest commercial fruits. Some fruits like guava and peach can harbour heavy fruit fly populations. The following examples show average infestation rates of these fruits:

Guava (ripe and overripe fruits on trees)

			B. psidii	*B. tryoni*	*B. curvipennis*	Average infestation per fruit
Site 1 Nouméa	171 fruits	10 403 g	158	1345	40	10
Site 2 Pocquereux	183 fruits	10 176 g	810	299	727	9

Peach (ripe and overripe fruits collected on trees)

			B. psidii	*B. tryoni*	*B. curvipennis*	*D. pornia*	Average infestation per fruit
Site 1 Mouirange	825 fruits	29 439 g	1608	745	—	9	2.9
Site 2 Pocquereux	911 fruits	28 313 g	2040	94	478	—	2.9

Other fruits like mangoes are less infested as shown in the following results obtained from fruits collected during the 1994–95 season: 75 samples representing 1235 fruits and 187 875 kg were collected from 15 different areas of New Caledonia. From the fruits, 357 *B. tryoni*, 126 *B. curvipennis* and 72 *B. psidii* were reared which gives on average less than one fruit fly per fruit. Fifty-one samples representing 747 fruits and 109 365 kg did not give any fruit fly.

The most important species is without a doubt *B. tryoni* or Queensland fruit fly. This species has the widest host range, it is distributed well over New Caledonia fruit production areas and is trapped in fairly high numbers. It is also considered a high quarantine risk in many countries and Japan prohibits import of fruits not treated by an approved treatment.

The two endemic species *B. curvipennis* and *B. psidii* are also found on several important fruit families like Anacardiaceae, Myrtaceae and Rutaceae. *B. curvipennis* frequently infests Solanaceae.

Host status tests made during the fruit fly research program have shown that some hosts generally not infested in the field can give positive responses when exposed to particular conditions of the tests (all tests followed the New Zealand MAF NASS Standard 155.02.01.08) (Anon. 1991).

This is the case for Tahiti lime and litchi. A sample of 3400 litchi fruits (63 kg) collected in 1990 in three different areas did not show any fruit fly. Only a small portion of these fruits came from treated orchards. However, host status field tests were positive with *B. curvipennis*.

Similarly, Tahiti lime is not infested in orchards but host status field tests were positive with *B. tryoni*.

These three fruit flies must be controlled by treatment programs when fruits are harvested for export. Fruits sold on the local market are generally not treated specifically for fruit flies but treatments intended for other pests maintain low fruit infestation.

Geographic Distribution

The distribution of fruit fly species in New Caledonia has been established mainly through interpretation of trapping data and also from host fruit surveys. Trapping data presented here (see Appendix II) has been obtained from 118 traps located in 41 different sites. Most traps were installed in the first part of 1993 and graphs show data obtained until the end of 1995.

Two species are most commonly trapped: *B. psidii* and *B. tryoni*. Locations of traps have shown that *B. psidii* is the major species caught in areas of low human density such as rural areas and rain forests. *B. tryoni* is dominant in densely populated areas such as Nouméa and its suburbs, villages and other urban areas.

This distribution is probably related to host availability and habitat: many different hosts and urban habitat favour *B. tryoni* while more specific hosts (Myrtaceae, wild hosts) and natural habitats favor *B. psidii*. Other species have also interesting geographic distributions:

- *B. umbrosa* is particularly dependant on jackfruit and breadfruit. These fruit trees are commonly grown on the hot and moist north east coast and *B. umbrosa* represents one third of the flies trapped in this area.
- *B. curvipennis* which is one of the three species of economic importance is not trapped frequently. A lack of attractivity of Cue-lure or a particular behaviour could explain this fact.
- *B. caledoniensis* and *B. ebenea* which are typical forest species are rarely trapped on the main island but are major species in Maré and Lifou respectively. These two islands are raised coral reefs still covered with significant forest areas.
- *B. grandistylus* has been found only on Maré island and *B. paraxanthodes* responded to methyl eugenol traps also on this island only. *B. tryoni* has not been found in Lifou and only a few individuals have been trapped in Maré.

Introduction of Queensland Fruit Fly

B. tryoni was probably brought to New Caledonia by returning residents who illegally introduced backyard fruits from Australia. Cochereau (1970) recorded its occurrence in 1969 in Cue-lure traps placed in Nouméa. This scientist made a trapping survey at ORSTOM Center in 1965 with the following results:

03 March 1965–23 August 1965

16 956	*B. curivpennis*	96.8%
115	*B. psidii*	0.6%
438	*B. umbrosa*	2.5%

Trapping data obtained from an adjacent site in 1994 gave the following results:

08 March 1994–22 August 1994

5868	*B. tryoni*	93.6%
298	*B. psidii*	4.75%
77	*B. umbrosa*	1.2%
12	*B. mucronis*	0.2%
10	*B. perpusilla*	0.15%
3	*B. curvipennis*	0.04%

These data show that prior to the introduction of *B. tryoni*, *B. curvipennis* was by far the dominant species trapped on this site. More than 140 000

B. curvipennis were trapped between 1965 and 1967. Thirty years later, *B. curvipennis* has almost disappeared from this site which is now dominated by *B. tryoni*.

Results from host fruit surveys (see guava and peach surveys) show that when *B. tryoni* is represented by dense populations, *B. curvipennis* is nearly absent, but where *B. tryoni* has low populations *B. curvipennis* is still an important species (for instance at Pocquereux Research Station). It seems that *B. psidii* is less affected by the presence of *B. tryoni* probably because they have different habitat and host preferences while *B. curvipennis* is closer to *B. tryoni* in its requirements and less competitive.

Conclusions

New Caledonia fruit flies have been studied only recently. Most species are endemic to the country and have no economic importance. One introduced species (*B. tryoni*) and two other species (*B. curvipennis*, *B. psidii*) are important pests. Host status tests and fruits surveys have shown that some commercial fruits like Tahiti lime and litchi are rarely attacked.

The geographic distribution reflects habitat and host preferences. *B. tryoni* is dominant in urban areas while *B. psidii* is mostly found in native forests and rural areas. Some endemic species rarely found on the main island are abundant in Loyalty Islands (*B. caledoniensis*, *B. ebenae*). The introduction of *B. tryoni* has induced a replacement of *B. curvipennis* in most areas favorable to Queensland fruit fly. This species is now the main fruit fly pest in New Caledonia and has important quarantine significance. A surveillance system comprising more than 40 sites should allow the early detection of any incursion of an exotic species. This issue is particularly critical with the introduction of *B. papayae* in North Queensland and *B. dorsalis* in Tahiti.

References

Anon. 1991. NASS Standard 155.02.01.08. Specification for determination of fruit fly host status as a treatment. MAF-New Zealand, 17 p.

Anon. 1996. Station de recherches fruitières de Pocquereux Rapport d'Activité 1995–1996. CIRAD-FLHOR, 45–53.

Cochereau, P. 1970. Les mouches des fruits et leurs parasites dans la zone Indo-australo-Pacifique et particulièrement en Nouvelle-Calédonie. Cah. ORSTOM, Sér. Biol. n° 12: 15–50.

Drew, R.A.I. and Hancock, D.I. 1995. New species, subgenus and records of *Bactrocera* Macquart from the South Pacific (Diptera: Tephrriditae: Dacinae). Journal of the Australian Entomological Society, 34: 7–11.

Appendix I. Host range of New Caledonia fruit flies.

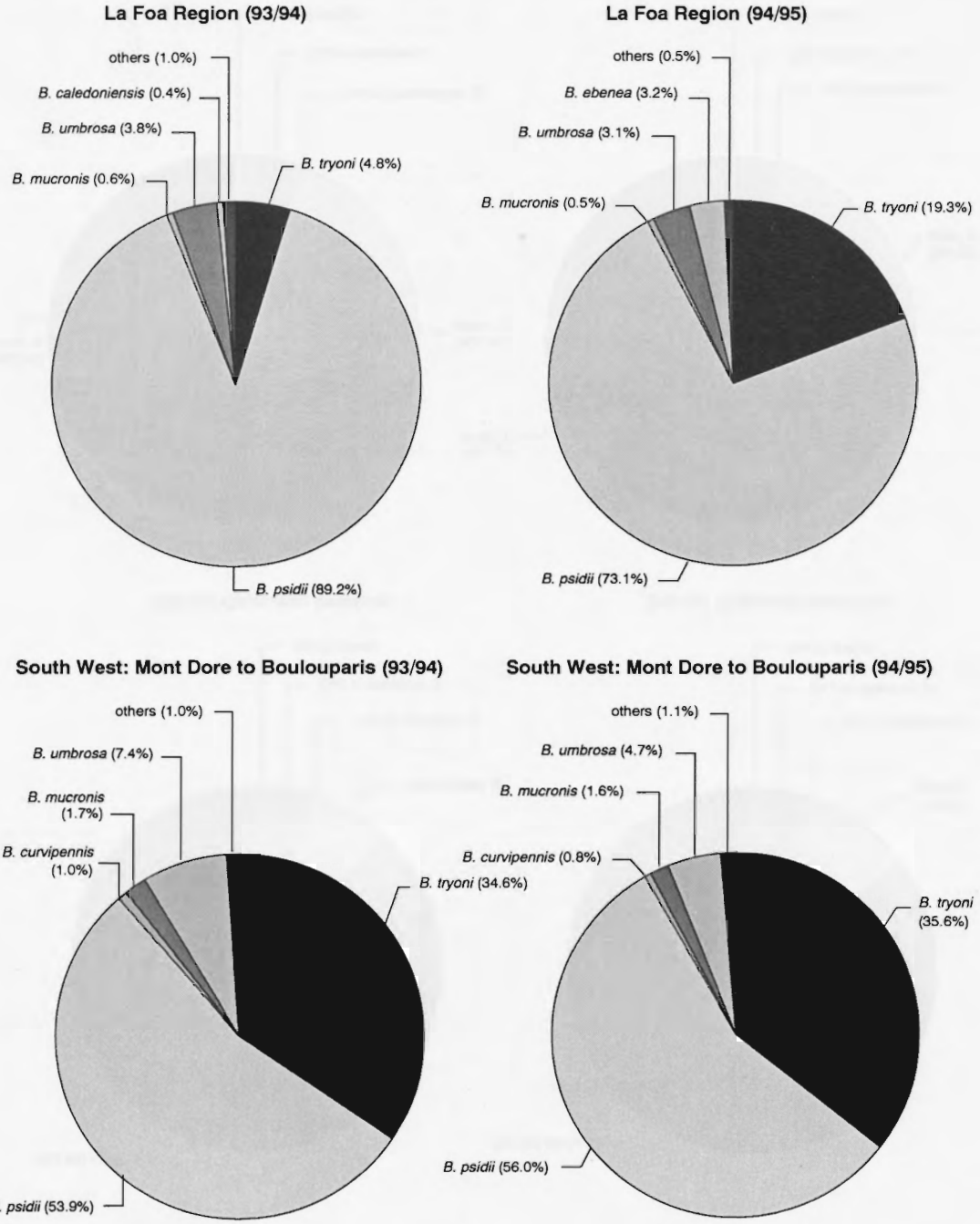
Fruit fly species	Host plant family	Host plant scientific name	Common name
Bactrocera tryoni	Anacardiaceae*	*Anacardium occidentale*	Cashew
9 economic		*Mangifera indica*	Mango
plant	Annonaceae*	*Annona reticulata*	Custard apple
families	Combretaceae	*Terminalia catappa*	Tropical almond
	Hernandiaceae	*Hernandia cordigera*	—
	Lauraceae	*Persea americana*	Avocado
	Malpighiaceae	*Malpighia glabra*	Huesito
	Moraceae*	*Ficus* sp.	Fig
		Artocarpus heterophyllus	Jack fruit
	Musaceae*	*Musa* sp.	Banana (cooking)
			Poingo (type)
	Myrtaceae*	*Eugenia uniflora*	Surinam cherry
		Psidium cattleianum	Strawberry guava
		P. guajava	Common guava
		Syzygium jambos	Rose apple
		S. malaccense	Malay apple
	Rhamnaceae	*Zizyphus mauritiana*	Indian jujube
	Rosaceae*	*Eriobotrya japonica*	Loquat
		Prunus persica	Peach
	Rubiaceae	*Morinda citrifolia*	—
	Rutaceae*	*Citrus grandis*	Pummelo
		C. latifolia	Persian (Tahiti) lime
		C. paradisi	Grapefruit
		C. reticulata	Tangerine (mandarin)
	Sapindaceae*	*Pometia pinnata*	Pacific lychee
	Solanaceae*	*Capsicum annuum*	Bell pepper

Appendix I (continued). Host range of New Caledonia fruit flies.

Bactrocera psidii	Anacardiaceae*	*Anacardium occidentale*	Cashew
5 economic		*Mangifera indica*	Mango
plant	Annonaceae*	*Annona reticulata*	Custard-apple
families	Combretaceae	*Terminalia catappa*	Tropical almond
	Ebenaceae	*Diospyros macrocarpa*	—
	Euphorbiaceae	*Aleurites moluccana*	—
	Moraceae	*Ficus* sp.	Fig
	Myrtaceae*	*Caryophyllus* sp.	—
		Eugenia uniflora	Surinam cherry
		Psidium cattleianum	Strawberry guava
		P. guajava	Common guava
		Syzygium jambos	Rose-apple
		S. malaccense	Malay-apple
	Rosaceae*	*Prunus persica*	Peach
	Rutaceae*	*Citrus grandis*	Pummelo
Bactrocera curvipennis	Anacardiaceae*	*Anacardium occidentale*	Cashew
5 economic		*Mangifera indica*	Mango
plant	Annonaceae*	*Annona reticulata*	Custard-apple
families	Combretaceae	*Terminalia catappa*	Tropical almond
	Ebenaceae	*Diospyros macrocarpa*	—
	Malpighiaceae	*Malpighia glabra*	Huesito
	Myrtaceae*	*Eugenia uniflora*	Surinam cherry
		Psidium cattleyanum	Strawberry guava
		P. guajava	Common guava
		Syzygium jambos	Rose-apple
		S. malaccense	Malay-apple
	Rutaceae*	*Citrus grandis*	Pummelo
		C. paradisi	Grapefruit
		C. reticulata	Mandarin
	Solanaceae*	*Capsicum annuum*	Bell pepper
Bactrocera umbrosa	Moraceae	*Artocarpus altilis*	Breadfruit
		A. heteropyllus	Jackfruit
Bactrocera aneuvittata	Asclepiadaceae	*Tylophora* sp.	—
Bactrocera caledoniensis	Convolvulaceae	*Merrenia tuberosa*	—
	Loganiaceae	*Fagraea berteroana*	—
Bactrocera mucronis	Apocynaceae	*Cerbera manghas*	—
	Combretaceae	*Terminalia catappa*	Tropical almond
	Myrtaceae	*Psidium guajava*	Common guava
Bactrocera fulvifacies	Oleaceae	*Olea paniculata*	—
Bactrocera paraxanthodes	Araliaceae	*Strobilopanax* sp.	—
		Schefflera gabriellae	—
Bactrocera grandistylus	Ebenaceae	*Diospyros fasciculosa*	—
Dirioxa pornia	Combretaceae	*Terminalia catappa*	Tropical almond
	Lauraceae	*Persea americana*	Avocado
	Myrtaceae	*Psidium guajava*	Common guava
		Syzygium jambos	Rose-apple
	Rosaceae	*Prunus persica*	Peach
	Rutaceae	*Citrus grandis*	Pummelo
		C. latifolia	Persian (Tahiti) lime
		C. paradisi	Grapefruit

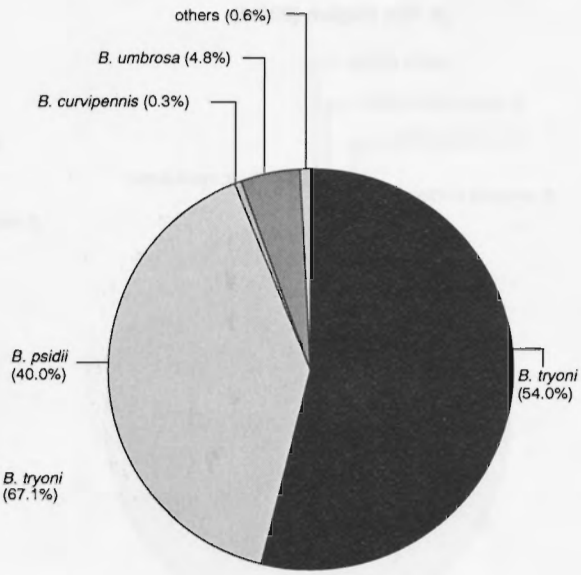
* — denotes plant families that contain economically important plant species.

Appendix II. Geographic distribution of fruit flies in New Caledonia.

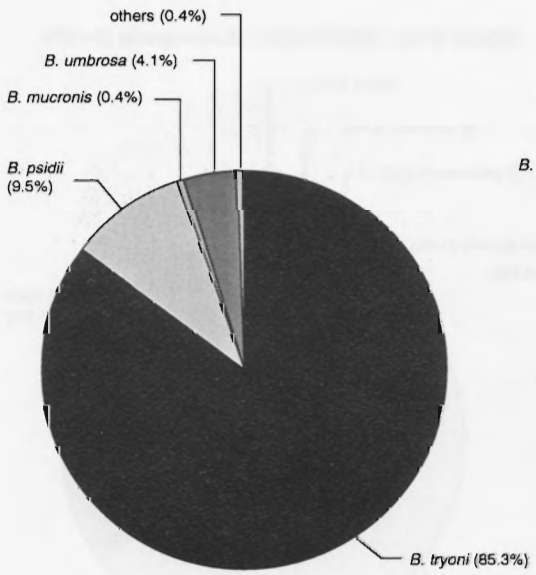


West Coast: Bourail to Voh (93/94)

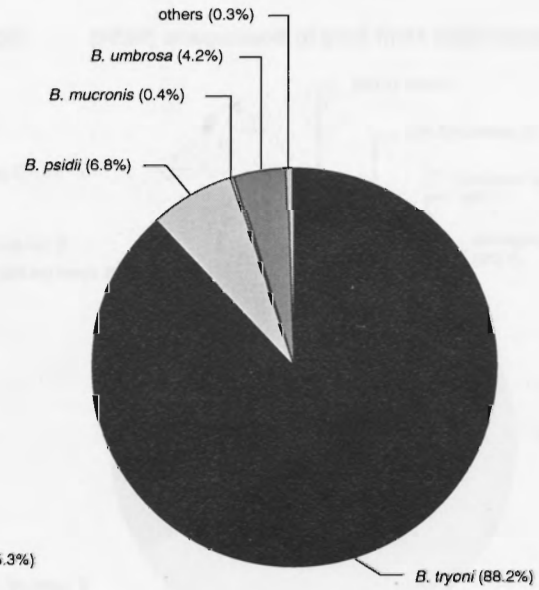
West Coast: Bourail to Voh (94/95)



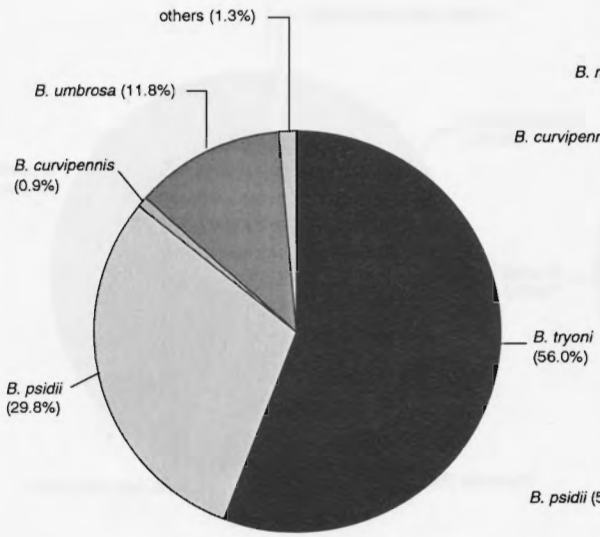
Noumea township (93/94)



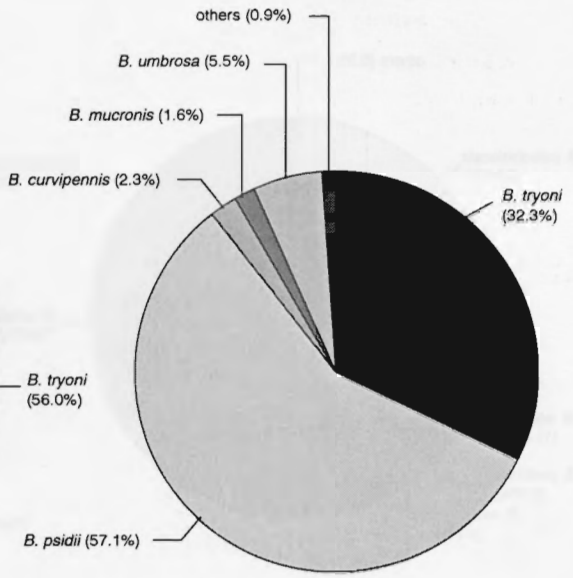
Noumea township (94/95)



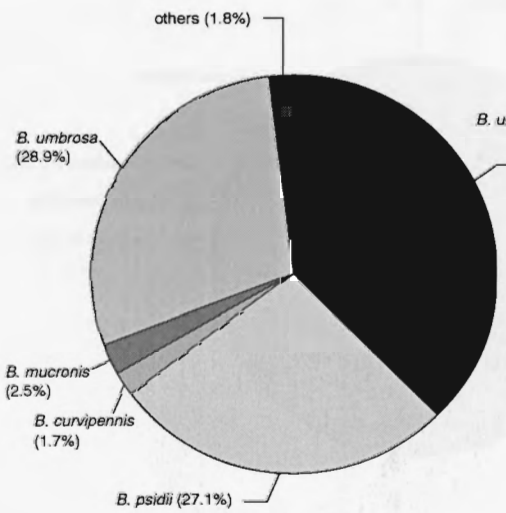
Tontouta Airport (93/94)



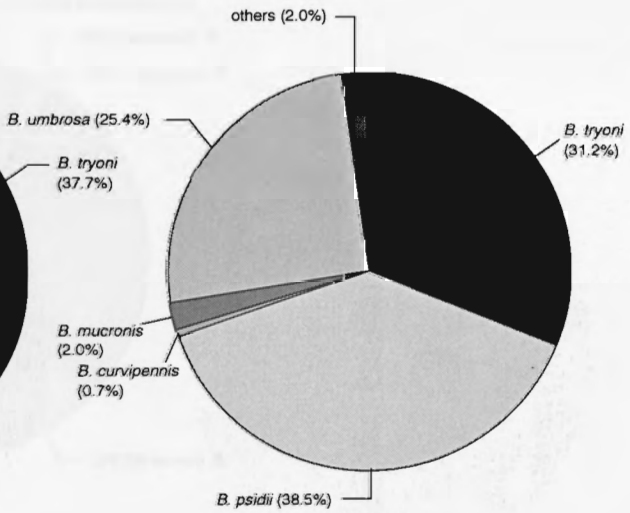
Tontouta Airport (94/95)

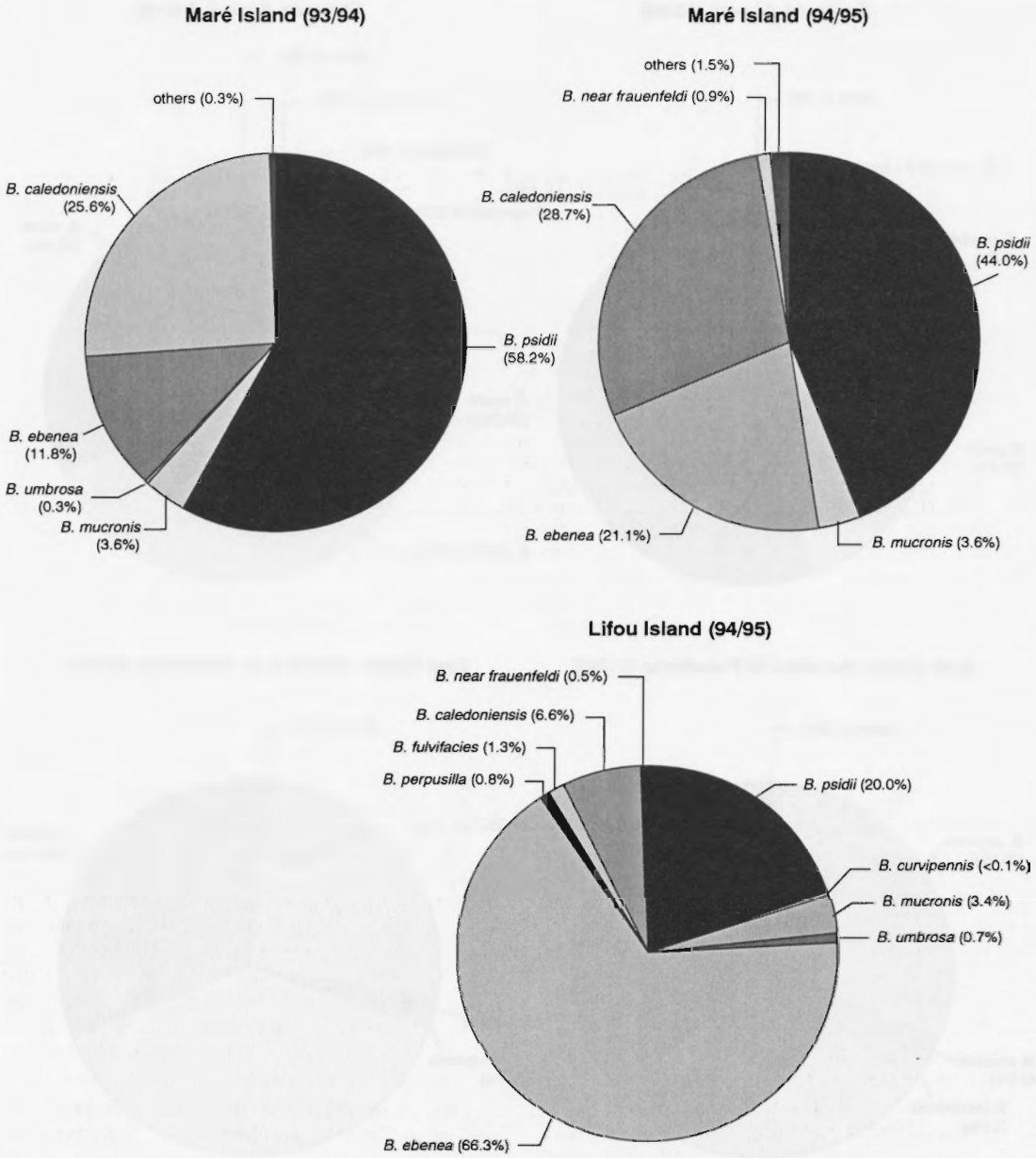


East Coast: Houailou to Poindimie (93/94)



East Coast: Houailou to Poindimie (94/95)




Maré Island (93/94)
others (0.3%)
B. caledoniensis (25.6%)
B. psidii (58.2%)
B. ebenea (11.8%)
B. umbrosa (0.3%)
B. mucronis (3.6%)
Maré Island (94/95)
others (1.5%)
B. near frauenfeldi (0.9%)
B. caledoniensis (28.7%)
B. psidii (44.0%)
B. ebenea (21.1%)
B. mucronis (3.6%)
Lifou Island (94/95)
B. near frauenfeldi (0.5%)
B. caledoniensis (6.6%)
B. fulvifacies (1.3%)
B. perpusilla (0.8%)
B. psidii (20.0%)
B. curvipennis (<0.1%)
B. mucronis (3.4%)
B. umbrosa (0.7%)
B. ebenea (66.3%)

Fruit Fly Fauna in Vanuatu

A.J. Allwood[1], T. Tumukon[2], D. Tau[2] and A. Kassim[1]

Abstract

Despite only limited collections of fruit flies (family Tephritidae) in Vanuatu prior to 1994, there is a reasonable understanding of the species that are present. Since 1994, under the auspices of the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project and a parallel ACIAR-funded project, systematic trapping and host surveys have confirmed the presence of 13 species. Trapping on Efate, Espiritu Santo, Banks Islands, Torres Islands, Ambrym, Epi, Emae, Malakula, and Tanna Island using methyl eugenol and Cue-lure baited traps has been combined with surveys of wild/forest and edible/commercial fruits to provide reliable data on the species of fruit flies present. The species present in Vanuatu are *Bactrocera* (*Afrodacus*) *minuta* (Drew), *B.* (*B.*) *anomala* (Drew), *B.* (*B.*) *curvipennis* (Froggatt), *B.* (*B.*) *quadrisetosa* (Bezzi), *B.* (*B.*) *redunca* (Drew), *B.* (*B.*) *trilineola* (Drew), *B.* (*B.*) sp.n. (near *obscura*), B. (*B.*) sp.n. (near *simulata*), *B.* (*B.*) *umbrosa* (Fabricius), *B.* (*Gymnodacus*) *calophylli* (Perkins and May), *B.* (*Notodacus*) sp.n. (near *xanthodes*), *B.* (*Zeugodacus*) *gracilis* (Drew), and *Dacus* (*Dacus*) sp.n.

Their distributions and economic significances are discussed. Also, several anomalies related to the fruit fly fauna of Vanuatu in literature and by inference are identified and discussed.

VANUATU, formerly known as New Hebrides, comprises some 80 islands and islets extending in a Y shape over 800 km from north to south. It has a land area of 11 880 km^2, with the largest island being Espiritu Santo (3947 km^2). Other large islands include Malakula, Efate, Ambrym, Pentecost, Epi, Erromango, Malo, Tanna, and Anatom. The Torres and Banks Islands are the most northerly and one of the important gateways to the introduction of exotic, unwanted fruit fly species from Solomon Islands.

The ethnic make-up of the population of over 140 000 is 98% Ni-Vanuatuan, with the remainder being European, Micronesian/Polynesian, other Melanesians, Chinese and Vietnamese. About 80% of the islanders live in rural communities, where traditional, subsistence farming is the major activity.

Coconut, cocoa, coffee and beef production forms the basis of agriculture. Copra, fish and beef make up over 70% of the country's export earnings. Market gardens are developing in the peri-urban areas of Port Vila and other major centres. These supply bananas, breadfruit, citrus, guavas, mangoes, papaya, plantains, and a range of local fruits to the newly established market in Port Vila and to tourist hotels. To lessen the reliance on copra, cocoa and beef, the agricultural sector is diversifying into pepper, vanilla, ginger, garlic, kava and fresh fruits and vegetables. As the fresh fruit and vegetable production and export expands, the importance of fruit flies has become evident. One of the major reasons given for slow development of fresh fruit and vegetable production and export in Vanuatu is the presence of damaging fruit fly species and the constraints that their presence places on exports.

This paper elucidates the species of fruit flies present in Vanuatu, provides comment on their distributions, seasonal abundances and economic importance, and corrects some anomalies in records of fruit flies that are purported to occur in Vanuatu.

[1] Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji
[2] Department of Agriculture and Horticulture, Tagabe Research Station, Port Vila, Vanuatu

Trapping and Host Surveys

Limited collections of fruit flies (family Tephritidae) by trapping with synthetic lures or host fruit surveys had been made prior to 1994. This was evidenced by

the relatively few fruit fly specimens in the Government insect collection at Tagabe Research Station in Port Vila. Nevertheless, some collections by David Tau and others of the Department of Agriculture and Horticulture (DAH) had been done, especially during 1970–74.

The Regional Fruit Fly Project in the South Pacific (RFFP) commenced systematic trapping and host surveys on the major islands of Vanuatu in January, 1994. Methyl eugenol and Cue-lure baited modified Steiner traps were established on Efate (15 trapping sites), Espiritu Santo (10 trapping sites), and on Banks Group (6 sites), Torres Group (2 sites), Malakula (4 sites), and Tongoa Island (2 sites). The traps on Efate and Espiritu Santo are cleared every two weeks, while those elsewhere are cleared less regularly.

To supplement the trapping data, sampling of wild/forest fruits and edible/commercial fruits and vegetables has been done since January, 1994. Two thousand three hundred and fourteen samples amounting to 8 000 kg of fruit have been collected under the RFFP and a parallel project under the Australian Centre for International Agricultural Research (ACIAR). These samples represent 217 plant species from 67 plant families. The host fruit surveys assist in identifying fruit flies not attracted to male lures. As part of the ACIAR inputs to the project, Dr Richard Drew of the Queensland Department of Primary Industries and his staff provide confirmatory identifications of all flies trapped and reared from fruits.

Fruit Fly Fauna

The following species have been recorded prior to the commencement of the RFFP or during the RFFP and the ACIAR Project:

Bactrocera (*Bactrocera*) *trilineola* Drew

This species is the most important economic species in Vanuatu. It has been recorded from 32 fruit species from 18 plant families. Of the 32 fruit species, 24 are classified as being edible or commercial and include mango, *Citrus* spp., guava, papaya, *Syzygium* spp., and soursop. *B. trilineola* has been recorded in traps wherever they have been set up and it is highly likely that it occurs on all islands and islets in Vanuatu. It occurs at all times of the year in reasonably high numbers compared to other species throughout the Pacific. Populations peak in January–February and April–May, which coincide with the fruiting seasons of mangoes and guavas, respectively.

Biological studies done during the RFFP (RFFP, unpublished data) showed that it mates in the morning, but tends to mate over a long period of time during the day. Adults mate in about 11 days after emergence. The life cycle is completed in approximately 21–22 days at 25 °C, using a papaya/torula yeast/Nipagin artificial diet.

Bactrocera (*Bactrocera*) *quadrisetosa* (Bezzi)

B. quadrisetosa is a minor pest though it is widespread throughout Vanuatu. It has been recorded from only one wild host. It is one of the three species in Vanuatu that is not attracted to male lures. This species was initially placed in the subgenus *Zeugodacus* by Drew (1973), but it possesses all of the characters of the *Bactrocera* including a short surstylus lobe and a deep concavity on the posterior margin of abdominal sternum V. However, despite its possessing four scutellar bristles, not two as in the *Bactrocera*, it is provisionally placed in the subgenus *Bactrocera* (Drew 1989).

Bactrocera (*Afrodacus*) *minuta* (Drew)

B. minuta is, as the name implies, a small species and has been reared from two hosts. It has been recorded from Malakula and Efate, and probably occurs on other islands.

Bactrocera (*Bactrocera*) *redunca* (Drew)

This species occurs on Malakula and Efate and also occurs in Bougainville, PNG, in several of the Torres Strait Islands, and in Solomon Islands (Drew 1989). It is probably widespread in Vanuatu. It has been recorded from one host during this program.

Bactrocera (*Notodacus*) sp.n. (near *xanthodes*)

B. sp.n. (near *xanthodes*) is similar to *B.* (*N.*) *xanthodes* (Broun) and *B.* (*N.*) *paraxanthodes* Drew and Hancock and is one the four species that make up the *xanthodes* complex (Drew et al., these Proceedings). Like *B. paraxanthodes*, it is not attracted to methyl eugenol. It has been recorded from two wild hosts only. It is restricted to Vanuatu at this stage.

Bactrocera (*Bactrocera*) *umbrosa* (Fabricius)

This species is widely distributed throughout Vanuatu, New Caledonia, Solomon Islands, PNG, and Palau in the Northern Pacific and Southeast Asia. It has been recorded from only one commercial host fruit, *Artocarpus altilis* (Parkinson) (breadfruit) in Vanuatu, but, based on its host elsewhere, it is likely to be reared from other cultivated and wild *Artocarpus* spp.

***Bactrocera* (*Gymnodacus*) *calophylli* (Perkins and May)**

This species was thought to be a species near *B. calophylli*, but on further examination and host surveys by Drew (pers. commun.), it was confirmed that indeed it was *B. calophylli*. It has been reared from *Calophyllum inophyllum* L., particularly from Espiritu Santo. It is not an economic species. It is the third species in Vanuatu that is not attracted to male lures.

Other species in Vanuatu

Other species reported to be in Vanuatu include *Bactrocera* (*Bactrocera*) *anomala* (Drew), *Bactrocera* (*Bactrocera*) *curvipennis* (Froggatt), *Bactrocera* (*Zeugodacus*) *gracilis* (Drew), *Bactrocera* (*Bactrocera*) sp. near *obscura*, *Bactrocera* (*Bactrocera*) sp. near *simulata*, and *Dacus* (*Dacus*) sp.

Anomalies or Potential Anomalies in Fruit Fly Fauna

Throughout the Pacific region there are records in the literature that are either erroneous or have not been validated during the recent systematic surveys using traps and host surveys. There are four anomalies in the fauna in Vanuata, these being:

***Bactrocera curvipennis* (Froggatt)**

There are apparently three female specimens of *B. curvipennis* in the British Museum-Natural History, collected by Cheesman in November, 1930 from Aneityum, New Hebrides. During surveys in the 1970s and 1980s by the DAH and during the current surveys, this species has not been trapped or reared from fruits. The species is attracted to Cue-lure. The record above needs to be validated because it is a pest of *Citrus* spp., guava, papaya, peach and (supposedly) grapes in New Caledonia (Cochereau 1966, cited in Waterhouse 1993). Also, it is the most heat tolerant species in New Caledonia (Sales et al., these Proceedings). It is necessary to clear up this anomaly to ensure that researchers in Vanuatu do not have to try to conduct heat tolerance studies on a species that does not exist in the main production areas or may be limited in its distribution to isolated islands.

***Bactrocera* (*Bactrocera*) *musae* (Tryon)**

Waterhouse (1993) incorrectly shows, in his Figure 2.1, that *B. musae* (commonly referred to as banana fruit fly) occurs in Vanuatu. No *B. musae* has been recorded in methyl eugenol traps during surveys or been reared from fruits during the current work. The record is obviously incorrect. The distribution of banana fruit fly as depicted in his Figure 2.1 does not include North Queensland, which is also incorrect. *B. musae* occurs in PNG as well as in North Queensland. Its recorded distribution in Solomon Islands requires confirmation.

***Bactrocera* (*Bactrocera*) *simulata* (Malloch)**

B. simulata is recorded as a minor pest in PNG, Solomon Islands and Vanuatu by Waterhouse (1993). It is also recorded as occurring in Vanuatu by Drew (1989). The record may result from a misidentification of the species now being referred to as *B.* sp. near *simulata* or, for some strange reason, confusion with *B. quadrisetosa* as indicated by incorrectly labeled specimens in the DAH collection. It seems that these records may be erroneous and need to be validated.

***Bactrocera* (*Notodacus*) *xanthodes* (Broun)**

Drew and Hancock (1995) stated that the records of *B. xanthodes* in Vanuatu obviously refer to *B. paraxanthodes*. Since then, additonal studies by Drew and Hancock (pers. commun.) indicate that this species is one of the four species in a complex. It is referred to as *B.* sp.n. (near *xanthodes*). The specimens referred to as *B. xanthodes* from Vanuatu and held in the Land Care Insect Collection in New Zealand need to be re-examined, preferably by Prof. Drew. Though these were supposedly bred from *Barringtonia edulis* Seem. in Vanuatu, it is almost certain that they are not *B. xanthodes*. No *B. xanthodes* has been recorded in methyl eugenol traps or reared from well known host fruits during the current projects. Therefore, *B. xanthodes* does not occur in Vanuatu. This is very important to establish and have accepted by international quarantine authorities.

Conclusion

The systematic trapping and fruit surveys under the RFFP and the ACIAR Project have provided up-to-date data that have been used for quarantine decision-making by New Zealand in particular. This demonstrates the value of basic surveys for fruit flies and shows that the data generated are essential before negotiations on quarantine protocols can be successfully commenced. It is necessary to maintain this impetus and to focus on the wild or forest plant species as well as the edible or commercial crops. It is important to try to obtain host records for those species currently without valid records and to validate or reject the anomalies identified in this paper. These anomalies need to be validated or otherwise before they are included in the Pacific Fruit Fly Database, to prevent further proliferation of erroneous records.

References

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanian regions. Memoirs of the Queensland Museum, 26: 1–521.

Drew, R.A.I. 1973. Revised descriptions of species of Dacini (Diptera: Tephritidae) from the South Pacific. I. Genus *Callantra* and the *Dacus* group of subgenera of the genus *Dacus*. Queensland Department of Primary Industries, Division of Plant Indusrty Bulletin 653: 101 p.

Drew, R.A.I. and Hancock, D.L. 1995. New species, subgenus and records of *Bactrocera* Macquart from the South Pacific (Diptera: Tephritidae: Dacinae). Journal of the Australian Entomological Society, 34: 7–11.

Waterhouse, D. 1993. Biological control Pacific prospects — Supplement 2. Published by Australian Centre for International Agricultural Research, Canberra, 1993, 138 p.

Fruit Fly Fauna in Solomon Islands

M. Vagalo[1], R. Hollingsworth[1] and F. Tsatsia[1]

Abstract

Solomon Islands is a country of biodiversity, but also has a large proportion of the fruit fly species present in the South Pacific region. At least 50 fruit fly species, many of which are unique and endemic, have been collected through trapping and host fruit surveys. Trapping has been carried out using two different types of male insect lures: methyl eugenol and Cue-lure. *Bactrocera frauenfeldi*, *B. umbrosa*, *B. cucurbitae* and *Dacus solomonensis* are common and economic fruit fly species. *B. musae* is said to attack banana but is not common. However, its purported existence in Solomon Islands may impose quarantine restrictions to markets overseas and, therefore, its presence requires confirmation. The majority of the other species are not economic and develop in wild host fruits. At least one species has been introduced. *B. cucurbitae* was first detected in 1984 in Solomon Islands and is currently spreading eastward. It is now found in all provinces except Rennell/Bellona, Makira and Temotu. Serious economic species such as *B. tryoni*, *Ceratitis capitata* and *dorsalis* complex pests might easily spill over into Solomon Islands from surrounding countries. There is an urgent need for a proper and workable quarantine surveillance system.

TROPICAL fruit flies of the family Tephritidae are ranked as the number one priority pests of fruits and vegetables in Solomon Islands. Losses may be due not only to crop damage and the cost of control measures but also to the restriction or loss of export markets. Fruit and vegetable production in Solomon Islands is remarkably low. As such, the country is not exporting any fruits and vegetables. To a large extent, fruit flies are the underlying cause of this. The presence of fruit flies in the country undermines and discourages many growers and leads them to produce for local markets only. The fruits are generally of low quality and occasionally infested by fruit flies.

Fruit Fly Species in Solomon Islands

Situated in the humid tropics, the Solomon Islands provides an ideal environment for tephritid fruit flies. It is believed that some of the *Bactrocera* species and one *Dacus* species may have evolved in the Solomon Islands. While the Western Province of Solomon Islands is a mere 5 km from Bougainville (PNG), its closest political neighbor to the east is Vanuatu, which lies about 700 km to the southeast of the main chain of Solomon Islands. There are similarities among these three countries in terms of scattered islands, flora and fauna. Geographically, most of the larger islands are rugged. However available fruit fly habitats vary from coral atolls to high mountain ridges. It is estimated that the total flora distributed on the islands of Solomon Islands are about 5000 species, of which about 3500 species have been identified (S.M. Qusa, pers. comm.).

The fruit fly fauna of Solomon Islands is not yet fully known. However, with lure trapping and rearing from infested hosts some valuable information has been attained. A review by Drew (1989) lists 29 species of the genera *Bactrocera* and *Dacus* from Solomon Islands. Only one out of the 29 species belongs to the *Dacus* genera. This species, *Dacus solomonensis*, is known only in Solomon Islands and Bougainville (PNG). There has been an on-going intensive trapping and fruit rearing program in Solomon Islands since May1994. This program is implemented under the Solomon Islands FAO/AusAID/UNDP/SPC Regional Fruit Fly Project and the parallel ACIAR fruit fly project. One of the immediate objectives is to reconfirm and

[1] Dodo Creek Research Station, PO Box G13, Ministry of Agriculture and Fisheries, Solomon Islands

update fruit fly information for the Solomon Islands. Two lure types are being used: Cue-lure and methyl eugenol. As of September 1996, a total of 50 fruit fly (tephritid) species have been identified from the Solomon Islands (Eddy Hamacek, pers. comm.) (Table 1). This represents an addition of 21 species since the publication of Drew's 1989 monograph on the Dacinae of the Austalasian and Oceania regions. Forty-one of the 50 species were attracted to either Cue-lure or methyl eugenol traps. Forty-two species belong to genera *Bactrocera* and *Dacus*. Nine species reared from fruits were never collected in traps. Thirty-two species are attracted to Cue-lure and nine species are attracted to methyl eugenol. Only a small number of species collected in traps have also been reared from fruits, despite the 1809 collections of wild and cultivated fruit made since 1994 (mostly along northern Guadalcanal). This suggests that there is more fruit-rearing work that needs to be done on different plant species and in different geographical areas.

Nine species were reared from fruit hosts but not detected in either Cue-lure or methyl eugenol. *Bactrocera* (*G*) sp. n. 11 is the only species that belong to *Bactrocera* genera that is reared from fruit host but not detected from the lures.

Among the fruit fly species present in Solomon Islands are some of economic importance. These are the flies that cause damage to edible fruits and fruits with commercial value, and that farmers are generally concerned about. Depending on the fruit fly species and their hosts, the degree and frequency of damage are different. The hosts for most of the non-economic fruit fly species are presumed to be wild fruits in forested areas. The species that are regarded as economic fruit fly species in the Solomon Islands are: mango fly (*Bactrocera frauenfeldi* (Schiner)); melon fly (*Bactrocera cucurbitae* (Coquillett)); breadfruit fly (*Bactrocera umbrosa* (Fabricius)); Solomon fly (*Dacus solomonensis* Malloch) and banana fly (*Bactrocera musae* (Tryon)).

Table 1. Solomon Islands fruit flies.

Fly species	Fruit fly host	Attractant
Fly species attracted to nale lures		Cue
Bactrocera (A.) minuta		
Bactrocera (B.) anomola		Cue
Bactrocera (B.) bancroftii		ME
Bactrocera (B.) biarcuata		ME
Bactrocera (B.) decumana		Cue
Bactrocera (B.) enochra		Cue
Bactrocera (B.) epicharis		Cue
Bactrocera (B.) frauenfeldi	*Mangifera indicum*	
	Psidium guajava	
	Carica papaya	
	Syzgium malaccense	
	Averrhoa carambola	
	breadfruit	
	jackfruit	
	soursop	
	black sapote	
	sapodilla	
	snake gourd	
	avocado	
	kumquat	
	orange	
	Scaevola taccada	
	Cerbera sp.	
	Ficus sp.	
	Calophyllum sp.	
	Manilkara achras	
	Polynesian chestnut	
	Neonauclea forsteri	
	paper mulberry	Cue
Bactrocera (B.) froggatti		ME
Bactrocera (B.) honiarae		ME
Bactrocera (B.) melanogaster		ME
Bactrocera (B.) morula		Cue

Table 1 (continued). Solomon Islands fruit flies.

Fly species	Fruit fly host	Attractant
Bactrocera (B.) musae		ME
Bactrocera (B.) nigriscentis		Cue
Bactrocera (B.) pepisalae		ME
Bactrocera (B.) picea		ME
Bactrocera (B.) pseudodistincta		Cue
Bactrocera (B.) redunca		Cue
Bactrocera (B.) simulata		Cue
Bactrocera (B.) trilineola		Cue
Bactrocera (B.) turneri		Cue
Bactrocera (B.) umbrosa	*Artocarpus altilis*	
	Artocarpus heterophyllus	
	Polycias sp.	ME
Bactrocera (B.) unifasciata		Cue
Bactrocera (B.) varipes		Cue
Bactrocera (B.) sp. n. (near *froggatti*)		Cue
Bactrocera (B.) sp. n. (near *nigriscentis*)		Cue
Bactrocera (B.) sp. n. (near *simulata*)		Cue
Bactrocera (B.) sp. n. (near *turneri*)		Cue
Bactrocera (B.) sp. n. S.I. 5		Cue
Bactrocera (B.) sp. n. S.I. 6		Cue
Bactrocera (B.) sp. n. S.I. 8		Cue
Bactrocera (B.) sp. n. S.I. 9		Cue
Bactrocera (B.) sp. n. S.I. 12		Cue
Bactrocera (S.) sp. n. (near *strigifinis*)		Cue
Bactrocera (Z.) cucurbitae	*Trichosanthes cucumerina*	Cue
Bactrocera (Z.) sp. n. S.I. 1		Cue
Bactrocera (Z.) sp.n. S.I. 2		Cue
Bactrocera (Z.) sp. n. S.I. 3		Cue
Bactrocera (Z.) sp. n. S.I. 4		Cue
Bactrocera (Z.) sp. n. S.I. 7		Cue
Dacus (C.) solomonensis	*Trichosanthes cucumerina*	
	Calophyllum inophyllum	Cue
Fly species only bred from fruit		
Bactrocera (G) sp. n. 11	*Calophyllum inophyllum*	
	Carica papaya	
Ceratitella sp. n. (near *bifasciata*)	name of host was not determined	
Clusiosoma pleurale	*Ficus septica*	
Euphranta scutellata	*Cerbera manghas*	
Hemiristina pleomeles	*Coccinea grandis*	
Phylophylla conjuncta	*Premna corymbosa*	
Rabaulia fascifacies	*Ficus copiosa*	
	Ficus pseudowassa	
Rhabdochaeta cockeri	*Wedelia biflora*	
Rhabdochaeta sp.	*Wedelia biflora*	

Source: Regional Fruit Fly Project in Solomon Islands.

Editors Note: The early records of banana fruit fly (*B. (B.) musae*) are questionable and its presence will require re-confirmation.

Mango fly

Mango fly is a species that responds to Cue and Willison's lures (Waterhouse 1993). This species is present in north Queensland as far south as Innisfail, the Bismarck Archipelago, Bougainville Island (PNG), Solomon Islands, Stuart Islands, Nauru, Kiribati, Federated States of Micronesia, Marshall Islands and Palau (Drew 1989; Waterhouse 1993). Mango fly in Solomon Islands is commonly reared from mango, papaya, guava, Malayan apple and carambola. It has also been reared from breadfruit, citrus (grapefruit, kumquat and 'orange'), soursop, Polynesian chestnut, paper mulberry, *Ficus* sp. (probably *Ficus copiosa*), black sapote, avocado, *Terminalia catappa*, *Calophyllum inophyllum*, *Cerbera manghas*, sapodilla, *Neonauclea forsteri*, snake gourd and *Scaevola taccada* (govugovu). Mango fly is the most dominant of all the fruit flies in Solomon Islands, almost always the most abundant species in Cue-lure traps. The most mango flies caught per day in a Cue-lure trap was 542 flies, recorded at Vila Maria in northern Guadalcanal (Fig. 1).

Melon fly

Melon fly is one of the world's most active and serious fruit fly pests and the most important fruit fly pest of vegetables, especially of cucurbit crops (Waterhouse 1993). Male melon fly responds to Cue-lure (Drew 1989). The melon fly in Solomon Islands is an introduced species. It was first found in September 1984 in Malaiae village, Shortland Islands, Western Province (Eta 1985). Apparently, this pest was confined to a small geographical area and eradication was initiated. Within a few months, melon fly was considered to be eradicated from Solomon Islands. In June 1985, melon fly again reappeared on the islands of Gizo, Kolombangara and north Choiseul (Eta 1985). Melon fly has continued to spread eastward and was first detected in Isabel in 1988 (Williams et al. 1990). It was found in Yandina in 1994, Malaita and Guadalcanal in 1995 (unpublished data). Out of the nine Solomon Islands provinces, only three are still free of melon fly infestation. These are Makira, Temotu, and Rennell/Bellona provinces. In Solomon Islands, melon fly attacks pumpkin, snake gourd and cucumber (Bateman 1989). It was also reared from papaya but pending verification. There could be some contamination on larvae from snake gourd on papaya because they were put together in one field bag when they were collected.

Breadfruit fly

The breadfruit fly is present in Southeast Asia, Palau, Papua New Guinea, including New Britain, New Ireland, Lihir Island, and Bougainville Island, Solomon Islands, Vanuatu and New Caledonia (Drew 1989; Waterhouse 1993). This fruit fly species is attracted to methyl eugenol lure and occurs in very large populations in lowland areas, particularly in disturbed situations. In Solomon Islands, it has been reared from breadfruit and jackfruit and *Polycias* sp. only. However, Waterhouse (1993) has recorded citrus as a host of *B. umbrosa* in the Pacific countries. It is still numerous even during breadfruit's off-season. This may suggest the presence of alternate hosts. Waterhouse (1993) mentions *Momordica charantia* in Kalimantan as a host.

Solomon fly

The Solomon fly is a pest of cucurbits. It is found in Bougainville Island and Solomon Islands only (Drew 1989). This fruit fly is attracted to Cue-lure. It is not

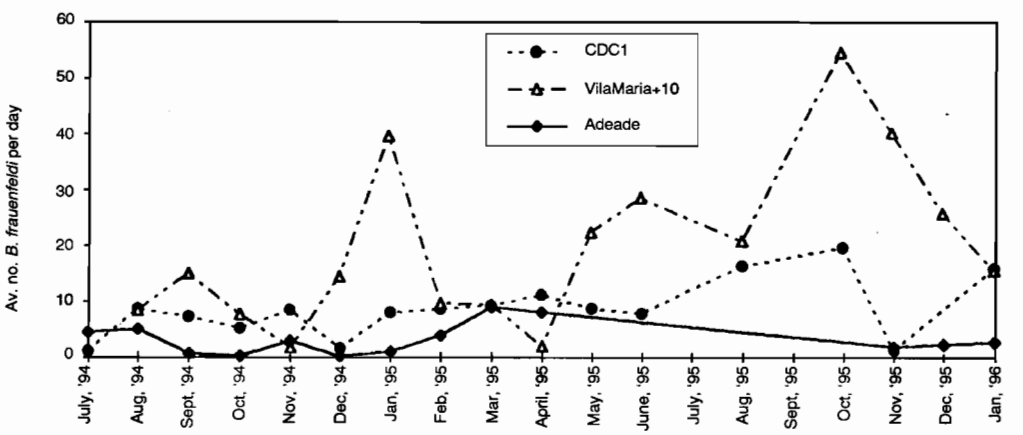


Figure 1. Seasonal abundance of *Bactrocera frauenfeldi* (Schiner) at the localities in northern Guadalcanal.

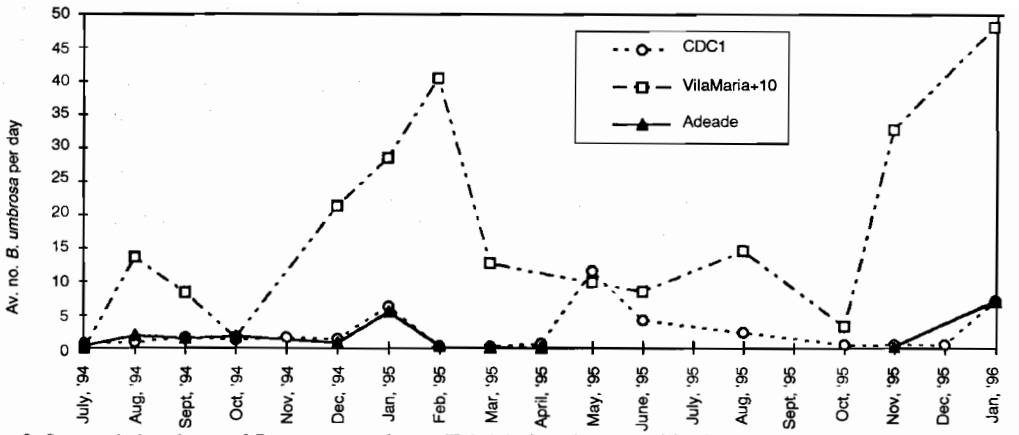


Figure 2. Seasonal abundance of *Bactrocera umbrosa* (Fabricius) at three localities in northern Guadalcanal.

as common and generally as destructive as the melon fly. However, on snake gourd, it is sometimes a serious pest (Williams et al. 1990). It may turn out to be a serious pest on other cucurbit crops as well, in areas where cucurbit crops are grown continuously on a large scale basis for a long period of time. The Solomon fly is also reared from *Calophyllum inophyllum*.

Banana fly

Banana fly is present in Queensland (Australia), Torres Strait islands, Papua New Guinea and Solomon Islands (Drew 1989). It is a major pest of banana in Queensland and PNG. It attacks both mature green and ripe banana. This fruit fly species has not been recorded in Solomon Islands during 1994–97. Banana fruit fly is attracted to methyl eugenol.

Seasonal Abundance of Mango Fly and Breadfruit Fly

Figures 1 and 2 show the seasonal abundance of two fruit fly species, *B. frauenfeldi* and *B. umbrosa* which are usually very common and abundant throughout Solomon Islands. Results of trapping documented that the abundance for each of these species is strongly dependent on season, apparently being influenced by availability of major hosts. Mango season, for example, falls between October and March, with peak fruiting months of December and January. These same months represent the peak period for trap catches of mango fly. Trap catches for three coastal areas along northern Guadalcanal are presented in Figures 1 and 2. Adeade is situated to the east; CDC1 is located centrally, and Vila Maria to the west. Vila Maria has a wide range of fruit trees and higher recorded fruit fly catches than the other two sites. *B. frauenfeldi* was more abundant than *B. umbrosa* at Vila Maria (Figs. 1 and 2).

Conclusions

The presence of a large number of fruit fly species currently recorded in Solomon Islands has detrimental affects on markets of fruits and vegetables overseas. In real terms, it is the presence of the five economic species that cause low productivities of fresh fruits and vegetables.

Many important economic fruit fly pests present in other Pacific Island countries are still absent from the Solomon Islands. These include several very serious and well-known pests in the *dorsalis* complex, Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann), and Queensland fruit fly (*Bactrocera tryoni* (Froggatt)). The ocean surrounding the Solomon Islands provides a natural barrier to the immigration of new fruit fly species. On the other hand, the multitude of scattered islands in the country make surveillance and monitoring difficult to achieve. The situation involving the melon fly provides a good example. Initially, the government of Solomon Islands seriously considered eradication. This was followed by strictly enforced quarantine measures which prevented the movement of fruits and vegetables from infested sites to the melon fly-free islands. Due to the very high expenses involved, the Agricultural Quarantine Service discontinued strict enforcement of these regulations after several years. If this trend continues, then it is expected that Solomon Islands will be referred to as the gate-way of economic fruit fly species in the Pacific islands region.

References

Bateman, M.A. 1989. A report on the tropical fruit flies of the South Pacific region. South Pacific Commission, Plant Protection Service. 32 p.

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanic regions. Memoirs of the Queensland Museum, Brisbane, Australia, 26: 1–151.

Johnson, V. 1988. Survey of melon fly in the Solomon Islands, final report. Internal report, Agricultural Quarantine Service, Solomon Islands Government.

Eta, C.R. 1985. Eradication of the melon fly from Shortland Islands, Western Province, Solomon Islands (special report). Solomon Islands Agricultural Quarantine Service, Annual report. Ministry of Agriculture and Lands, Honiara, 14–23.

Waterhouse, D.F. 1993. Biological control: Pacific prospects. Supplement 2. Australian Centre for International Agricultural Research, Canberra. Monograph No. 20, 138 p.

Williams, C., Vagalo, M., Tsatsia, F. and Pauku, R. 1990. Entomology section report 1987–1990 (Dodo Creek Research Station). Internal report of the Research Division, Ministry of Agriculture and Lands, Solomon Islands.

Fruit Fly Fauna in Papua New Guinea

D. Tenakanai[1]

Abstract

The pest fruit fly species in Papua New Guinea (PNG) occur within the subfamily Dacinae. The Dacinae occur in the tropics and subtropics of the world, causing economic losses to horticultural industries and disrupting international trade when control measures and post-harvest disinfestation treatment facilities are not put in place. Drew (1989) reported a large south Pacific fauna of the Dacinae, comprising the two genera *Bactrocera* and *Dacus*. The genus *Bactrocera* consists of the following subgenera in PNG: *Afrodacus, Bactrocera, Gymnodacus, Polistomimetes, Trypetidacus, Melanodacus, Hemisurstylus, Hemizeugodacus, Zeugodacus, Heminotodacus, Hemiparatridacus, Niuginidacus, Papuadacus, Paratridacus, Paradacus* and *Sinodacus*. The genus *Dacus* comprises four subgenera: *Callantra, Dacus, Didacus* and *Semicallantra*. All 20 subgenera generate 180 species, 12 of which are pest species in PNG. The current fruit fly research program in PNG, involving host surveying and trapping, is restricted to locations in the Central Province of PNG and does not represent the status at national level.

FRUIT flies (Diptera: Tephritidae) are the most serious insect pest of fruits and vegetables in tropical and subtropical areas of the world. They destroy horticultural produce by breeding in fresh plant tissues while still on the plant and causing serious economic losses. Producing countries may also lose potential export markets and are forced to carry out expensive disinfestation treatment to avoid disruption to international trade caused by stringent quarantine regulations imposed by importing countries. Monetary estimates of fruit production and fruit fly damage in Papua New Guinea (PNG) are not available. Taking Australia as an example, White and Elson-Harris (1992) reported that with Australia's annual fruit production running at more than $850 million, the potential losses if fruit flies were not controlled are believed to exceed $150 million.

Past and current fruit fly research in PNG has been focused on the subfamily Dacinae. The economic significance it poses to the traditional staple crops and the surging shift from subsistence to commercial horticultural production warrants the need for extensive research. Smith (1977) studied the biology and commodity control of the banana fruit fly, *Dacus musae* (Tryon). He used fenthion and dimethoate as insecticidal dippings and found that using freshly prepared 0.05% fenthion emulsion had some success in reducing banana fruit fly infestation. Ismay (1982) described the biology of fruit flies and listed some fruit flies of economic importance in PNG. Detailed morphological and taxonomic descriptions, identification and distribution of the Dacinae in PNG were reviewed by Drew (1989). The current status of fruit flies in PNG was reported by Dori et al. (1993). They described and discussed fruit fly pest species of economic importance which pose a potential threat to the future of the fruit and vegetable industry in PNG.

The current fruit fly program in PNG is based on trapping and host surveys involving the collection of rainforest and cultivated fruits. The host surveys facilitate the determination of species of fruit flies, host ranges, seasonal abundance, species of parasitoids and the parasitism rates. Many more species remain to be determined due to the fact that past collections were made largely from male attractant traps (methyl eugenol, Cue-lure and Willison's lure), to which some species do not respond at all (Dori et al. 1993). Likewise, due to the topography of the country, some areas were not covered.

The program is restricted to the Central Province of PNG due to scarcity of funds and manpower and

[1] Department of Agriculture and Livestock, PO Box 417, Konedobu, Papua New Guinea

therefore does not fully reflect the status at national level. However, with the current restructuring of the Department of Agriculture and Livestock, it is envisaged that the program will be extended to all provinces, so that the fruit fly fauna of PNG will be thoroughly documented.

Fruit Flies (Tephritidae: Dacinae) in PNG

The family Tephritidae contains four significant subfamilies, including Dacinae, Ceratitinae, Trypetinae and Tephritinae. The Dacinae occur throughout the tropical and subtropical environs of the world, originally associated with rainforest fruits and then successively shifting to horticultural produce in these areas. Whereas the Dacinae are the principal fruit pests, other non-Dacinae exist in PNG. An example regularly collected in the Central Province of PNG is a Trypetinae species, *Euphranta perkinsi.* This species attacks the plant family Verbenaceae and is frequently reared from the fruit of *Faradaya splendida.* Non-Dacinae will not be discussed because their economic status has not been investigated in PNG.

PNG has a large Dacinae fauna compared with other South Pacific island countries and Australia. More than 200 species are suspected to exist. Drew (1989) reviewed 290 species of the genera *Bactrocera* and *Dacus* consisting of 21 subgenera and four subgenera respectively, occurring in the region east of Sulawesi and south of the equator and extending eastward to the Society Islands in French Polynesia (Waterhouse 1993). About 63% (180 species) of the 290 species (Table 1) occur on the PNG mainland and major islands lying to the east (New Britain, New Ireland, Bougainville).

Table 1. Fruit flies (Tephritidae: Dacinae) recorded in PNG (mostly after Drew 1989).

Genera and Subgenera	Species	Location	Attractant
Genus *Bactrocera* Macquart			
Bactrocera Group of Subgenera			
Subgenus *Afrodacus* Bezzi	1. *Bactrocera (Afrodacus) hypomelaina* Drew	Morobe Province (MP), Western Highlands (WHP)	Cue-lure
	2. *B. (A.) ochracea* Drew	Central Province (CP)	Cue-lure
Subgenus *Bactrocera* Macquart	1. *aemula* complex	Western H/lands Province	Cue-lure
	3. *B. (Bactrocera) aemula* Drew		
	4. *B. (B.) consectorata* Drew	Morobe and New Britain (NB)	Cue-lure
	5. *B. (B.) fuliginus* (Drew and Hancock)	Oro Province (OP) and Morobe	Cue-lure
SPECIES PLACED IN COMPLEXES	6. *B. (B.) inconstans* Drew	Morobe and Central	Cue-lure
	7. *B. (B.) indecora* (Drew)	NB and New Ireland Province (NIP)	Cue-lure
	8. *B. (B.) laticosta* Drew	CP, MP and NB	Cue-lure
	9. *B. (B.) trivialis* (Drew)	PNG	Cue-lure
	10. *B. (B.) vulgaris* (Drew)	PNG	Cue-lure
	2. *alyxiae* complex		
	11. *B. (B.) alyxiae* (May)	PNG	Cue-lure
	12. *B. (B.) repanda* Drew	Western Prov. (WP) and East Sepik Prov. (ESP)	No known record (NKR)
	3. *anthracina* complex		
	13. *B. (B.) anthracina* (Drew)	New Britain	Cue-lure
	14. *B. (B.) aterrima* (Drew)	Bougainville Is. (BI)	Cue-lure
	15. *B. (B.) calignosa* (Hardy)	New Britain	NKR
	16. *B. (B.) terminaliae* Drew	Morobe	NKR

Table 1 (continued). Fruit flies (Tephritidae: Dacinae) recorded in PNG (mostly after Drew 1989).

4. *assita* complex		
17. *B. (B.) assita* Drew	Milne Bay Prov. (MBP) and Morobe	Cue-lure
18. *B. (B.) brevistriata* (Drew)	Morobe	Cue-lure
19. *B. (B.) circamusa* Drew	Morobe	Cue-lure
20. *B. (B.) commina* Drew	Morobe	NKR
21. *B. (B.) contermina* Drew	Morobe	NKR
22. *B. (B.) contigua* Drew	Morobe	NKR
23. *B. (B.) finitima* Drew	Morobe	NKR
24. *B. (B.) robertsi* Drew	Morobe and WHP	Cue-lure
25. *B. (B.) tinomiscii* Drew	CP, MP and Eastern H/Lands Prov. (EHP)	Cue-lure
5. *bryoniae* complex		
26. *B. (B.) bryoniae* (Tryon)	PNG	Cue-lure
27. *B. (B.) latissima* Drew	Morobe and WHP	Cue-lure
28. *B. (B.) paramusa* Drew	Central, Oro and Western Provs.	Cue-lure
29. *B. (B.) simulata* (Malloch)	Bougainville	Cue-lure
6. *distincta* complex		
30. *B. (B.) ampla* (Drew)	New Britain	Cue-lure
31. *B. (B.) atriliniellata* Drew	Central and Morobe	Cue-lure
32. *B. (B.) curreyi* Drew	MP, ESP, WHP, CP and Gulf Prov. (GF)	Cue-lure
33. *B. (B.) decumana* (Drew)	Bougainville	Cue-lure
34. *B. (B.) fergussoniensis* Drew	Milne Bay	NKR
35. *B. (B.) fulvilineata* Drew	CP, MP and WHP	Cue-lure
36. *B. (B.) morobiensis* Drew	Morobe and ESP	Cue-lure
37. *B. (B.) oblineata* Drew	CP, MBP and MP	Cue-lure
38. *B. (B.) propedistincta* Drew	Morobe	NKR
39. *B. (B.) pseudodistincta* (Drew)	NB, NIP, Central, Morobe	Cue-lure
40. *B. (B.) rhabdota* Drew	CP, MP, ESP and WHP	Cue-lure
7. *dorsalis* complex		
41. *B. (B.) obdolonginqua* (Drew)	New Britain	Methyl eugenol lure (ME)
42. *B. (B.) dapsiles* Drew	MP, EHP and Simbu (SP)	ME lure
43. *B. (B.) diallagma* Drew	Morobe	ME lure
44. *B. (B.) papayae* Drew and Hancock	Western and West Sepik Prov. (WSP)	ME lure
45. *B. (B.) endiandrae* (Perkins and May)	Central	ME lure
46. *B. (B.) mimulus* Drew	Morobe	ME lure
47. *B. (B.) nigrescens* (Drew)	NB, NIP and BI	ME lure
8. *frauenfeldi* complex		
48. *B. (B.) frauenfeldi* (Schiner)	PNG	Cue-lure
9. *fulvicauda* complex		
49. *B. (B.) fulvicauda* (Perkins).	PNG	ME lure
50. *B. (B.) latilineata* Drew	WHP	Uncertain
51. *B. (B.) unistriata* (Drew)	New Britain and NIP	ME lure
10. *furfurosa* complex		
52. *B. (B.) furfurosa* Drew	Morobe	Cue-lure
53. *B. (B.) nigrovittata* Drew	Morobe	Cue-lure
54. *B. (B.) obfuscata* Drew	Morobe	Cue-lure
55. *B. (B.) popondettiensis* Drew	Oro Prov.	NKR
56. *B. (B) ustulata* Drew	Morobe & Central	Cue-lure
11. *musae* complex		
57. *B. (B.) musae* (Tryon)	PNG	ME lure
58. *B. (B.) prolixa* Drew	Western Province	ME lure

Table 1 (continued). Fruit flies (Tephritidae: Dacinae) recorded in PNG (mostly after Drew 1989).

	12. *nigella* complex		
	59. *B. (B.) keleana* Drew	Central	ME lure
	60. *B. (B.) nigella* (Drew)	Morobe	ME lure
	13. *quadrata* complex		
	61. *B. (B.) aurantiaca* (Drew & Hancock)	East Sepik Province	Cue-lure
	62. *B. (B.) erubescentis* (Drew & Hancock)	Central Province	Cue-lure
	63. *B. (B.) peninsularis* (Drew & Hancock)	Western Province	Cue-lure
	64. *B. (B.) quadrata* (May)	PNG	Cue-lure
	14. *recurrens* complex		
	65. *B. (B.) absidata* Drew	Morobe Province	NKR
	66. *B. (B.) anfracta* Drew	Western Milne Bay	Cue-lure
	67. *B. (B.) nigrescentis* (Drew)	NB, NIP and BI	Cue-lure
	68. *B. (B.) recurrens* (Hering)	Madang, Milne Bay	Cue-lure
	69. *B. (B.) resima* (Drew)	East Sepik	NKR
	15. *silvicola* complex		
	70. *B. (B.) abundans* Drew	WHP and Morobe	Cue-lure
	71. *B. (B.) breviaculeus* (Hardy)	Western, Central and Oro	Cue-lure
	72. *B. (B.) cinnamea* Drew	Morobe	Cue
	73. *B. (B.) quasisilvicola* Drew	Central	Cue-lure
	74. *B. (B.) turneri* Drew	Milne Bay	Cue-lure
	16. *tryoni* complex		
	75. *B. (B.) neohumeralis* (Hardy)	PNG	Cue-lure
Subgenus *Bactrocera* Marquart	76. *B. (B.) abdofuscata* (Drew).	Central	NKR
	77. *B. (B.) abdonigella* (Drew)	PNG	Cue-lure
	78. *B. (B.) angustifasciata* Drew	Lihir Is NIP	NKR
	79. *B. (B.) atramentata* (Hering)	New Brit. & NIP	Cue-lure
SPECIES NOT PLACED IN COMPLEXES	80. *B. (B.) birarcuata* (Walker)	BI & Morobe	ME lure
	81. *B. (B.) buinensis* Drew	Bougainville	NKR
	82. *B. (B.) bullata* Drew	East Sepik	NKR
	83. *B. (B.) buloloensis* Drew	Morobe	NKR
	84. *B. (B.) cabonaria* (Hendel)	New Britain	NKR
	85. *B. (B.) cheesmanae* (Perkins)	PNG	ME lure
	86. *B. (B.) confluens* (Drew)	Bougainville	ME lure
	87. *B. (B.) congener* Drew	Morobe	Cue-lure
	88. *B. (B.) curvifera* (Walker)	PNG	ME lure
	89. *B. (B.) daruensis* Drew	Western	NKR
	90. *B. (B.) dyscrita* (Drew)	New Britain	Cue-lure
	91. *B. (B.) enochra* (Drew)	Bougainville	Cue-lure
	92. *B. (B.) eximia* Drew	Madang & Central	NKR
	93. *B. (B.) expoliata* (Hering)	Central	NKR
	94. *B. (B.) furvescens* Drew	Morobe & WHP	Cue-lure
	95. *B. (B.) ismayi* Drew	New Ireland	NKR
	96. *B. (B.) lampabilis* (Drew)	New Brit. & NIP	ME lure
	97. *B. (B.) lineata* (Perkins)	PNG Lowlands	Cue-lure
	98. *B. (B.) longicornis* Macquart	NIP & Bougainville	Cue-lure
	99. *B. (B.) melanogaster* Drew	Bougainville	ME lure
	100. *B. (B.) moluccensis* Perkins	PNG	Cue
	101. *B. (B.) neocheesmanae* Drew	WHP & Central	ME lure
	102. *B. (B.) neonigrita* Drew	NB, NIP & Bougainville	ME lure
	103. *B. (B.) obliqua* (Malloch)	NB, BI & Admiralty	NKR
	104. *B. (B.) ochromarginis* (Drew)	New Britain	ME lure
	105. *B. (B.) penefurva* Drew	Central	NKR
	106. *B. (B.) pepisalae* (Froggatt)	Bougainville	ME lure
	107. *B. (B.) phaea* (Drew)	New Brit. & NIP	Cue-lure
	108. *B. (B.) picea* (Drew)	Bougainville	ME lure
	109. *B. (B.) pisinna* Drew	Morobe	Cue

Table 1. Fruit flies (Tephritidae: Dacinae) recorded in PNG (mostly after Drew 1989).

	110. *B. (B.) reclinata* Drew	Bougainville	ME lure
	111. *B. (B.) retrorsa* Drew	Morobe & Oro Prov.	ME lure
	112. *B. (B.) rutila* (Hering)	PNG	NKR
	113. *B. (B.) seguyi* (Hering)	ME lure	ME lure
	114. *B. (Bactrocera) thistletoni* Drew	WHP, CP & Western	Cue-lure
	115. *B. (B.) trifaria* (Drew)	New Britain	Cue-lure
	116. *B. (B.) umbrosa* (Fabricius)	PNG	ME lure
	117. *B. (B.) uniliniata* Drew	Morobe & WHP	Cue-lure
Subgenus *Gymnodacus* Munro	118. *B. (Gymnodacus) hastigerina* (Hardy)	New Britain	NKR
	119. *B. (G.) petila* Drew	Morobe	Cue-lure
Subgenus *Polistomimetes* Enderlein	120. *B. (Polistomimetes) fuscalata* Drew	Morobe & WHP	ME lure
	121. *B. (Polistomimetes) mesonotochra* Drew	Morobe	NKR
	122. *B. (P.) neopagdeni* Drew	Central	NKR
	123. *B. (P.) visenda* (Hardy)	Western & Central	ME
Trypetidacus	124. *B. (Trypetidacus) invisitata* Drew	Morobe & EHP	ME lure
Melanodacus Group of subgenera			
Hemisurstylus	125. *B. (Hemisurstylus) melanoscutata* Drew	New Britain	NKR
Subgenus *Hemizeugodacus* Hardy	126. *B. (Hemizeugodacus) abdomininigra* Drew	Morobe	NKR
Subgenus *Melanodacus* Perkins	127. *B. (Melanodacus) satanellus* (Hering)	Central	NKR
Zeugodacus Group of subgenera			
Heminotodacus	128. *B. (Heminotodacus) dessidens* Drew	Morobe	NKR
Hemiparatridacus	129. *Bactrocera (Hemiparatridacus) abdoaurantiaca* Drew	Eastern Highlands Province	NKR
Niuginidacus	130. *B. (Niuginidacus) singularis* Drew	Morobe	Cue-lure
Subgenus *Papuadacus* Drew	131. *B. (Papuadacus) neopallescentis* Drew	Central	Cue-lure
Subgenus *Paradacus* Perkins	132. *B. (Paradacus) aurantiventer* Drew	Morobe	Cue-lure
	133. *B. (P.) citroides* Drew	Central	Cue
	134. *B. (P.) decipiens* (Drew)	New Britain	NKR

Table 1 (continued). Fruit flies (Tephritidae: Dacinae) recorded in PNG (mostly after Drew 1989).

Subgenus *Paratridacus* Shiraki	135. *B. (Paratridacus) alampeta* Drew	WHP	ME lure
	136. *B. (P.) atrisetosa* (Perkins)	Central & Oro Prov.	NKR
	137. *B. (P.) coracinus* (Drew)	East Sepik	NKR
	138. *B. (P.) expandens* (Walker)	East Sepik	NKR
	139. *B. (Paratidacus) mesonotaitha* Drew	East Sepik	NKR
	140. *B. (Paratridacus) unichromata* Drew	Central & Morobe	ME lure
Subgenus *Sinodacus* Zia	141. *B. (Sinodacus) abdopallescens* (Drew)	Morobe, Central & ESP	Cue-lure
	142. *B. (Sinodacus) angusticostata* Drew	EHP, WHP & Morobe	Cue-lure
	143. *B. (S.) buvittata* Drew	Central	Cue-lure
	144. *B. (S.) emarginata* (Perkins)	Central	NKR
	145. *B. (Sinodacus) paulula* Drew	Morobe	Cue-lure
	146. *B. (Sinodacus) sepikae* Drew	West Sepik	NKR
	147. *B. (S.) strigifinis* (Walker)	PNG	Cue-lure
	148. *B. (S.) surrufula* Drew	Morobe	Cue-lure
	149. *B. (Sinodacus) triangularis* (Drew)	New Brit. New Ird. & Bougainville	Cue-lure
	150. *B. (S.) univittata* (Drew)	Bougainville	Cue-lure
Subgenus *Zeugodacus* Hendel	151. *B. (Zeugodacus) abdoangusta* (Drew)	Bougainville	Cue-lure
	152. *B. (Zeugodacus) amoena* (Drew)	Bougainville	Cue-lure
	153. *B. (Zeugodacus) anchitrichota* Drew	East Sepik	NKR
	154. *B. (Z.) brachus* (Drew)	Central	Cue-lure
	155. *B. (Z.) chorista* (May)	PNG	Cue-lure
	156. *B. (Z.) cucurbitae* (Coquillett)	PNG	Cue-lure
	157. *B. (Z.) curta* (Drew)	New Britain	Cue-lure
	158. *B. (Z.) daula* Drew	WHP	Cue-lure
	159. *B. (Zeugodacus) macrovittata* Drew	Central	Cue-lure
	160. *B. (Z.) reflexa* (Drew)	New Britain	Cue-lure
	161. *B. (Zeugodacus) sandaracina* Drew	East Sepik	NKR
	162. *B. (Z.) trichota* (May)	NB, EHP & Central	Cue-lure
	163. *B. (Z.) unilateralis* Drew	Central	NKR
Genus *Dacus* Fabricius			
Subgenus *Callantra* Walker	164. *Dacus (Callantra) axanus* (Hering)	PNG	Cue-lure
	165. *D. (C.) capillaris* (Drew)	Bougainville	Cue-lure
	166. *D. (C.) discors* Drew	Morobe	Cue-lure
	167. *D. (Callantara) impar* Drew	Morobe & WHP	NKR
	168. *D. (C.) mayi* (Drew)	Morobe	Cue-lure
	169. *D. (Callantra) melanohumeralis* Drew	Central	ME lure
	170. *D. (Callantra) solomonensis* Malloch	Bougainville	Cue-lure
	171. *D. (C.) unicolor* (Hendel)	New Britain	NKR
Subgenus *Dacus* Fabricius	172. *Dacus (Dacus) alarifumidus* Drew	Morobe	Cue-lure
	173. *D. (Dacus) alulapictus* Drew	Morobe	NKR
	174. *D. (Dacus) badius* Drew	Morobe	Cue-lure
	175. *D. (Dacus) bellulus* (Drew and Hancock)	Central	Cue-lure
Subgenus *Didacus* Collart	176. *Dacus (Didacus) dissimilis* Drew	Morobe, CP & Oro	Cue-lure
	177. *Dacus (Didacus) maprikensis* Drew	East Sepik	NKR
Semicallantra	178. *D. (Semicallantra) aquilus* Drew	Morobe	Cue-lure
	179. *D. (Semicallantra) memnonius* Drew	Central	ME lure
	180. *D. (Semicallantra) nigriculus* Drew	Morobe	NKR

Pest Species of Economic Significance in PNG

From the 180 species, Ismay (1982) and Drew (1989) identified a number of pest species. By updating the list, Dori et al. (1993) listed 12 species of economic significance in PNG compromising 7% of the 180 species recorded in PNG. Another exotic species which has been recorded beside the introduced melon fly, *Bactrocera cucurbitae (*Coquillett), a primary pest of cucurbits, is the Queensland fruit fly, *Bactrocera tryoni* (Froggatt), three specimens of which were recorded from the Western Province (Drew 1989). Drew (1989) expressed doubts as to whether *B. tryoni* is an integral part of PNG's fruit fly fauna as no other recording has been made since at the sites or from elsewhere in PNG (Dori et al. 1993). Dori et al. (1993) assumed that a new record was *Bactrocera* Taxon B species which has now been accurately described as *Bactrocera papayae* (Drew and Hancock 1994). It entered PNG from Irian Jaya in 1992 and became established in North Queensland in 1993.

Bactrocera frauenfeldi (Schiner) is abundant and wide spread in PNG. Dori et al. (1993) reported that because it is polyphagous (recorded from 10 plant families), it poses serious threats to fruits with potential export status. It attacks ripe bananas, papaya, sapodilla *(Manilkara zapota)*, egg fruit *(Lucuma* sp.*)*, bread fruit, beetle nut *(Areca catechu)*, *Terminalia* spp., star apple *(Chrysophyllum canito)*, cashew nut, mango, guava, *Syzygium* spp., Tahitian chestnut and *Pometia pinnata* (Sapindaceae).

Bactrocera musae (Tryon), the banana fruit fly, is a major pest of banana throughout PNG. Green, fully mature banana fruits of all cultivars are attacked. It was reared once from papaya in Central Province but not from other fruits (Dori et al. 1993).

Bactrocera cucurbitae (Coquillett), the introduced melon fly, is widespread throughout PNG and infests all cucurbits, wild and cultivated. Infestation on stem, flowers and fruits has been recorded on water melon at Laloki in the Central Province.

Bactrocera atrisetosa (Perkins) attacks tomato, cucumber and zucchini in Central Province. Drew (1989) reported the species attacking tomato and cucurbits at higher altitudes, (1200 m – 1650 m) in Oro Province.

Bactrocera strigifinis (Walker) attacks flowers and developing fruits of zucchini and fully mature pods of snake beans, *Phaseolus unguiculata* at Laloki in the Central Province.

Bactrocera bryoniae (Tryon) is continuously reared from *Capsicum* spp. It also attacks snake beans in the same manner as *B. strigifinis*. Dori et al. (1993) recorded it from fruits of *Bryonopsis affinis* (Cucurbitaceae) and it also attacks *Passiflora foetida* in the Central Province.

Bactrocera umbrosa (Fabricius) infests bread fruits in the lowlands and islands. Dori et al. (1993) reported premature ripening and falling of fruits due to oviposition on developing fruits.

Bactrocera moluccensis Perkins infests Tahitian chestnut, *Inocarpus fagifer*. Dori et al. (1993) reported it on the fibrous tissue as well as the kernel of the nut, compared to *B. frauenfeldi* which was found only on the fleshy tissue.

Bactrocera trivialis (Drew) has been recorded on guava and mango fruits at Laloki (Dori et al. 1993). Other host records from PNG include *Capsicum frutescens* from Sogeri and grapefruit, *Citrus paradisi*, at Mt Hagen (Drew 1989).

Bactrocera decipiens (Drew) was recorded infesting pumpkin at Keravat, East New Britain (Ismay, 1992).

Bactrocera papayae Drew and Hancock of the *Bactrocera dorsalis* complex entered PNG in 1992. It is a serious pest attacking 209 fruit species belonging to 47 plant families in its native habitat of Southeast Asia. The full distribution of this species in PNG apart from being trapped in the Western Province and West Sepik Province has not been determined. It is believed to be spreading eastward.

Bactrocera neohumeralis (Hardy) of the *tryoni* complex attacks common guava fruits in the Central Province.

Drew (1989) recorded *Bactrocera tryoni* (Froggatt) from Western Province but expressed doubts as to whether it was established. *B. tryoni* will remain included in the list because it has been detected in PNG and because of its economic importance in Australia as a serious pest of a wide range of fruits (Dori et al. 1993).

Discussion

Two pest genera of Dacinae (*Bactrocera* and *Dacus*) are recorded in PNG. The genus *Bactrocera* constitutes 16 subgenera, the largest of which is the subgenus *Bactrocera* comprising 115 species, 73 of which are placed in complexes and 42 species not placed in complexes. Twelve species of the genus *Bactrocera* are recorded as pest species of economic significance in PNG. The genus *Dacus* consists of four subgenera comprising 17 species. One species known to be a pest is *D. (Callantra) solomonensis* (Malloch) which infests flowers and fruits of cucurbitaceae in Bougainville (Table 2).

Table 2. Summary of subfamily Dacinae in PNG.

Genera	Subgenera	Number of species
Bactrocera	*Afrodacus*	2
	Bactrocera	73 placed in
	8 pest species of	16 complexes
	economic	42 not in complexes
	significance	115
	Gymnodacus	2
	Polistomimetes	4
	Trypetidacus	1
	Hemisurstylus	1
	Hemizeugodacus	1
	Melanodacus	1
	Heminotodacus	1
	Hemiparatridacus	1
	Niuginidacus	1
	Papuadacus	1
	Paradacus	3
	1 pest species	
	Paratridacus	6
	1 pest species	
	Sinodacus	10
	1 pest species	
	Zeugodacus	13
	1 pest species	
Dacus	*Callantra*	8
	1 pest species	
	Dacus	4
	Didacus	2
	Semicallantra	3

The known fruit fly fauna reported in PNG is composed of the subfamily Dacinae because most research in the past was based largely on this subfamily and secondly it contains the major pest species of horticultural produce in PNG. The most urgent requirement for further research is to provide a complete and comprehensive list of the range of hosts of cultivated and non-cultivated plants by extending the program to other parts of the country.

References

Dori, F.M., Tenakanai, D. and Kurika, K. 1993. The current status of fruit flies (Tephritidae) in Papua New Guinea. Pan-Pacific Journal of Agricultural Extension, Vol. 15 No. 2, 22–25.

Drew, R.A.I. 1989. Memoirs of Queensland Museum. Brisbane. Vol. 26. 521 p.

Drew, R.A.I. and Hancock, D.L. 1994. Bulletin of Entomological Research pp 48–50. Supplement Series. The Bactrocera dorsalis complex of fruit flies (Diptera Tephritidae: Dacinae) in Asia. CAB International, UK, 68 p.

Ismay, J. 1982. Fruit Flies. Entomology Bulletin No. 19. Harvest 28 (3): 134–137.

Smith, E.S.C. 1977. Studies on the biology and commodity control of Banana fruit fly, *Dacus musae* (Tryon) in PNG. PNG Agriculture Journal, 28: 47–56.

Waterhouse, D.F. 1993. Biological Control: Pacific Prospects. Supplement 2. ACIAR, Canberra, 4–47.

White, I.M and Elson-Haris, M.M. 1992. Fruit Flies Of Economic Significance: Their Identification and Bionomics. 72–92. CAB International, UK.

Biology and Ecology: Prerequisites for Understanding and Managing Fruit Flies (Diptera: Tephritidae)

A.J. Allwood[1]

PLANT protection personnel are regularly faced with the problem of having to develop strategies for control of a pest species in a crop, often urgently. Pressure comes from various sources. Farmers who may be losing significant quantities of crop and earnings, and exporters who may be losing national and overseas markets, apply pressure in many different ways. Governments react to this pressure, and, for expediency's sake and to reduce the pressure applied by the farmers or exporters, a control strategy is quickly developed. More often than not, the solution relies exclusively on the use of agricultural chemicals and does not take into account the deleterious effects these measures may have in the long term. In many cases, no conscious effort is made to understand the pest in its environment as part of developing pest management strategies. Unfortunately, understanding the pest so that it can be managed more effectively and with fewer adverse effects on the consumers and the environment takes time. Though the approach of developing a short-term solution based on insecticides may have been acceptable 20 years ago, it is no longer acceptable.

The fruit fly work being conducted in the South Pacific under the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project (RFFP) and the ACIAR-funded projects has involved an enormous effort to understand fruit flies in each of the project countries so that practical, environmentally sound strategies for control of fruit flies are formulated and adopted by farmers at both the subsistence and commercial level. Also, decisions on quarantine protocols are based on scientific reasoning as required by international trade agreements. The project operates in Cook Islands, Federated States of Micronesia (FSM), Fiji, Solomon Islands, Tonga, Vanuatu and Western Samoa.

This paper discusses the importance of understanding the biology and ecology of fruit flies and how this knowledge is put to use in formulating control strategies for this important pest species.

[1]Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji

Biology and Ecology of Fruit Flies

Biology may be defined as the study of the life systems of individuals within a species. Among the components of these life systems are behaviour, morphology, physiology, nutrition, foraging and host selection and utilisation. Ecology, on the other hand, relates to understanding the populations of species in relation to their environments or, in other words, it deals with the populations of species as dictated by environmental factors. These environmental factors may include moisture, temperature, light, host availability and quality, food, natural enemies and beneficial micro-organism associations.

It is not possible, within a symposium like this, to cover all of the components of biology and ecology that affect the populations of fruit flies. However, a selection of these components has been made to illustrate the importance of basic studies on biology and ecology to understanding and managing pest fruit flies in the Pacific.

Mating behaviour

Mating behaviour has been studied vigorously for many species and probably has received greater emphasis than any other component of fruit fly behaviour. Flies from different climatic zones have different mating behaviours. Flies belonging to the temperate genus *Rhagoletis* have brightly coloured bodies and light and dark markings on the wings, both of which are species specific. Flashy displays on the fruit without assistance from pheromones is part of their courtship (Bush 1969). Other temperate flies meet on the fruits when the female comes to lay eggs (Prokopy 1968). In contrast, many of the tropical and sub-tropical species mate in the host plant, primarily on the leaves, as light decreases at dusk (Bateman 1972). However, in the south Pacific region, *Bactrocera kirki* (Froggatt), *Bactrocera frauenfeldi* (Schiner), *Bactrocera melanotus* (Coquillett) and *Bactrocera trilineola* (Drew) mate during the late morning and early afternoon when the light intensity is greatest.

Though sexual behaviour of fruit flies is reasonably well understood, Prokopy (1980) and Burk and Calkins (1983) suggested that improved understanding of tephritid sexual behaviour may lead to more effective control techniques.

Oviposition behaviour

Searching for feeding and ovipositional sites by fruit flies commences with locating a habitat, using olfactory and visual cues. Volatile components of ripening fruits are the stimuli that guide mature fruit flies to host plants (Prokopy and Reitberg 1989). Also, Prokopy (1977) pointed out that green leaves that reflect between 500–600 nm may be the guide for fruit flies to vegetation. Once in the habitat, temperate fruit fly species use shape, size, colour and hue to locate fruits. Prokopy (1968) reported that *Rhagoletis pomonella* (Walsh) flies of both sexes were more attracted to spheres of dark colours (red, blue, black) than light colours (yellow, green, white). In Australia, Queensland fruit fly (*Bactrocera tryoni* Froggatt) was only weakly attracted to blue spheres (R.A.I. Drew, pers. comm.) and in Fiji, *Bactrocera xanthodes* (Broun) was weakly attracted to grey spheres. Tropical fruit flies probably use food and fruit odours as the main method of locating host fruits at short range.

Invariably, once a gravid female has located a host fruit, the fly will explore the fruit surface and spittle on the surface before laying eggs. Tropical fruit flies will choose the ripest or softest fruits and prefer to lay eggs in rough areas on the fruit surface, such as in cracks or in areas damaged by birds, fruit bats, rats or other insects. Several species in the South Pacific such as *B. melanotus*, *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* have been observed ovipositing in fallen fruits (RFFP, unpubl. data).

Dispersal

Fruit flies are strong fliers and are capable of flying large distances. Macfarlane et al. (1986) released large numbers of sterile, marked Queensland fruit flies in a country town in Victoria (Australia) and recorded a maximum dispersal of 94 km in two weeks. Drew and Hooper (1983) observed a high rate of dispersal of immature male Queensland fruit flies in release experiments in the Brisbane area. Nishida and Bush (1957) determined that melon fly (*Bactrocera cucurbitae* Coquillett) migrated for large distances in Hawaii. Miyahara and Kawai (1979) also recorded long-distance movement of melon fly between Kume Island and the Amani Islands. In general terms, Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) moves much shorter distances than the species of *Bactrocera*.

Fruit fly movements may be categorised as dispersive or non-dispersive (Bateman 1972). Dispersive movements include those between habitats or those that are migratory. The post-teneral movements that occur between emergence and the onset of sexual maturity fits into this category. Fletcher (1973) determined that at least 75% of new emerged adults emigrated from orchards in the week following emergence. As fruits disappear from the immediate habitat, sexually mature flies will disperse to find new hosts. In temperate areas, there are also dispersive movements from adult overwintering sites at the onset of warmer weather in spring (Bateman 1972). In semi-arid areas with distinct wet and dry seasons, i.e. monsoonal areas, dacine fly populations tend to shrink to the wetter habitats along rivers, creeks and gullies during the dry season. During the wet season, the population expands in response to adequate moisture and availability of host plants.

Non-dispersive movements are those within the habitat and are usually foraging flights in search of food, water and oviposition sites. Studies by Nishida and Bess (1957) revealed that melon fly adults showed distinct daily movement patterns in melon fields in Hawaii. No flies were present in the melon fields in the morning, but, by 5 pm, the population peaked and then disappeared by dark. The populations of flies in the melon fields were predominantly gravid female, so the purpose of the movement was oviposition. Sonleitner and Bateman (1963) showed that Queensland fruit fly persisted in blocks of trees where there was ripening and ripe fruits. As soon as fruits were depleted, the flies moved to new sites where fruits were available.

Nutrition

Essential nutrients for fruit flies (adults and larvae) are amino acids, vitamins, sugars, minerals and growth factors. To meet these nutritional requirements, a large array of ingredients are used for artificial diets for larvae. Included among these are dried carrot, wheat products (germ, bran, flour, shorts), yeasts (brewer's yeast, Torula yeast, yeast extracts), proteins (acid or enzymatic hydrolysate, autolysate), oils, sucrose, cholesterol, choline chloride, vitamins and salt. To provide texture, products such as tissue paper, cellulose, corn grits, bagasse and cassava have been used. Antimicrobial agents such as nipagin, potassium sorbate, butoben, sodium benzoate and formalin are used to keep artificial diets free from spoilage by micro-organisms at least until after the first instar.

Egg production and hatchability are significantly reduced when vitamin E, biotin, choline chloride,

inositol, nicotinic acid and riboflavin are individually omitted from diets.

Adult fruit flies require a carbohydrate source, water and a protein substance, in order to reach sexual maturity. In nature, although fruit flies have been observed feeding on a range of products, such as decaying fruit, damaged fruits, plant sap, nectar, animal faeces, and honeydew, their major source of protein comes from bacteria belonging to the Enterobacteriaceae, commonly referred to as the fruit fly bacteria (Drew and Lloyd 1989). A combination of sugar and enzymatic hydrolysed protein smeared on cards suspended from the tops of cages and isolates of Enterobacteriaceae on agar plates placed on the tops of cages provides adequate nutrients for a range of fruit fly species in the south Pacific region (Walker et al.; Lloyd, these Proceedings).

Moisture

Adequate moisture is of special importance as a factor that influences populations of fruit flies. In some instances, there appear to be direct relationships between rainfall and the abundance of fruit flies. For example, in India, the population of melon fly expands when rainfall is adequate and contracts during dry periods. Similar trends in abundance of fruit flies occur in islands of the south Pacific region, where peak populations occur in the December–March period with lower populations in mid-year (RFFP, unpubl. data). It is likely that the apparent relationship between rainfall and fruit fly abundance may really be a relationship between fruiting times of host plants and the onset of rainy periods, rather than rainfall alone. Major fruiting times in the tropics coincide with the onset of the rainy season.

The stages of the life cycle that are most susceptible to desiccation are the mature larva as it exits the fruit to pupate and the newly emerging adult. Observations in Malaysia suggest that greater mortality of these stages may occur as a result of excess moisture during intense tropical rain, rather than desiccation. Under laboratory conditions, in the south Pacific region, pupation into dry sawdust resulted in lower pupal weights and greater pupal mortality than if larvae pupated into moist sawdust (RFFP, unpubl. data).

Temperature

Temperature plays a dominant role in the rate of development of immature stages and, consequently, determines the timing of population increases (Fletcher 1989). Even in the tropics where there are relatively small fluctuations in temperatures, distinct fluctuations in fruit fly populations still occur. Populations are greater during the summer months than during the winter months. The impact of temperature on seasonality of fruits may explain these seasonal abundance differences.

Univoltine species, such as *R. pomonella* and *Bactrocera minax* (Enderlein), overwinter as diapausing pupae. Adults emerge during the following summer, with egg-laying being restricted to a relatively short period during summer and autumn. In contrast, multivoltine tropical and subtropical species overwinter as adults in habitats that provide shelter and food.

For multivoltine species, the ideal temperature for development is between 25 °C and 30 °C. Temperatures lower than 21 °C decrease the rate of development of immature stages (RFFP, unpubl. data). Maximum egg production occurs at temperatures between 25 °C and 30 °C (Bateman 1972). As ambient temperatures in the south Pacific region fall within the range of 25–30 °C, fruit flies produce many overlapping generations per year and have the capability of breeding at all times of year, providing host fruits are available. This results in very large populations in some countries in the Pacific region and large losses to fruit and vegetable production.

Light

Light plays a major role in the fecundity of fruit flies and, consequently, influences their daily activities. Virgin female flies are most active at dusk, with a smaller peak in activity at dawn. Mated females exhibit increased activity as light intensity increased, reflecting an ovipositional activity. Mated and unmated male flies have an activity peak at dusk, corresponding to mating and a smaller peak in activity at dawn, corresponding to feeding activity.

Generally, increasing light intensity in the morning promotes feeding and egg-laying responses, while decreasing light intensity promotes a mating response in those species that mate at dusk. Observations in Cook Islands on *B. melanotus* showed that the field activity for both males and females peaked at between 11.00 am and 1.00 pm and this is when mating occurred both in the field and in the laboratory.

Light intensity plays a critical role in the synchronisation of mating. In some sympatric species, e.g., *B. tryoni* and *Bactrocera neohumeralis* (Hardy), mating occurs at different times of the day and possibly reduces the chances of hybridisation in the field. *B. tryoni* mates at dusk, while *B. neohumeralis* mates in the morning. Some species reach sexual maturity earlier, mate sooner and lay eggs earlier when subjected to bright light rather than dim light, e.g., *Bactrocera dorsalis* (Hendel). Correlations between changes in fecundity, changes in illumination and photoperiod and feeding activity and rate

of ovarian maturation have been recorded (Barton Browne 1956).

Most species in the south Pacific region mate in response to decreasing light intensity at dusk, e.g., *B. passiflorae*, *B. xanthodes*, *Bactrocera facialis* (Coquillett), *Bactrocera quadrisetosa* (Bezzi), *Bactrocera minuta* (Drew), *Bactrocera umbrosa* (Fabricius) and *Bactrocera distincta* (Malloch). However, as identified earlier in this paper, some species mate in response to increasing light intensity, e.g., *B. melanotus*, *B. frauenfeldi*, *B. trilineola* and *B. kirki*.

Competition

Natural enemies are associated with all stages of fruit flies. Egg and larval parasitoids (Hymenoptera) exist at relatively low densities in wild or forest fruits and in commercial or edible fruits infested with fruit flies. However, it is uncommon for parasitoids to reduce the infestation rates in commercial fruits (Nishida 1963; Snowball et al. 1962). Some parasitoids, such as Strepsiptera, attack adults, but it is unlikely that they influence populations of fruit flies. Predators such as ants, carabid beetles, mites, earwigs and crickets will cause mortality to larvae in the fruit on the ground, as the larvae leave the fruit to pupate and to teneral adults as they emerge from the soil. Canopy dwelling and ground dwelling vertebrates that feed on fruits probably play an important role in reducing populations of fruit flies in the forests.

Overcrowding of adult fruit flies, leading to a shortage of food or space in a habitat, is probably rare in natural populations (Bateman 1972). However, males of some species will defend fruits until females arrive. Males of *Rhagoletis completa* (Cresson) will fight other males away from a single walnut while waiting for a female to arrive. *B. kirki* in Tonga has been observed to defend a guava fruit against other males, presumably while waiting for a female to arrive. Mating on the fruit by *B. kirki* has been observed (RFFP, unpubl. data).

Interspecific competition in fruit flies has been documented by various authors. Christenson and Foote (1960) summarised the interspecific competition between *B. dorsalis* and *C. capitata* in Hawaii. Within a short time after *B. dorsalis* was introduced into Hawaii around 1946, the populations of *C. capitata* declined to such a degree that it was rare to find this species in coastal areas. *C. capitata* now occupies specific niches at high altitudes and in coffee in the lowlands, while *B. dorsalis* is found over wide areas in Hawaii. There is evidence of host polarization as well as niche polarisation. The major host for *B. dorsalis* is guava and for *C. capitata* peaches and coffee. A similar dominance of one species over another occurred in New South Wales, where *C. capitata* was completely replaced by *B. tryoni*.

Although overcrowding of larvae in fruit is not likely to occur in nature, overcrowding in laboratory cultures may reduce larval body size, delay development and increase larval mortality. Adults resulting from overcrowded larval conditions have smaller body sizes (RFFP, unpubl. data).

Importance of Biology and Ecology to Managing Fruit Flies

As stated in the beginning of this paper, basic knowledge on the biology and ecology of fruit flies is a prerequisite to understanding and managing fruit flies. To illustrate this, the application of biological and ecological principles to taxonomy, laboratory rearing of fruit flies, field control, development of quarantine treatments and to quarantine surveillance and eradication programs will now be briefly discussed.

Taxonomic studies

Taxonomic studies are basic to all biological research. The first step in solving a biological research problem is to know the identity of the organism being studied (Hardy 1991). Correct identification is essential. Unfortunately, within the Dacinae, sibling species are common (Drew 1991). This was illustrated by Drew (1989) who defined 20 species complexes in the south Pacific region.

To separate some of these sibling species, an array of techniques has been used, e.g., taxonomic characters using light and electron microscopes, differences in biology and ecology, enzyme analyses, and DNA configurations. The differences in biology and ecology between like species, such as responses to male lures, differences in mating times, differences in the host ranges of species and variations in seasonal abundances, have proved useful in separating sibling species. In Vanuatu, it was concluded that *B. xanthodes* does not occur because no *B. xanthodes*-like species were attracted to methyl eugenol baited traps. Specimens of a species similar to *B. xanthodes* were reared from *Barringtonia edulis* Seem. only. These differences, together with morphological differences, showed that it was a new species (Tau et al., these Proceedings). The *B. xanthodes* complex is probably made up of four sibling species (Drew, pers. comm.). The correct identification of species in this complex may have significant effects on the access to overseas fresh

fruit markets because only one species, *B. xanthodes*, is economically important.

Similarly, in Southeast Asia, the unravelling of the species belonging to the *B. dorsalis* complex has meant that of the 50 species belonging to the complex, only eight are regarded as economically important. Differences in responses to lures, host ranges, mating times, seasonal abundances, enzyme structures, and DNA substantiate the identification of the sibling species in this complex (Drew 1991).

Laboratory rearing of fruit flies

To rear fruit flies in the laboratory successfully in the south Pacific region, it is an advantage to have an understanding of the host ranges of fruit flies so that, if necessary, artificial diets can be based on pulped susceptible fruits. Information on other diet requirements, e.g., the role of bacteria as a protein source for adults, responses of adults to protein and sugar mixtures, and the importance of minerals and vitamins, is essential. Overcoming the deleterious effects of micro-organisms such as yeasts and some bacteria to first instars in diet is necessary. This may be achieved by using nipagin or sodium benzoate as a component of artificial diets and keeping the diet in the dark for 3–5 days after seeding with eggs. The relationship between moisture content of the pupation medium (sterilised sawdust in the Pacific region) and the quality of flies is important. Dry pupation media result in increased larval mortality, smaller pupae and consequently smaller adults.

Knowing the conditions that enhance adult feeding, mating and oviposition is critical to successfully establishing and maintaining laboratory colonies. In the Pacific region, laboratory temperatures are maintained at 25–28 °C, ideal conditions for rearing tropical tephritids. Knowledge of the biological activities of various species of fruit flies in the field, e.g., mating times and peak feeding activity, has assisted in defining optimum lighting in the laboratory. Most fruit fly species in the Pacific region mate at dusk, but there are several species that mate during late morning and early afternoon. For these species, increased light intensity is provided in the laboratory by placing strip lights immediately above the cages to encourage better mating and egg production.

Field control of fruit flies

The methods of control of fruit flies in the Pacific region focus on sound crop hygiene by destroying over-ripe, damaged and fallen fruit, by physically protecting fruits using double layer paper bags to cover fruits, by harvesting at a time when the fruit is not susceptible to fruit fly attack, by using non-susceptible fruit varieties, and by using protein bait sprays.

Basic to developing and implementing field control systems is the determination of the host ranges of fruit fly species. Establishing data on the levels of damage caused by fruit fly attack and on the stages of maturity at which fruits become susceptible is also important. In Tonga, capsicums and some chilli varieties become susceptible to fruit fly infestation soon after fruit set. It is necessary, therefore, to protect the crop with protein bait sprays from fruit set. Other crops, such as banana and papaya, are less susceptible to fruit fly infestation at the green stage. In the case of bananas in areas non-endemic for banana fruit fly (*Bactrocera musae* Tryon), bananas can be exported in the green stage without additional quarantine treatments. Papaya is not susceptible to fruit fly infestation until after colour break in several countries in the Pacific region and only require protein bait spray applications from just before colour break.

Understanding the biology of fruit flies in the field may determine when and where control techniques should be applied. The best example of this is the control of melon fly in cucurbit crops in Hawaii. Nishida and Bess (1957) found that the population generally inhabited the vegetation around the edges of the fields and that female melon flies entered the fields to lay eggs only. Controlling the flies in this border vegetation reduced damage to the crop significantly. Similar results were obtained in zucchini crops in Queensland, where *Bactrocera cucumis* (French) also inhabits the vegetation surrounding zucchini fields rather than the crop itself. Controlling flies in the vegetation on the edges of fields was successful, as it was in Hawaii (Drew, pers. comm.).

In some Pacific island countries, although there is not a great fluctuation in temperature between summer and winter, there is still a considerable reduction in fruit fly populations during the May–August period. This is reflected in differences in levels of damage to fruits during summer and winter. For example, in Cook Islands, the levels of damage to colour break papaya by *B. melanotus* in summer and winter are 12% and less than 1%, respectively (RFFP, unpubl. data). Providing adequate field control using protein bait sprays is achieved and stringent grading occurs, the levels of infestation in winter would be extremely low, thus placing less pressure on the forced hot air quarantine treatment.

Quarantine treatment development

To develop quarantine treatments to combat fruit flies, many elements of biology and ecology of fruit flies are utilised.

Trapping using male lures and targeted host fruit surveys provides information that allows area of freedom status for fruit flies to be determined for countries or parts of countries. Knowledge on lure responses for the native and exotic species is essential in determining area of freedom. For those species not attracted to lures, host survey results become the baseline for guaranteeing area of freedom. Trapping and host surveys also provide a catalogue of species in each country. This is an essential requirement before quarantine treatments for commodities will be considered or approved by importing countries.

Seasonal abundance, determined by trapping and fruit surveys, may influence quarantine and trade decisions to allow low risk commodities to be imported at times when fruit fly infestation is very low into areas that have a winter climate that is not conducive to fruit fly establishment. The term coined for this is to export into a 'Winter Window'.

Host surveys in the exporting country provides valuable information on fruit flies that assists the quarantine decision-making process in the importing country. Data on the percentage fruit damaged by fruit flies, the stage of maturity at which fruits become susceptible, and the numbers of larvae per fruit or per kilogram of fruit, form part of the suite of information used for quarantine decision-making on trade. When combined with the frequency and weight of consignments of particular commodities, these data provide the importing country with a clear picture of the level of risk of introducing particular fruit fly species. This information is also relevant to undertaking pest risk analyses.

Prerequisites for developing quarantine treatments include having viable fruit fly colonies and undertaking biological studies on life cycles and rates of development of immature stages in artificial diets and in fruits.

Determining the susceptibility of fruits to fruit flies at various stages of maturity under laboratory and field conditions provides biological information that may be used to categorise commodities as hosts or non-hosts. If a fruit at a specified stage of maturity is classed as a non-host, it may be exported to New Zealand without additional quarantine treatments. Two varieties of chillies, 'Hot Rod' and 'Red Fire', are classed as non-hosts to *B. passiflorae* and *B. xanthodes* in Fiji and these are being exported to New Zealand. Non-host status is regarded as a valid quarantine treatment under New Zealand's phytosanitary measures.

Biological studies to determine the heat tolerance of early eggs (less than 10 hours old), late eggs (more than 36 hours old), first instars, feeding third instars and non-feeding instars form the basis of formulating forced hot air treatment to guarantee quarantine security for export fruit fly host commodities. The tests are done in static hot water baths using naked insects and later in fruit as part of confirmatory tests. A forced hot air treatment based on raising the seed surface or centre temperature of fruits to 47.2 °C and holding it there for 20 minutes has been accepted by New Zealand for all varieties of papaya and mangoes from Fiji.

Conclusion

Understanding the biology and ecology of fruit flies is essential to developing an effective, integrated approach to their management in the Pacific region. This understanding must be based not only on studies done in laboratories under controlled conditions, but also on sound field studies done in the natural habitat of fruit flies. It must take into account information on the species, their host ranges, levels of damage, seasonal abundances, stages of maturity at which fruits become susceptible to infestation, parasitoids, biotic and abiotic factors that influence populations, and environmentally sound pre-harvest and post-harvest control systems. Adoption of an holistic approach to fruit fly control is likely to result in an effective integrated control system that is less damaging to consumers of commodities produced and to the environment than a system reliant on insecticides.

References

Barton Browne, L. 1956. The effect of light on the fecundity of Queensland fruit fly, *Strumeta tryoni*. Aust. J. Zool. 4: 125–145.

Bateman, M.A. 1972. The ecology of fruit flies. Ann. Rev. Entomol., 17: 493–518.

Burk, T. and Calkins, C.O. 1983. Medfly mating behaviour and control strategies. Florida Entomologist, 66: 3–18.

Bush, G.L. 1969. Mating behaviour, host specificity, and the ecological significance of sibling species in frugivorous flies of the genus *Rhagoletis*. Amer. Nat. 103: 669–672.

Christenson, L.D. and Foote, R.H. 1960. Biology of fruit flies. Ann. Rev. Entomol., 5: 171–192.

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae:Dacinae) of the Australian and Oceanian regions. Memeoirs of the Queensland Museum, 26: 1–521.

Drew, R.A.I. 1991. Taxonomic studies on Oriental fruit fly. In: Proceedings of the First International Symposium on Fruit Flies in the Tropics. Vijaysegaran, S. and Ibrahim, A.G., eds., MARDI, Serdang, Malaysia, 430 p.

Drew, R.A.I. and Hooper, G.H.S. 1983. Population studies of fruit flies (Diptera: Tephritidae) in southwest Queensland. Oecologia, 56: 153–159.

Drew, R.A.I. and Lloyd, A.C. 1989. Bacteria associated with fruit flies and their host plants. In: World Crop Pests, Fruit flies: their biology, natural enemies and control. Robinson, A.S. and Hooper, G., eds., Elsevier, Amsterdam, 3A: 131–140.

Fletcher, B.S. 1973. The ecology of a natural population of Queensland fruit fly, *Dacus tryoni*. IV. The immigration and emigration of adults. Aust. J. Zool., 21: 541–565.

Fletcher, B.S. 1989. Temperature—development rate relationships of the immature stages and adults of tephritid fruit flies. In: World Crop Pests, Fruit flies: their biology, natural enemies and control. Robinson, A.S. and Hooper, G., eds., Elsevier, Amsterdam, 3A: 273–289.

Hardy, D.E. 1991. Contribution of taxonomic studies to integrated pest management of fruit flies with emphasis on the Asia-Pacific region. In: Proceedings of the First International Symposium on Fruit Flies in the Tropics. Vijaysegaran, S. and Ibrahim, A.G., eds., MARDI, Serdang, Malaysia, 430 p.

Macfarlane, J.R., East, R.W., Drew, R.A.I. and Betlinski, G.A. 1986. The dispersal of irradiated Queensland fruit fly, *Dacus tryoni* (Froggatt) (Diptera: Tephritidae) in southeastern Australia. Aust. J. Zool.

Miyahara, Y. and Kawai, A. 1979. Movement of sterilised melon fly from Kume Island to the Amani Islands. Appl. Ento. and Zool., 14: 496–497.

Nishida, T. 1963. Zoogeographical and ecological studies of *Dacus cucurbitae* in India. Hawaii Agricultural Experiment Station Technical Bulletin, 54: 28 p.

Nishida, T. and Bess, H.A. 1957. Studies on the ecology and control of melon fly *Dacus* (*Strumeta*) *cucurbitae*. Hawaii Agricultural Experiment Station Technical Bulletin, 34: 44 p.

Prokopy, R.J. 1968. Visual responses of the apple maggot flies, *Rhagoletis pomonella* (Diptera: Tephritidae): Orchard studies. Entomologia Experimentales et Applicata 11: 403–422.

Prokopy, R.J. 1980. Mating behaviour of frugivorous tephritidae in nature. Proceedings of Symposium on Fruit Fly Problems, XVI International Congress of Entomology, Kyoto, Japan, 37–46.

Prokopy, R.J. and Reitberg, B.D. 1989. Fruit fly foraging behaviour. In: World Food Crop Pests, Fruit flies: their biology, natural enemies and control, Robinson, A.G., and Hooper, G., eds., 3A: 293–306.

Snowball, G.J., Wilson, F., Campbell, T.G. and Lukins, R.G. 1962. The utilisation of parasites of Oriental fruit fly (*Dacus dorsalis*) against Queensland fruit fly (*Strumeta tryoni*). Aust. J. Agr. Res., 13: 443–460.

Sonleitner, F.J. and Bateman, M.A. 1963. Mark-recapture analysis of a population of Queensland fruit fly (*Strumeta tryoni*). J. Anim. Ecol., 32: 259–269.

Host Records of Fruit Flies in the South Pacific

E. Hamacek[1]

Abstract

Understanding the host range for all of the fruit fly species within the South Pacific region is vital to establishing trade and quarantine protocols. This is important for the countries within the region and their trade partners. A significant aspect of the Australian Centre for International Agricultural Research (ACIAR) and Regional Fruit Fly Projects (RFFP) has been host fruit collecting which has provided information on fruit fly host records in the seven participating countries. This work is still continuing in all project countries at different intensities. In the Cook Islands, Fiji, Tonga and Western Samoa, fruit surveys have assumed a quarantine surveillance role, with a focus on high risk fruits, such as guava, mango, citrus, bananas, cucurbits and solanaceous fruits. In the Solomon Islands, Vanuatu and the Federated States of Micronesia (FSM), fruit surveys are still at the stage where host ranges are far from complete. By the end of the current project a more complete picture of the fruit fly hosts in these countries will have been gained.

A brief summary of the data collected to date is as follows: 23947 fruit samples collected to date; 2181 positive host fruit records; 31 fruit fly species reared from fruit; 12 species reared from commercial fruit.

A commercial fruit is classed as an edible fruit with potential for trade at either a local or international level. This allows for the inclusion of endemic fruit species that have cultural significance as a food source. On the basis of these results, there are fruit fly species of major economic importance in the South Pacific region. However, considerably more fruit survey work is required in order to establish a detailed understanding of all the pest species.

THE information presented here is a summary of work carried out as part of the combined ACIAR projects on fruit flies in the South Pacific region and the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project (RFFP). This work is still continuing in all project countries at different intensities. To date samples collected in the seven participating countries total 23 947.

[1] Queensland Department of Primary Industries, 80 Meiers Road, Indooroopilly 4068 Australia

Fruit Collection

Standardised methods are used for host fruit sampling in all countries participating in the combined ACIAR/RFFP (Allwood and Hamacek 1990).

Each sample comprises only one type of fruit from one location. Samples are collected into brown paper bags. The location, date, fruit identification (if known) and stage of maturity are written on the bag. In the laboratory, each sample is allocated a sample number. The following information is recorded on data sheets for each sample:

- sample number;
- date of collection;
- location where the sample was collected;
- the common name for the fruit, if it has one;
- the scientific name, if it is known, (if not, botanical specimens are prepared and sent to one of the regional botanists for identification);
- stage of maturity of the fruit;

- number of fruit;
- weight of the sample in grams.

The fruit samples are then held in containers in the laboratory where, over time, observations are made to determine whether the fruit is infested. If there are indications of fruit fly infestation, the flies are reared to the adult stage and preserved for identification.

By recording information on the stage of maturity, sample weight and number of fruit, information is gained on the stage at which a host becomes susceptible. An estimation of the number of larvae per fruit and the number of larvae per gram of fruit can also be made.

Host Fruit Records

Of the 23 947 fruit samples collected during the projects, 2181 produced fruit flies (Family: Tephritidae) comprising 31 species. Of these, 12 species have been reared from commercial hosts.

For these purposes a broad definition is used. A commercial fruit is classed as an edible fruit with potential for trade at either a local or international level. This allows for the inclusion of endemic fruit species that have cultural significance as a food source. The fruit fly species can be classed as either a major or minor pest species. A major pest is one with seven or more commercial hosts (Table 1). A minor pest is one with fewer than seven commercial hosts (Table 2). These categories are arbitrarily based on the records for the seven project countries and are not based on the economic importance of the species worldwide.

Table 1. Distribution and number of hosts for major pest fruit fly species.

Species	Distribution	Non-commercial host records	Commercial host records
B. facialis	Tonga	37	27
B. frauenfeldi	FSM, PNG, Solomons, N. Qld	16	23
B. kirki	Western Samoa, American Samoa, Tonga	12	14
B. melanotus	Cook Is.	13	20
B. passiflorae	Fiji, Niua's	25	24
B. trilineola	Vanuatu	12	19
B. xanthodes	Fiji, Cook Is., Samoa, Tonga, Wallis & Futuna	14	14

Table 2. Distribution and number of hosts for minor pest fruit fly species.

Species	Distribution	Non-commercial host records	Commercial host records
B. distincta	Fiji, Western Samoa, American Samoa, Tonga	7	2
B. umbrosa	SE Asia, PNG, Solomons, Vanuatu, New Caledonia	1	2
B. cucurbitae	SE Asia, PNG, Solomons	0	3
D. solomonensis	Solomon Is.	1	2
B. (G). sp. (SI 11)	Solomon Is.	1	1

Discussion

Data collected from the ACIAR/RFFP has increased knowledge of the fruit flies in the region. Host collections have been made for species which previously had no known hosts e.g. *Bactrocera aenigmatica* and *B. obscura*. New species which do not respond to lures have been collected e.g. *B. gnetum, B. paraxanthodes* and two new species in the *xanthodes* complex. However, of the Dacinae present in the South Pacific region, only approximately one third have so far been reared from host fruit.

Host records in the Solomon Islands and Vanuatu are incomplete. This situation can be rectified before the end of the project. Some of the shortcomings are indicated below.

B. frauenfeldi

In FSM there are host records from 31 species comprising 22 genera and 16 families. In the Solomon Islands there are host records from 18 species comprising 14 genera and 11 families. In the surveys carried out in North Queensland as part of the papaya fruit fly eradication campaigns carried out in the Torres Strait and in the Cairns region, there are host records of *B. frauenfeldi* from 22 species comprising 17 genera and 12 families. The host records for each country, including Australia, need to be used by all three countries to target potential host families and genera for collection. In this way a more complete understanding of the full host range of this fly species can be gained.

B. cucurbitae

This species is considered to be a major pest species worldwide. In Southeast Asia, this species has a host range of 34 species from eight families. In the Solomon Islands only three species from two families are recorded as hosts.

Solomon Islands undescribed species

At present there are approximately 10 undescribed species recorded from traps in the Solomon Islands. So far, host records are not available for these species.

Vanuatu fauna

In Vanuatu, there are seven species recorded for which there are no host data. It is also extremely important to determine whether *B. musae* is present in this country as it is a serious pest of bananas.

Xanthodes complex

More host collections need to be made in Vanuatu, Western Samoa and New Caledonia to obtain more specimens for taxonomic work and for DNA analysis. This is vitally important in sorting out this complex of species. Survey work needs to be carried out in other countries in the region e.g. PNG.

Acknowledgements

The author acknowledges the major contribution of the staff of the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project, the governments and staff of the countries participating in the RFFP, and the United Nations volunteer entomologists.

Reference

Allwood, A.J. and Hamacek, E.L. 1990. Fruit Fly Host Recording. Lecture No. 7, DPI International Training Workshop in Fruit Flies, Brisbane.

Host Availability — Its Impact on Seasonal Abundance of Fruit Flies

E. Tora Vueti[1], L. Ralulu[1], G.P. Walker[2], A.J. Allwood[3], L. Leweniqila[1] and A. Balawakula[1]

Abstract

Fruit fly trapping and host fruit surveys have been established in Fiji since 1991 by the Regional Fruit Fly Project. Host fruit surveys have confirmed the fruit fly fauna, host fruit range, host susceptibility, levels of damage, levels of parasitism, geographical distributions and seasonal abundance. Fruit fly trapping and host fruit surveys have confirmed the presence of *Bactrocera passiflorae* (Froggatt), B. sp.n. (near *passiflorae*), *B. xanthodes* (Broun), *B. distincta* (Malloch), and *B. gnetum* Drew and Hancock in Fiji.

The availability of host fruit explains the seasonal abundance of fruit fly species, as indicated by trap catches. For *B. xanthodes*, the greatest populations occur in January–June. This reflects the overlapping fruiting times and the abundance of the major hosts, breadfruit (*Artocarpus altilis*), jackfruit (*Artocarpus heterophylla*), *Barringtonia edulis* and *Ochrosia oppositifolia*. Populations of *B. xanthodes* are relatively low in the west and in the interior of Viti Levu (Leweniqila et al, these Proceedings) and Vanua Levu. Similarly, for *B. passiflorae*, high populations occur in January–June which coincides with the fruiting times of the major host fruits guava, mango, kumquat, *Terminalia*, *Inocarpus fagifera*, *Chrysobalanus icaco* and cherry guava.

Records of *B. gnetum* have indicated that this endemic species is not attracted to synthetic male attractants but is reared from *Gnetum gnemon* during its fruiting season of January–February. *B. distincta* has been reared from one introduced host fruit, sapodilla (*Manilkara zapota*), but has been found throughout the year in large numbers in traps, indicating that there must be more than one host. The occurrence of more than one species of fruit fly in one host at the same time is discussed in relation to the availability of the major host fruits.

Bactrocera passiflorae (Froggatt) was originally described in 1910 by Froggatt and has since shown economic importance in the damage caused to commercial and wild edible fruits. *B. xanthodes* (Broun) was first described in 1905 by Broun from pineapples (assumed to be over-ripe or damaged) imported into New Zealand from Cook Islands and Fiji (Simmonds 1936; Drew et al. 1978). In 1936, Simmonds recorded *B. passiflorae* and *B. xanthodes* from host fruit collections and fruit fly trapping and trapping records confirmed the presence of *B. distincta* (Malloch) in Fiji. The major host fruits recorded in 1936 for *B. passiflorae* were guava (*Psidium guajava*), mango (*Mangifera indica*), rose apple (*Syzygium jambos*), granadilla (*Passiflora quadrangularis*) and a native fruit, dawa (*Pometia pinnata*). For *B. xanthodes*, hosts were pawpaw, pomelo (*Citrus grandis*) and granadilla (Regional Fruit Fly Project (RFFP), unpubl. data). Population studies that have been carried out for major pest fruit fly species such as Oriental fruit fly (*Bactrocera dorsalis*) (Hendel), melon fly (*B. cucurbitae*) (Coquillett), Queensland fruit fly (*B. tryoni*) (Froggatt) and *B. neohumeralis* (Hardy) have shown the direct relationship of seasonal abundance of fruit flies and availability of host fruits (Drew and Hooper 1983; Vargas et al. 1990).

There were virtually no continuous records on host fruit surveys and fruit fly trapping prior to 1991,

[1] Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2] Crop and Food Research, Mt. Albert Research Centre, Private Bag 92169, Auckland, New Zealand
[3] Regional Fruit Fly Project, South Pacific Commission, Private Mailbag, Suva, Fiji

the year when the RFFP began these activities. The aim was to understand fruit flies in their habitat by determining the fruit fly fauna, host fruit ranges, host susceptibility, levels of damage, levels of parasitism, geographical distributions and seasonal abundances. The extensive data generated from these activities have been consolidated into a database which is currently serving as the basis for making quarantine and trade decisions for the export of fresh fruits and vegetables. Pest Risk Analysis is part of the assessment process for these decisions and utilises much of this information.

This paper provides results of fruit fly trapping and host survey activities from 1991–1996 and discusses the relationship between seasonal abundance and host availability. The occurrence of more than one species of fruit fly in one host at the same time is also discussed.

Materials and Methods

Trapping

Cue-lure and methyl eugenol traps were established from 1991 at ports of entry, production areas, residential areas in backyard gardens, forest areas and tourist resort hotel gardens in the coastal area throughout Fiji. Trimedlure traps were added to the trapping program at the ports of entry in 1995. Lynfield traps were used for a short period in 1991 and were changed to modified Steiner traps. At the commencement of the RFFP, traps were cleared weekly in the Suva areas and monthly in the west of Viti Levu and Vanua Levu areas. After 1992, permanent trap sites were established on Viti Levu and Vanua Levu while temporary sites were also established in the Lau Groups, Lomaiviti islands and Malololailai island. Trap records used in this paper for 1992 covered western and central Viti Levu and Vanua Levu.

Host fruit survey

Host fruits were collected either through broad host surveys (fruits collected at any size, but preferably ripe, in various quantities, periodically throughout the year) or opportunistic sampling (collection of fruit samples whenever they are available) (Allwood 1995). Fruits were collected from west and central areas of Viti Levu and Vanua Levu. Host survey records used in this paper covered 1991–1996.

This paper reports on trapping records for six sites, Dobuilevu Research Station (Ra), Legalega Research Station (Nadi), Suva, Naduruloulou Research Station (Nausori) on Viti Levu and Seaqaqa Research Station and Savusavu on Vanua Levu. The main fruiting times of the major host fruits *of B. passiflorae*, *B. xanthodes* and *B. distincta* are indicated on each graph.

Results and Discussion

Fruit fly trapping and host fruit survey records confirmed the presence of *B. passiflorae*, *B.* sp. n. (near *passiflorae)*, *B. xanthodes*, *B. distincta* and *B. gnetum* in Fiji. Host fruit surveys showed that representatives of 23 host plant families are infested by one or more fruit fly species in Fiji. The host fruit families, total number of host species and type of male synthetic attractant of each fruit fly species are shown in Table 1.

The major host fruits for *B. passiflorae* are guava, cherry guava, mango, kumquat, mandarin, *Syzygium malaccense*, rose apple (*Syzygium jambos*), star apple (*Chrysophyllum cainito*), *Pometia pinnata*, *Terminalia catappa*, *Terminalia littoralis*, *Amaroria soulameiodes*, *Chrysobalanus icaco*, *Neubergia coryncarpa, Inocarpus fagifer*, *Ochrosia oppositifolia*, *Cerbera manghas* and *Barringtonia edulis*. For *B. xanthodes*, they are breadfruit, jackfruit, *Ochrosia oppositifolia* and *Barringtonia edulis*. The host fruit for *B. distincta* is sapodilla (*Manilkara zapota*) and *B. gnetum* is *Gnetum gnemon*. Light form *B.* sp.n. (near *passiflorae)* is reared from *Ochrosia oppositifolia.*

Host fruit surveys have shown that breadfruit, *Barringtonia edulis* and *Ochrosia oppositifolia* are major host fruits for both *B. passiflorae* and *B. xanthodes*. Trapping records have shown that *B. distincta* is present in large numbers during the year but is presently found in only one host fruit, sapodilla.

Host availability graphs for the western areas of Viti Levu, Figures 1 and 2, show that high populations of *B. passiflorae* occur in the December–June period and lower populations occur in the January–June period for *B. xanthodes*. The high populations of *B. passiflorae* coincide with the overlap of fruiting times of mango, guava, cherry guava, kumquat, *Terminalia* spp., *Inocarpus fagifer, Chrysobalanus icaco, Pometia pinnata, Syzygium malaccense* and *Syzygium jambos.*

The central areas of Viti Levu, Suva and Nausori (Figs. 3 and 4) show high populations in the January–June period for *B. passiflorae* and for *B. xanthodes*, November–June period. The high populations of *B. xanthodes* coincide with the overlap of fruiting times of breadfruit, *Ochrosia oppositifolia* and *Barringtonia edulis.*

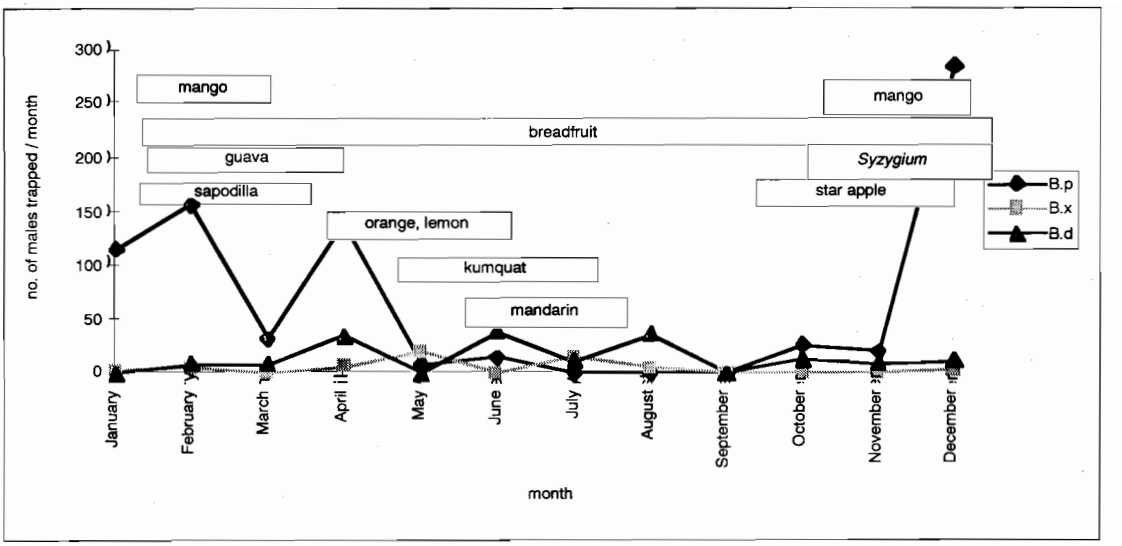


Figure 1. Host Availability of Fruit Flies at Dobuilevu Research Station, Ra.

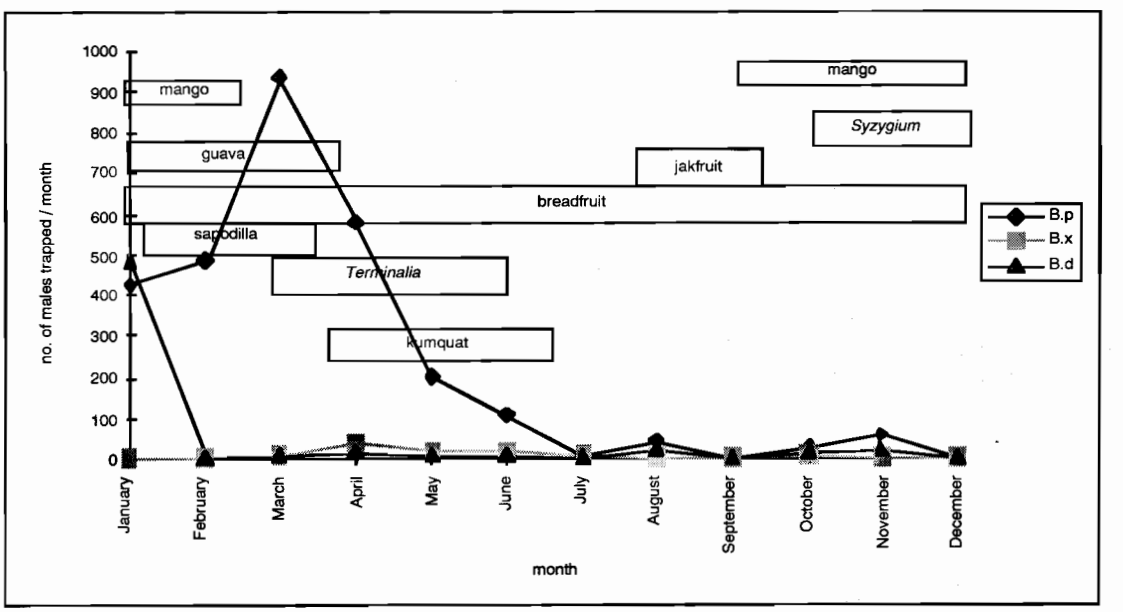


Figure 2. Host Availability of Fruit Flies at Legalega Research Station, Nadi.

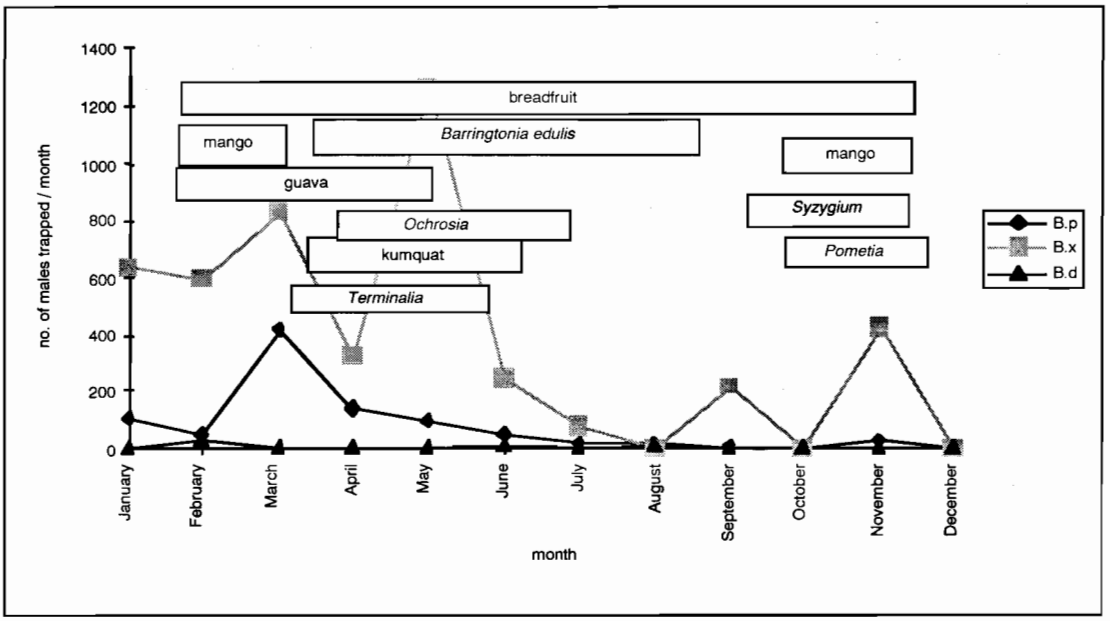


Figure 3. Host Availability of Fruit Flies at Nabua, Suva.

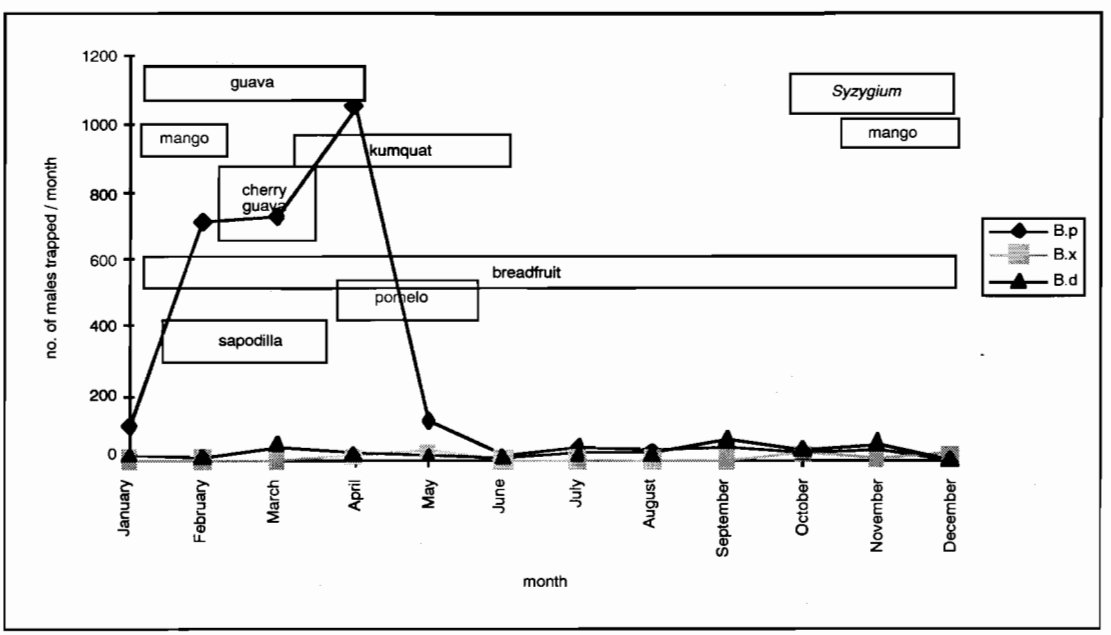


Figure 4. Host Availability of Fruit Flies at Naduruloulou Research Station, Nauaori.

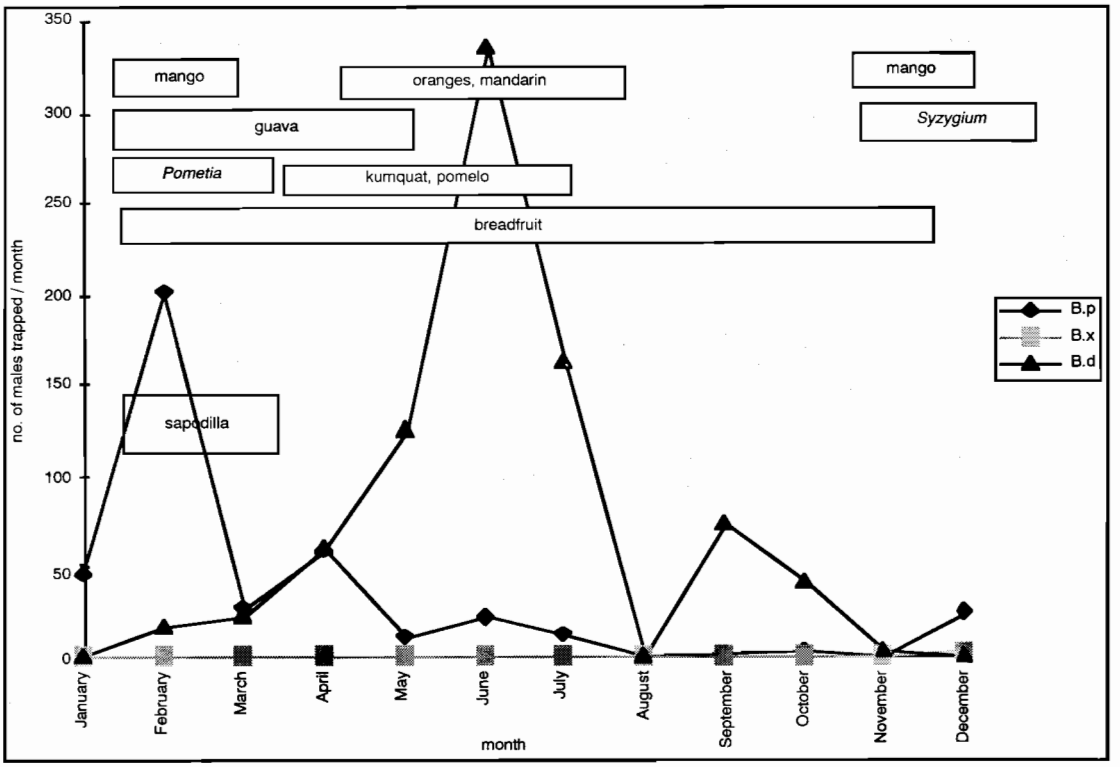


Figure 5. Host Availability of Fruit Flies at Seaqaqa Research Station, Vanua Levu.

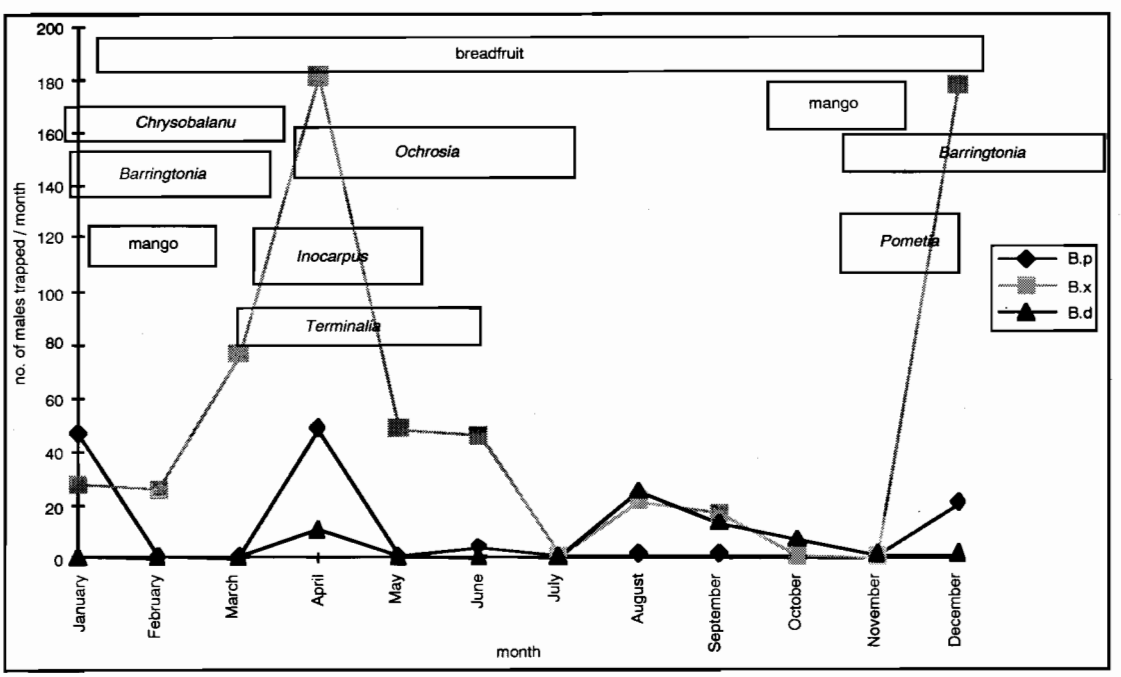


Figure 6. Host Availability of Fruit Flies at Savusavu, Vanua Levu.

Table 1. Major host fruit families, total number of host species and synthetic male attractant response of fruit flies in Fiji, 1990–1996.

Fruit fly species	Host fruit families	Number of host fruit species		Lure response
		Commercial	Wild	
B. passiflorae (E)	Anacardiaceae Annonaceae Apocynaceae Barringtoniaceae Caesalpiniaceae Combretaceae Guttiferae Lauraceae Loganiaceae Moraceae Myrtaceae Oxalidaceae Passifloraceae Punicaceae Rosaceae Rubiaceae Rutaceae Santalaceae Sapindaceae Sapotaceae Simaroubaceae	24	25	Cue-lure
B. xanthodes	Apocynaceae Barringtoniaceae Caricaceae Moraceae Rutaceae	4	2	Methyl eugenol
B. distincta	Sapotaceae	1	0	Cue-lure
B. passiflorae (coloured form) (E)	Apocynaceae	0	1	Cue-lure
B. gnetum (E)	Gnetaceae	0	1	Not attracted

E — endemic fruit fly species.
Plant families in bold type indicate the major families for *B. passiflorae* and *B. xanthodes*.

The trap records in Vanua Levu, Seaqaqa Research Station and Savusavu (Figs. 5 and 6) show the differences in *B. passiflorae* and *B. xanthodes* populations in the inland and coastal areas. There are high populations of *B. passiflorae* in the Seaqaqa area representing the inland area which is due to the presence of the major host fruits such as guava, oranges, mandarin, mango, *Syzygium jambos*, *Syzygium malaccense* and *Pometia pinnata* in the area. The presence of large numbers of *B. distincta* suggests that there are other host fruits other than sapodilla.

The large numbers of *B. xanthodes* in the coastal area near Savusavu coincides with the overlap of fruiting times and the abundance of breadfruit, *Barringtonia edulis* and *Ochrosia ooppositifolia* in the area.

This paper has highlighted the importance of fruit fly trapping and host survey records in determining the fruit fly fauna, host fruit range, seasonal adundance and geographical distributions. Reduced fruit availability during the 'winter' months (May–August) is a major contributing factor to low fruit fly numbers in Fiji and other Pacific Islands. This feature of fruit fly populations may be helpful in gaining access to markets in New Zealand during its winter on the basis of low risk of infestation in some commodities during May–August.

References

Allwood, A.J. 1995. Detection of Fruit Flies (Family: Tephritidae) by Trapping. Workshop on Fruit Flies and Their Control in the South Pacific, Koronivia Research Station, Nausori, Fiji, October, 1995.

Drew, R.A.I., Hooper, G.H.S and Bateman, M.A. 1978. Economic Fruit Flies of the South Pacific Region. Queensland Dept. of Primary Industries, First Edition, 137 p.

Drew, R.A.I. and Hooper, G.H.S. 1983. Population Studies of Fruit Flies (Diptera: Tephritidae) in South-East Queensland. *Oecologia (Berlin)*, 56: 153–159.

Simmonds, H.W. 1936. Fruit Fly Investigation, 1935. Department of Agriculture, Fiji. Bulletin No. 19: 1–18.

Vargas, R.I., Stark, J.D. and Nishida, T. 1990. Population Dynamics, Habitat Preference, and Seasonal Distribution Patterns of Oriental Fruit Fly and Melon Fly (Diptera: Tephritidae) in an Agricultural Area. Environmental Entomology, 19: 6: 1820–1828.

Responses of Fruit Flies (Family Tephritidae) to Male Lures in Seven Pacific Island Countries

A.J. Allwood[1]

Abstract

Trapping of fruit flies (Family Tephritidae) provides information on the species present in an area, is widely used for quarantine surveillance and is essential for monitoring populations during control or eradication programs or for ecological studies. In seven Pacific Island countries (Cook Islands, Federated States of Micronesia (FSM), Fiji, Solomon Islands, Tonga, Vanuatu and Western Samoa) under the Regional Fruit Fly Project and ACIAR Project, systematic trapping has been conducted as part of cataloguing of the species present and establishing early warning systems to record the incursions or introductions of exotic fruit fly species. Separate modified Steiner traps baited with methyl eugenol and Cue-lure were distributed in urban, village, farming and forest habitats in each country. The traps were serviced weekly in some areas of FSM, but generally every two weeks or monthly in most countries. Specimens were identified either nationally or by submitting them to the Queensland Department of Primary Industries, Australia. In some countries (Tonga, Fiji), trimedlure baited traps have been included in the early warning system.

The responses to male lures of the known species in the seven countries are listed. Flies that do not respond to male lures are also identified. Though the trapping and host surveys seem comprehensive in these countries, there is still a large number of host surveys to be done in rainforest areas of Solomon Islands, Vanuatu and Papua New Guinea.

TRAPPING of fruit flies (family Tephritidae) serves many purposes, but generally the purposes are for cataloguing the species present in an area, country or region, for quarantine detection or surveillance for exotic unwanted species, and for monitoring populations of fruit flies already established as a component of control or eradication strategies or for ecological studies. Cataloguing species involves undertaking taxonomic studies on trapped flies and the determination of their geographic distributions, both nationally and regionally. The responses to male lures have, together with other biological information such as host ranges and mating behaviour, assisted in elucidating the taxonomy of complexes or species of fruit flies. For example, *Bactrocera (Notodacus) xanthodes* (Broun) is now one species in a complex of four species, that are differentiated from each other by taxonomic characters, differences in responses to male lures and host ranges (Drew et al., these Proceedings).

[1] Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji

Trapping for quarantine detection or surveillance for exotic species is, as Cunningham (1989) states, '... a rather thankless task because it brings either no news or only bad news and further, it costs considerable money to do so'. Nevertheless, quarantine surveillance systems provide information on the species of fruit flies present as well as acting as an early warning system for unwanted, exotic species. Intensive trapping may also certify that areas are free from particular fruit fly species, thus guaranteeing area of freedom status for areas or countries. This is critical for countries that wish to export fresh commodities that are hosts for fruit flies. Trapping also forms an integral part of monitoring the effectiveness of eradication or suppression programs, together with targetted host surveys.

Trapping using male lures plays an important role in collecting information on the seasonal abundances of fruit fly species and, consequently, helps workers gain a better understanding of fruit flies in various habitats. Knowledge of the seasonal abundance of fruit flies in different cropping habitats may assist in conducting pest risk analyses for possible exports of

fresh fruits and vegetables. Pacific Island countries recognise the value of exporting fresh fruits and vegetables into small niche markets in Australia, New Zealand, Japan, Canada and United States of America. However, they also recognise the need to have current, valid data on the species of fruit flies present in their country so that meaningful discussions on quarantine protocols with importing countries may take place. This approach has resulted in many Pacific Island countries implementing fruit fly trapping programs.

This paper highlights the trapping programs in seven Pacific Island countries (Cook Islands, Federated States of Micronesia (FSM), Fiji, Solomon Islands, Tonga, Vanuatu and Western Samoa) and the responses to fruit flies to the male lures, methyl eugenol and Cue-lure.

Materials and Methods

Permanent trapping stations, consisting of pairs of modified Steiner traps (Drew et al. 1978), one baited with methyl eugenol and the other with Cue-lure were set up in Cook Islands, Fiji, Tonga and Western Samoa in 1991 as part of the Regional Fruit Fly Project in the South Pacific (RFFP) and a project funded by the Australian Centre for International Agricultural Research (ACIAR). The toxicant used was malathion, which was mixed with the lures in a ratio of 4 parts lure to 1 part malathion. Traps were cleared every two weeks initially; the frequency of clearing of traps was decreased to once per month at most sites. The lure and insecticide in each trap was recharged every 8–12 weeks. All insect specimens were identified within country and then shipped to the Queensland Department of Primary Industries Laboratory, Brisbane, for Dr Richard Drew and his staff to confirm identifications. After 1993, national staff undertook identification of specimens without confirmation from Australian workers. In 1994, permanent trapping stations were set up in Solomon Islands, Vanuatu and FSM. All specimens from Solomon Islands and Vanuatu are sent to Australia for identification or confirmation. As there is only one species of fruit fly in FSM, *Bactrocera (Bactrocera) frauenfeldi* (Schiner), there was no need to obtain confirmation from Australia. Table 1 shows the number of permanent trapping stations in each country and the number of islands where the trapping stations are located within each country. The lures used were methyl eugenol (4-allyl-1,2-dimethoxybenzene or O-methyl eugenol — an ether) and Cue-lure (4-(p-acetoxyphenyl)-2-butanone). In Fiji and Tonga, trimedlure (t-butyl-4(or 5)-chloro-2-methyl cyclohexane carboxylate) has been included into the early warning system for Mediterranean fruit fly (*Ceratitis capitata* Wiedemann). Cue-lure attracts male flies belonging to the genera *Bactrocera* and *Dacus*. Methyl eugenol attracts males belonging to the genus *Bactrocera*, with the exception of those in the subgenus *B. (Zeugodacus)*.

Table 1. The numbers of permanent trapping stations for fruit flies (Diptera: Tephritidae) using methyl eugenol and Cue-lure in modified Steiner traps in seven Pacific Island countries.

Country	No. of trapping stations	No. of islands
Cook Islands	32	8
FSM	67	8
Fiji	57	6
Solomon Islands	64	23
Tonga	22	5
Vanuatu	39	6
Western Samoa	37	2

Results

Table 2 shows the male lure responses of the known species in Cook Islands, FSM, Fiji, Solomon Islands, Tonga, Vanuatu and Western Samoa. The species that do not respond to methyl eugenol or Cue-lure are identified in Table 2.

Discussion

No fruit flies, except for Mediterranean fruit fly in Hawaii and south west Western Australia, are attracted to trimedlure in the South Pacific. Many more species in the seven countries are attracted to Cue-lure than methyl eugenol. Forty-seven species in the seven Pacific Island countries are attracted to Cue-lure; 10 species are attracted to methyl eugenol. Seven species of Dacinae are not attracted to either lure and have been recorded through host surveys. It is expected that, with the increased surveys of rainforest fruits in the Solomon Islands, the records of the species not attracted to male lures will increase substantially.

Reference

Cunningham, R.T. 1989. Population detection. In: Robinson, A.S. and Hooper, G.H.S., eds., Fruit flies: their biology, natural enemies and control, World Crop Pests 3A: 169–173.

Table 2. Responses of fruit flies (Diptera: Tephritidae) to the male lures, (methyl eugenol and Cue-lure), in seven Pacific Island countries ('+' denotes a positive response).

Country	Species	Lure responses		
		Cue-lure	Methyl eugenol	No responses
Cook Islands	*B. (B.) melanotus*	+		
	B. (N.) xanthodes		+	
FSM	*B. (B.) frauenfeldi*	+		
Fiji	*B. (B.) distincta*	+		
	B. (Buladacus) gnetum			+
	B. (B.) passiflorae	+		
	B. (N.) xanthodes		+	
Solomon Islands	*B. (A.) minuta*	+		
	B. (B.) anomala	+		
	B. (B.) bancroftii		+	
	B. (B.) biarcuata		+	
	B. (B.) decumana	+		
	B. (B.) enochra	+		
	B. (B.) epicharis	+		
	B. (B.) frauenfeldi	+		
	B. (B.) froggatti		+	
	B. (B.) honiarae		+	
	B. (B.) melanogaster		+	
	B. (B.) morula	+		
	B. (B.) musae		+	
	B. (B.) nigrescentis	+		
	B. (B.) pepisalae		+	
	B. (B.) picea		+	
	B. (B.) pseudodistincta	+		
	B. (B.) redunca	+		
	B. (B.) simulata	+		
	B. (B.) sp. n. S.I.11			+
	B. (B.) sp. near *simulata*	+		
	B. (B.) sp. near *nigrescentis*	+		
	B. (B.) sp. n. S.I.5	+		
	B. (B.) sp. n. S.I.6	+		
	B. (B.) sp. n. S.I.8	+		
	B. (B.) sp. n. S.I.9	+		
	B. (B.) sp. n. S.I.12	+		
	B. (B.) sp. n. near *froggatti*	+		
	B. (B.) sp. n. near *turneri*	+		
	B. (B.) trilineola	+		
	B. (B.) turneri	+		
	B. (B.) umbrosa		+	
	B. (B.) unifasciata	+		
	B. (B.) varipes	+		
	B. (S.) sp. n. near *strigifinis*	+		
	B. (Z.) cucurbitae	+		
	B. (Z.) sp. n. S.I.1	+		
	B. (Z.) sp. n. S.I.2	+		
	B. (Z.) sp. n. S.I.3	+		
	B. (Z.) sp. n. S.I.4	+		
	B. (Z.) sp. n. S.I.7	+		
	B. (Z.) sp. n. S.I.13	+		
	Dacus (C.) solomonensis	+		
Tonga	*B. (B.) distincta*	+		
	B. (B.) facialis	+		

Table 2 (continued). Responses of fruit flies (Diptera: Tephritidae) to the male lures, (methyl eugenol and Cue-lure), in seven Pacific Island countries ('+' denotes a positive response).

Country	Species	Lure responses		
		Cue-lure	Methyl eugenol	No responses
	B. (B.) kirki	+		
	B. (B.) obscura	+		
	B. (B.) passiflorae (Niuas only)	+		
	B. (N.) xanthodes		+	
Western Samoa	*B. (A.) aenigmatica*			+
	B. (B.) distincta	+		
	B. (B.) kirki	+		
	B. (b.) obscura	+		
	B. (N.) sp. n. near *xanthodes*			+
	B. (B.) samoae			+
	B. (N.) xanthodes		+	
Vanuatu	*B. (A.) minuta*	+		
	B. (B.) anomala	+		
	B. (B.) curvipennis	+		
	B. (B.) sp. n. near *obscura*	+		
	B. (B.) quadrisetosa			+
	B. (B.) redunca	+		
	B. (B.) sp. n. near *simulata*	+		
	B. (B.) trilineola	+		
	B. (B.) umbrosa		+	
	B. (G.) calophylli			+
	B. (n.) sp. n. near *xanthodes*			+
	B. (Z.) gracilis	+		
	Dacus (Dacus) sp.	+		

Development of Attractants for Female Fruit Flies in Hawaii

E.B. Jang[1]

Abstract

Attractants for tephritid fruit fly pests are key elements of many programs aimed at detecting, monitoring, controlling and/or eradicating these flies thoughout the world. However, many of the attractants thus far developed have been found empirically to attract primarily males. Development of female attractants for fruit flies are of interest for the following reasons: 1) enhanced selectivity and (perhaps) sensitivity of traps; 2) ability to trap gravid females which would eliminate future offspring; and 3) improved monitoring of effectiveness of programs such as sterile male releases. Ongoing research in Hawaii aimed at developing useful female attractants have focused on female behavior at various physiological states. Newly emerged females are initially attracted to food-based semiochemicals, then male-produced pheromone and finally switch to oviposition/host odors in a behavioral cascade which closely follows its physiology. Various plant odors have also been empirically discovered to be attractive to females of certain *Bactrocera* species. Effective female attractants will improve the ability to detect, monitor, control and/or eradicate pest fruit flies and augment current male lures.

SEMIOCHEMICAL attractants are important components of fruit fly detection, monitoring, control and eradication programs world-wide. Various synthetic and natural semiochemicals provide the means to detect the introduction and/or occurrence of flies in a particular area. Traps baited with attractants are also used to monitor fruit fly populations over time. Attractants mixed with various insecticides are used in 'bait-spray' formulations to control flies and more powerful attractants are the basis for technologies such as male annihilation, the eradication of a population through trapping of males. The status of semiochemical attractants for tephritid fruit flies has recently been reviewed by Jang and Light (1996a).

While these powerful techniques have been used for many years, except for a few situations, most attractants for fruit flies have been male attractants. Hydrolysed protein baits are known to capture males and females; the male attractant for the Mediterranean fruit fly, *Ceratitis capitata,* will capture females in the absence of males (Cunningham 1989); a female pheromone formulation has been developed for use in trapping female papaya fruit fly, *Toxotrypana curvicauda* (Landolt et al. 1988). A few non-host plant and ovipositional attractants for females have been reported in the literature as well (Jang and Light 1996b). Female attractants for tephritid fruit flies are needed to complement currently used male attractants. The major benefits which will come with the development of such attractants will include:

- increased selectivity (and perhaps sensitivity) of trapping for flies of a particular species or physiological status;
- improved control through elimination of females who carry eggs;
- ability to monitor female populations during eradication programs using techniques such as bait-sprays and the sterile insect technique (SIT).

Extensive testing of chemicals in the 1960s which resulted in the discovery of the male attractants did not uncover any female attractants of potency equal to the male attractants. However, during that time, information on the biology of tephritids was still relatively meagre. Now, more than 30 years later, much is still not known about the fundamental ecology and physiology of these flies. Recent research over the past ten years has, however, improved the knowledge base.

[1]USDA-ARS, Tropical Fruit and Vegetable Research Laboratory, PO Box 4459, Hilo, Hawaii, 96720, USA

In Hawaii the ecology and physiology of the four species of fruit flies have been studied in hopes of uncovering new information which would lead towards the development of new female attractants. Research has lead to the belief that males and females have some fundamentally different behaviors which are a result of changes in physiological state of the animals. Females have a more complex behavioral repertoire which includes the need for food used in nutrition and ovarian development, mating, oviposition related host-finding and egg-laying. In contrast, males do not engage in the oviposition and egg-laying behaviors. In the Medfly, females switch their olfactory attraction from male-pheromone to host-fruit odor as a result of mating. Virgin females injected with male accessory glands will act as though already mated and prefer host odor. Thus virgin females may be attracted to male pheromone while mated females may be more attracted to host-fruit odors characteristic of ripening fruit. These insights into how female behaviour might be regulated in these and other species may be key discoveries towards developing female lures.

For example, the components of the male-produced pheromone from Medfly have been identified and a synthetic blend of five components developed which is nearly as attractive as the real male odor (Jang et al. 1994). Pheromone-type attractants have been found to attract primarily virgin females. Other intermediate and minor identified components of the male odor have also been found to play an important role in mediating increased attractancy (Jang and Light 1996b).

Plant odors represent olfactory signals which may mediate feeding, mating and/or oviposition behaviors. Recently, water extracts of ripe coffee berries have been found to be attractive to female Medflies. Plant leaf odors from a hedge row plant used as a wind break for papaya fields in Hawaii has been found to be attractive to female oriental fruit flies (*Bactrocera dorsalis*).

The pressing need to establish practical control strategies for tephritid fruit flies, most of them being quarantine pests, has influenced the development of semiochemical-based female attractants for the economically important tephritids. Based on the large numbers of species for which little or nothing is known, this need will likely continue in the immediate future. Although pheromone-based technology has not yet been widely successful for tephritids, there is hope that with time and a better understanding of the pheromone systems which these flies utilise, pheromones may yet find a place in detection, control and eradication programs.

Conclusions

Semiochemicals are an important part of the knowledge base for understanding the fundamental ecology of tephritids, and in the development of semiochemical-based control strategies for economically important tephritid fruit flies. The past ten years has seen an increasing number of scientific publications dealing with semiochemicals in tephritids, yet for all of the new knowledge, technology for controlling these pests has not advanced proportionally. Central to these discussions has been the recognition of semiochemical complexity for both pheromonal and plant-type odors, especially the possible numbers of volatile chemicals which make up the natural habitat and how these influence behavior. Complexity is real in nature and should be one of the primary considerations in looking for improved female attractants. The chemoreception of any semiochemicals is a function of the perception of associated innate and learned contextual stimuli within the immediate environment. Volatile chemicals can thus act coactively, synergystically or antagonistically with one another to provide olfactory inputs. Understanding how complexity, homology, commonality, and natural context act to influence behavior will be a challenging task given the number of species being studied, and the different habitats in which these flies live.

References

Cunningham, R.T. 1989. Parapheromones. In: Robinson, A.S. and Hooper, G., eds., Fruit Flies: Their Biology, Natural Enemies and Control. World Crop Pests Vol. 3A, 221–230. Elsevier, Amsterdam.

Landolt, P.J., Heath, R.R., Agee, H.R., Tumlinson, J.H. and Calkins, C.O. 1988. Sex pheromone based trapping system for papaya fruit fly (Diptera: Tephritidae) J. Econ. Entomol. 81: 1163–1169.

Jang, E.B., Light, D.M., Binder, R.G., Flath, R.A. and Carvalho, L.A. 1994. Attraction of female Mediterranean fruit flies to the five major components of male-produced pheromone in a laboratory flight tunnel. J. Chem. Ecol. 20: 9–20.

Jang, E.B. and Light, D.M. 1996a. Olfactory Semiochemicals of tephritids. pp.73–90. in Fruit Fly Pests: A world assessment of their biology and management. (B.A. McPheron and G.J. Steck eds.).St. Lucie Press. Delray Beach, FL. 1996.

— 1996b. Attraction of female Mediterranean fruit flies to identified components of the male-produced pheromone: Qualitative aspects of major, intermediate and minor components. In: McPheron, B.A. and Steck, G.J., eds., Fruit Fly Pests: A world assessment of their biology and management. St. Lucie Press. Delray Beach, FL. 1996, 115–121.

Progress in Developing an Alternative to Protein Hydrolysate Bait Sprays

R.A. Vickers[1]

Abstract

Protein hydrolysate bait sprays have been used successfully to control fruit flies since the 1950s. However, they have not been particularly effective under high population densities or in crops that are highly susceptible to fruit fly attack. They also have poor longevity.

In a research program at the Division of Entomology, CSIRO researchers have identified a natural product ('novel compound') that in laboratory bioassays has proven more attractive to Queensland fruit fly (*Bactrocera tryoni* Froggatt) than protein hydrolysate. It is hoped that long-life formulations of this product can be developed both as a spray and as a bait suitable for use within traps.

To facilitate development of these products, researchers have been attempting to identify the attractive chemical(s) within the compound. It is known from behavioural bioassays and electrophysiological studies that they lie in particular fractions of the novel compound, but further work is required to complete the identification.

Field trials have shown that the attractive fractions in a suitable formulation are superior to protein hydrolysate when released within traps. However, the results from field tests of the novel compound put out as a spray have been inconclusive and further trials are to be conducted.

ALTHOUGH protein is required by both male and female adult fruit flies for their normal development, females, who need protein to mature their eggs prior to oviposition, are attracted to protein bait sprays in greater numbers than males. These sprays were first developed for fruit fly control in the 1950s. They consist of a 3–5% aqueous solution of protein autolysate or hydrolysate, combined with about 2% of an insecticide such as malathion, and are generally applied at 100–200 mL spot sprays to the foliage of susceptible crops.

Protein hydrolystate is normally prepared by hydrolysing proteinaceous waste from other commercial processes. Perhaps because of its complex chemical nature, the identity of the compound or compounds responsible for attraction have still to be determined, although limited progress has been made. Bateman and Morton (1981) demonstrated that ammonia was attractive and although its importance has been questioned by Drew and Fay (1988), fruit flies do show some attraction to weak ammonia solutions. However, the relatively low level of response clearly indicates that other volatiles are likely to play an important role. More than 40 volatile components have been isolated from protein hydrolysate (Morton and Bateman 1981; Buttery et al. 1983; Flath et al. 1989) but none have been shown to have other than marginal attractiveness.

Despite the general success of protein hydrolysate for fruit fly control, under some circumstances, it is inadequate. When population densities are high, protein hydrolysate is not sufficiently attractive to lure females to baited foliage before some find fruit suitable for oviposition. Furthermore, in crops that are particularly susceptible to fruit fly attack, some females find the ripening fruit more attractive than the baits (HPC 1991). Protein hydrolysate bait sprays also have poor longevity and may need to be applied as often as every 7–10 days, particularly during hot weather.

[1] CSIRO Division of Entomology, PB 3, Indooroopilly, Qld 4068

The objective of this research was to improve the efficacy of bait sprays and although it is proposed that a sprayable formulation be developed, researchers are also attempting to develop a formulation suitable for release within traps. Because baits within traps are better protected from the elements, the prospects of developing a long-life formulation are enhanced. Furthermore, control by trapping rather than spraying would eliminate insecticide contact with the foliage, fruit and non-target organisms. Several scientists are involved in the research: M. Lacey (chemistry), E. Rumbo (electrophysiology), R. Vickers (behaviour and field trials) and R. Akhurst (microbiology).

Early behavioural observations indicated that aged protein hydrolysate was more attractive than fresh material (Fig. 1). An attempt was made to determine the differences between the two in the hope that it might lead to a means of improving the attractiveness. There are many reports in the literature indicating that bacterial metabolites play a role in attracting fruit flies to protein hydrolysate, but although four species of bacteria that were present only in aged protein were isolated, inoculation of fresh protein with monocultures of these bacteria did not produce more attractive baits and this line of investigation was discontinued.

Concurrent investigations into alternative food sources revealed a compound that showed considerable promise as an attractant. Because of the need to protect a provisional patent, it is referred to here simply as a 'novel compound'. In laboratory bioassays, the compound has proved more attractive than aged protein hydrolysate (Fig. 2). Most efforts have subsequently been devoted to identifying the attractive components so that a synthetic and hopefully cheaper version can be produced. Furthermore, knowledge of the attractant's chemical nature will provide a better appreciation of the sorts of dispensing systems, UV protectants and anti-oxidants needed to develop long-life formulations.

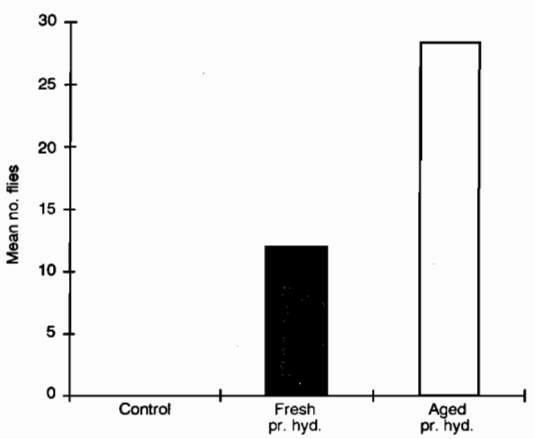


Figure 1. Fresh vs aged protein hydrolysate.

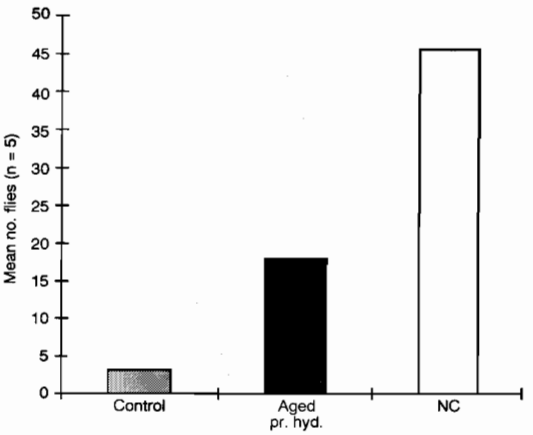


Figure 2. Aged protein hydrolysate vs novel compound.

Materials and Methods

Laboratory bioassays

Behaviour

Bioassay methods evolved as the project progressed and one has been chosen that resembles reasonably well the conditions likely to be encountered in the field in terms of the way in which a fly might locate the source of an attractant.

Twenty-five µL or 250 µL aliquots of the compounds to be tested are applied to 7 cm diameter green paper discs which are allowed to dry and are then suspended from a metal rod at the upwind edge of a group of ornamental fig trees within a laboratory glasshouse. A domestic fan provides a gentle breeze

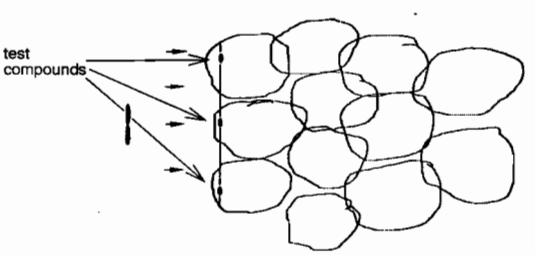


Figure 3. Plan view of behavioural bioassay. Breeze created by fan passes over baits suspended from a rod and carried odour into the foliage. Flies move upwind towards attractive baits.

across the baits, creating an odour plume that passes into the foliage (Fig. 3). On the morning of each test day, 100 mixed-sex protein-starved 7–11 day old adults are released into the foliage at least 1 hour before the tests commence (11 am–2 pm). Temperatures range from 20–26 °C.

Either two or three discs are tested in each bioassay. The number of flies landing on each disc are counted over a three minute period, after which the bait positions are rotated and counting recommenced. During the entire bioassay, each disc is evaluated 15 times.

Electrophysiology

The electroantennogram technique (EAG), which has been used successfully in odour studies of lepidoptera, was adapted for use with fruit flies to enable quantitative measurement of interactions between different chemicals and the antennae. The shape of the trace produced following exposure to a particular chemical provides an indication of how the chemical is perceived by the insect's nervous system. However, because a strong EAG response is no guarantee of a strong behavioural response, EAG tests must be used in conjunction with behavioural bioassays to determine their significance.

Field bioassays

Trapping trials

The compounds to be tested are placed in 1.5 L yellow plastic containers into which four 30 mm diameter evenly spaced holes have been punched around the circumference, about 30 mm below the lid. A small piece of dichlorvos pest strip is placed inside each trap as a killing agent. Traps containing only pest strip serve as controls.

Traps were set up either in potted apple trees enclosed within a 4 m × 4 m cage, ('cage trials') or within a Nashi pear orchard ('orchard trials'). In the cage trials, 5000 protein-starved, mixed-sex flies from the cultures were released at least 3 hours before the bioassays began.

Spray trials

Depending on the amount of material available, 30–100 mL of solution incorporating 2% malathion is sprayed until run-off on the foliage immediately above a 1.2 m^2 ground sheet. Efficacy of the bait is determined by counting the number of flies that fall onto the ground sheet.

Results and Discussion

So far, more than 340 laboratory bioassays and even more chemical extractions, identifications and fractionations have been conducted in attempts to identify the attractive component(s) of the novel compound.

Extracts of the novel compound are superior to protein hydrolysate and the activity resides in particular fractions of those extracts. Fractions that proved behaviourally active also gave good EAGs (Fig. 4).

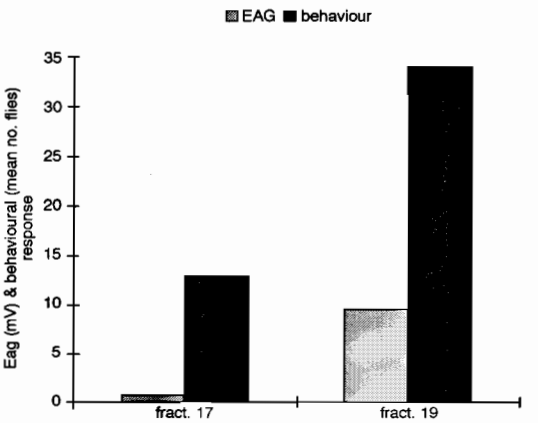


Figure 4. EAG and behavioural responses to novel compound fractions.

Some solvents are much more effective in removing the active compounds than others, and this has provided some clues about the broad chemical group that the compound(s) belong to.

Gas chromatography/mass spectrometry analyses of the extracts revealed a complex mixture of carboxylic acids, alcohols, aldehydes, phenols, amides, amines, lactones, pyridines and pyraxzines. Some of these were synthesised for behavioural bioassay but none proved active, either alone or in various combinations. It should be noted that such a large number of compounds makes it almost impossible to test all permutations.

Although fly numbers were rather low, in the most recent field trial, traps baited with the novel compound in a new formulation produced a mean catch significantly better than protein hydrolysate (Fig. 5). This was the first occasion that the novel compound had out-performed protein hydrolysate in the field and suggests that under field conditions formulation may be critical. A spray trial was conducted at the

same time but although flies were attracted to all baits, catches were too low to analyse for differences between bait types.

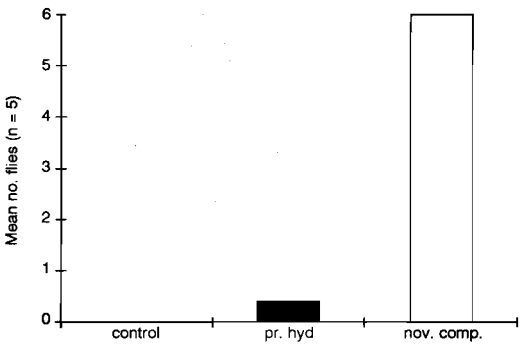


Figure 5. Mean catch of feral flies at unbaited (control) traps and traps baited with either protein hydrolysate or novel compound.

Attempts to identify the chemical(s) responsible for the attractiveness of the novel compound continue and some very recent studies have revealed a fraction with a unique EAG response that will be tested in behavioural bioassays as soon as possible. Intensive field trials are planned for the coming season, particularly with sprayable formulations of the novel compound.

References

Bateman, M.A. and Morton, T.C. 1981. The importance of ammonia in proteinaceous attractants for fruit flies. (Family: Tephritidae). Australian Journal of Agricultural Research, 32: 883–903.

Buttery, R.G., Ling, L.C., Terenashi, R. and Mon, T.R. 1983. Insect attractants: volatiles of hydrolised protein baits. Journal of Agricultural and Food Chemistry, 31: 689–692.

Drew, R.A.I. and Fay, H.A.C. 1988. Comparisons of the roles of ammonia and bacteria in the attraction of *Dacus tryoni* (Froggatt) (Queensland Fruit Fly) to proteinaceous suspensions. Journal of Plant Protection in the Tropics, 5: 27–30.

Flath, R.A., Matsumoto, K.E., Binder, R.G., Cunningham, R.T. and Mon, T.R. 1989. Effect of pH on the volatiles of protein hydrolysate insect baits. Journal of Agricultural and Food Chemistry, 37: 814–819.

HPC (Horticultural Policy Council) Industry Report No. 3. 1991. The impact of fruit flies on Australian Horticulture, 124 p.

Morton, T.C. and Bateman, M.A. 1981. Chemical studies on proteinaceous attractants for fruit flies, including the identification of volatile constituents. Australian Journal of Agricultural Research, 32: 905–916.

Seasonal Abundances of *Bactrocera facialis* (Coquillett), *B. passiflorae* (Froggatt), *B. xanthodes* (Broun) and *B. melanotus* (Coquillett) in Orchard and Forest Habitats

L. Leweniqila[1], V. Heimoana[2], M. Purea[3], L. Munro[3], A.J. Allwood[4], L. Ralulu[1] and E. Tora Vueti[1]

Abstract

Bactrocera facialis (Coquillett) is one of the three major fruit fly species in Tonga. At Vaini Research Station, representing an orchard situation, highest numbers are found between October and March and the lowest numbers between the winter months of June and August. In the forest area at Lafalafa, populations are lower than the orchard situation with peak populations between March and May.

The relative populations of *Bactrocera passiflorae* (Froggatt) and *Bactrocera xanthodes* (Broun) were determined at Colo-i-Suva Forest Park, and Wainigata Research Station in Fiji by trapping males. At Colo-i-Suva Forest Park, which represents a forest habitat, only two species were present, namely *B. passiflorae* and *B. distincta*. This confirms that *B. xanthodes* is not a rain-forest species. At Wainigata Research Station, typifying an orchard habitat, all three species, *B. passiflorae, B. xanthodes* and *B. distincta* are present throughout the year and in higher numbers than at the forest site. The survey of the populations was part of Fiji's trapping program under its quarantine surveillance system which was established in 1991 by the Regional Fruit Fly Project. For the purposes of this paper, data from January 1995 to September 1996 for Colo-i-Suva Forest Park and from January 1992 to December 1992 for Wainigata Research Station are included. The composition and fluctuations in populations at the two sites are compared and discussed.

Bactrocera melanotus (Coquillett) is indigenous to the Southern Cook Islands forests. Data collected in the past ten years revealed consistently high populations during the warmer months and low populations during the cooler months. In orchard habitats, populations increase towards the end of fruiting seasons, particularly in orange orchards, but the same trend of low populations during cooler months and high during the warmer months is observed.

AS exporting countries, Fiji, Tonga and Cook Islands are expected to provide background information on fruit flies to importing countries for Pest Risk Analyses. Trapping, as a component of quarantine surveillance, provides information on species present, seasonal distribution and helps to establish area freedom from exotic fruit flies. The responses of fruit fly species to male attractants in the South Pacific have been published (Drew 1974) and in Fiji, the two economic pest species, *B. passiflorae* and *B. xanthodes*, respond to Cue-lure and methyl eugenol respectively. In Tonga, *B. facialis* responds to Cue-lure and in Cook Islands, *B. melanotus* and *B. xanthodes* respond to Cue-lure and methyl eugenol respectively. The trapping program initiated in Tonga and Fiji by the Regional Fruit Fly Project in 1991 and in Cook Islands by the New Zealand government use these two attractants in their quarantine surveillance systems. In Fiji, the forest habitat under study is Colo-i-Suva Forest Park, situated 11 km north of Suva. It is part of a 369.5 ha area declared as Forestry Reserve in 1963. Wainigata Research Station, located 28 km east of Savusavu, is the

[1] Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2] Ministry of Agriculture and Forestry, Research Division, Nuku'alofa, Kingdom of Tonga
[3] Ministry of Agriculture, Cook Islands
[4] Regional Fruit Fly Project, South Pacific Commission, Suva

orchard habitat studied. In Tonga, *B. facialis* is one of the three major fruit fly species. It is the most abundantly detected species in traps. On Tongatapu, trap sites at Lafalafa, representing a forest habitat, and at Vaini Research Station, representing an orchard habitat, were used. Also, the trap sites on Eua at the MAF station, representing an orchard habitat, and MAF farm, representing a forest habitat, were used. This paper discusses the composition and seasonal abundance of the respective species present at each site. The presence of host plants is also considered.

Materials and Method

Modified Steiner traps (Bateman et al. 1978) were used to catch adult males of *B. facialis*, *B. passiflorae*, *B. xanthodes*, and *B. melanotus*. Each site had two traps set up: one baited with Cue-lure and the other with methyl eugenol. Each trap was baited with about 3 mL of a mixture of 80% attractant and 20% malathion (50% emulsifiable concentrate) by volume in a cotton wick (4 cm long by 1 cm diameter). The wick was rebaited at 12 week intervals. The traps were placed on host plants about 1.5–2.0 m above ground. Trapped flies were collected monthly and counted.

Results and Discussion

Trapping data from Vaini Research Station and Lafalafa have been summarised in Figure 1 and data from Eua MAF station and farm in Figure 2. At Vaini Reseach Station, the trap is situated in a neglected, poorly fruiting citrus orchard (major host) surrounded by large mango trees (major host) and papaya plantations (minor host). A small peak between January and March 1993 was therefore most likely due to the fruiting season of mango. This peak was greatly magnified between January and May 1995 when Tonga experienced one of the best mango seasons ever. Smaller peaks during July and December 1994 may be explained by the capsicum bait spray trial that was carried out at the research station during this period

Between March 1993 and May 1994, populations were very low. This is attributed to the drought that struck Tonga which affected adversely the fruiting of many plant species. At this time, Lafalafa forest showed slightly higher populations than the orchard and this could be explained by the presence of a wider range of host plants such as takafalu (*Micromellum minutum*), pumelo (*Citrus maxima*), ahi vao (*Vavaea amicorum*), tropical almond (*Terminalia catappa*), fao (*Ochrosia oppositifolia*) and guava

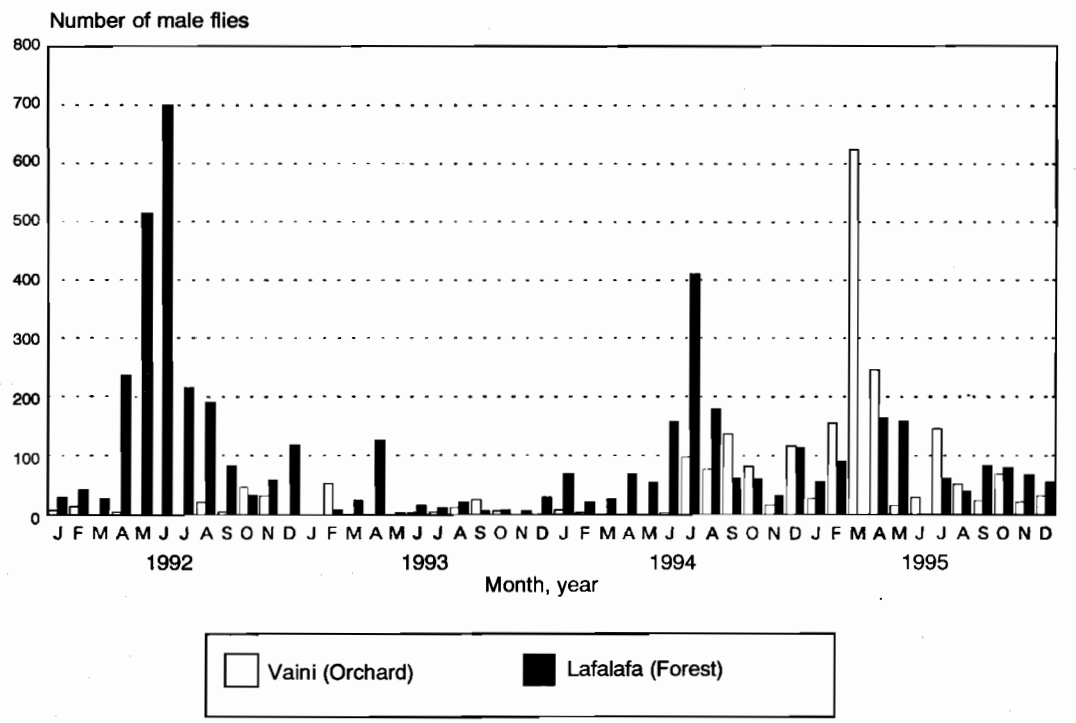


Figure 1. Seasonal abundance of *Bactrocera facialis* in Tonga. Trap catches from Tongatapu Island.

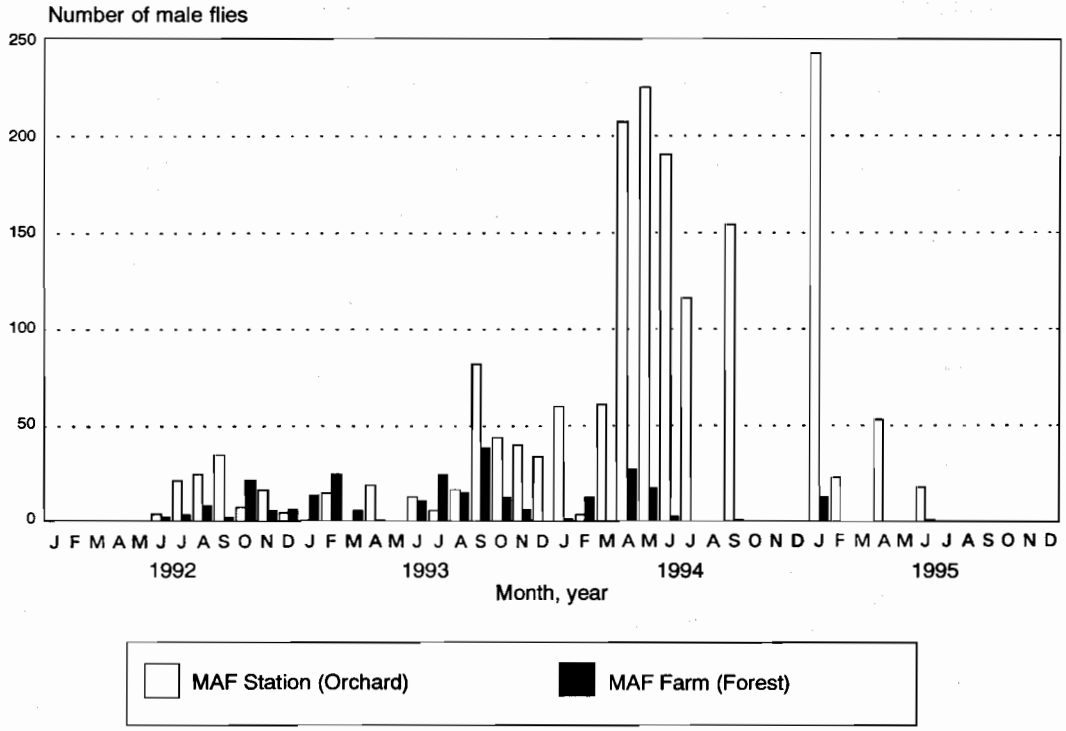


Figure 2. Seasonal abundance of *Bactrocera facialis* in Tonga. Trap catches from Eua Island.

(*Psidium guajava*). The peak between March and May in 1993 was linked to the fruiting of tropical almond and guava, while the peaks at December 1992, 1994 and January 1993 could be the result of the fruiting of ahi vao, fao, ifi (*Inocarpus fagifer*), toto (*Cerbera manghas*) and huni (*Phaleria disperma*).

From the results of trap catches in Figure 1, the population of *B. facialis* was generally higher in the forest habitat in Tongatapu than in the orchard habitat. It could also be said that populations in the forest peak between March and July, and in orchard habitats during December and January, are related to the mango fruiting period.

Data from 'Eua are not complete as trap collections were not carried out regularly, but results as shown in Figure 2 indicate that peaks in populations coincide with fruiting seasons of *Citrus* species (May–July), rose apple (*Syzygium jambos*) (Dec.,–Feb.) and (June–July), kakala'uli and tutuna (unidentified species), fao (Jan.,–March) and takafalu.

As shown in Figure 3, the trap clearances at the forest habitat in Fiji were not regular. However, data indicate the presence of *B. passiflorae* in both orchard and forest type habitats. Its abundance at the Colo-i-Suva Forest Park is more seasonal, showing a marked increase in the cooler, dry months of February, March, April, May, and a gradual decrease in numbers in the warmer, wet months. The peak in the forest population is reached in April, coinciding with the fruiting of *Amaroria soulameoides*, its major host. An interesting point about data collected from this habitat is the absence of *B. xanthodes*. This confirms that *B. xanthodes* is not a forest species, particularly undisturbed rainforest habitats. The abundance of *B. passiflorae* at Wainigata Research Station (Fig. 4), the orchard type habitat, does not indicate such a marked variation although the trend towards lower numbers in the cooler dry months is seen. On the abundance of *B. xanthodes*, the results indicate its presence in the orchard habitat throughout the year and a total absence from the forest habitat. The *B. xanthodes* population shows a peak in the months of December and January, coinciding with the time of fruiting of its major host, *Artocarpus altilis*.

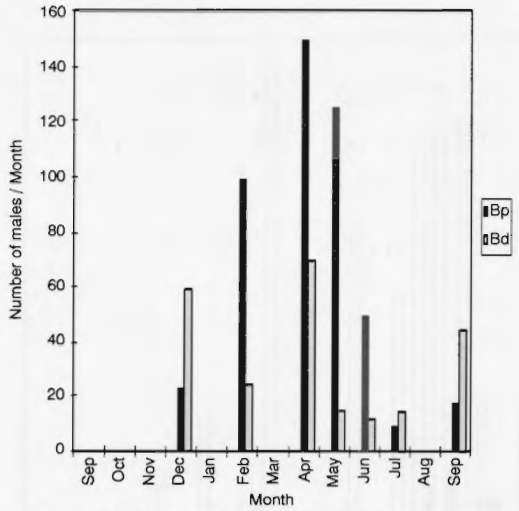


Figure 3. Seasonal abundance of Fruit Flies at Colo-i-Suva, Forest Park for September 1995 to September 1996.

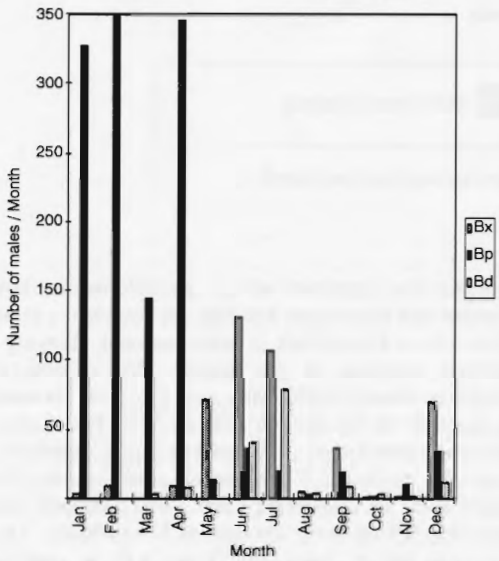


Figure 4. Seasonal abundance of Fruit Flies at Wainigata Research Station, Savusavu for 1992.

In Cook Islands, trap catches indicate that *B. melanotus* is an inland species. Native trees such as Polynesian chestnut (*Inocarpus fagifer*), Malay apples (*Syzygium malaccense*), and wild guavas are common host plants for *B. melanotus* and, because of overlapping fruiting times, guarantee high populations, particularly in rainforest areas compared to those in orchard areas (Figure 5 and 6). The population peaks in the cooler months of June and July and declines towards the summer months. The population of *B. xanthodes* is higher in coastal areas (representing an orchard habitat) and lower in the forest habitats.

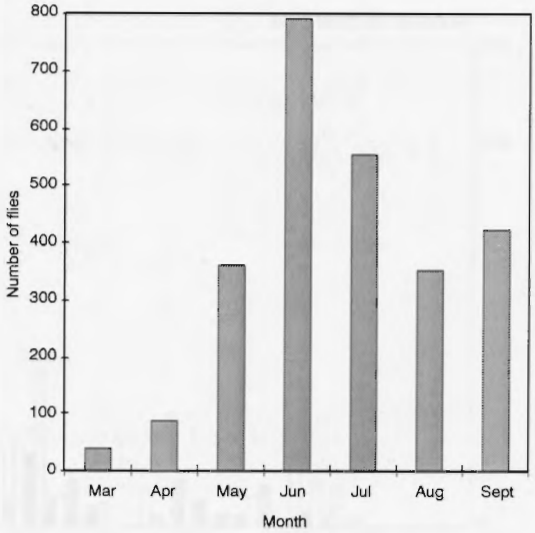


Figure 5. Seasonal abundance of *Bactrocera melanotus* in an orchard habitat on Rarotonga, Cook Islands (1995).

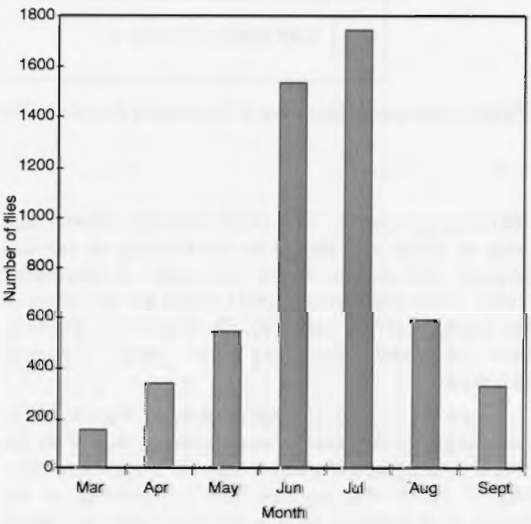


Figure 6. Seasonal abundance of *Bactrocera melanotus* in a forest habitat on Rarotonga, Cook Islands (1995).

References

Bateman, M.A., Drew, R.A.I. and Hooper, G.H.S. 1978. Economic Fruit Flies of the South Pacific Region, Queensland Department of Primary Industries, 130 p.

Drew, R.A.I. 1974. The responses of fruit fly species (Diptera: Tephritidae) in the South Pacific area to male attractants. Journal of Australian Entomological Society 13: 267–270.

Mango Fruit Fly (*Bactrocera frauenfeldi*): Why So Many in Federated States of Micronesia?

L. Leblanc[1] and A.J. Allwood[1]

Abstract

Mango fruit flies (*Bactrocera frauenfeldi*) are extremely abundant throughout the year on the islands of Pohnpei and Kosrae in the Federated States of Micronesia (FSM). Cue-lure traps on Pohnpei and Kosrae collect an average of 443 and 327 flies/trap/day, respectively. Fruit surveys have identified 31 species of hosts. Evaluations of levels of infestation in individual fruits have provided insights into the reasons for large fruit fly populations. The main reasons are the widespread abundance of the major hosts, the large numbers of fruits produced by the major hosts, the availability of host fruits throughout the year, the high proportion of unharvested fruits that become over-ripe, fall to the ground and become fly breeding sites, the absence of other fruit fly species to compete against mango fruit fly, the apparent lack of intraspecific competition within fruits, and the absence of parasitoids.

FEDERATED States of Micronesia (FSM) is very scattered geographically. Its 700.8 km^2 is made up of 607 small islands, scattered over 2.5 million km^2 of ocean. It is composed of four States: Kosrae, Pohnpei, Chuuk and Yap, each with one or a few main volcanic islands and a number of outer atolls. Mango fruit fly (*Bactrocera frauenfeldi* (Schiner)) has been intensively surveyed in FSM since December 1994 and is the only fruit fly species in the country. It is present over the whole of FSM, even on remote atolls. Mango fruit fly populations are extremely large, especially on Pohnpei and Kosrae islands. This paper discusses some reasons for the large fly populations.

Seasonal Abundance of Mango Fruit Fly

Since December 1994, trapping has been carried out continuously on Pohnpei, periodically on Kosrae and for a few months on Yap and Chuuk Lagoon Islands. One Cue-lure and one methyl eugenol trap has been set up on each of 67 sites covering six volcanic islands and four atolls. No flies were collected at the methyl eugenol traps. Cue-lure traps, on the other hand, collected extremely large numbers of mango fruit flies. Trapping on Pohnpei (Fig. 1) yielded the highest numbers of flies, a mean of 443 flies/trap/day (range of 100–1387 flies/trap/day). The maximum number of flies collected in one trap on Pohnpei was 14 900 flies in eight days in August 1996. Trapping results also showed that mango fruit fly is abundant throughout the year with a slight but consistent drop in June and July. The sharp increase in trap catches in August to October 1996 was due to the replacement of the traps by larger traps that hold more flies. Periodic trapping on Kosrae (Fig. 2) also shows very high numbers of flies at all times during the year, with a mean of 327 flies/trap/day (range of 175–458 flies/trap/day). Limited trapping in primary forests on Pohnpei and Kosrae has confirmed the presence of mango fruit flies even far away from village, production, agroforestry and coastal areas.

Limited Trapping on Yap and Three Chuuk Lagoon Islands

Figure 3 clearly demonstrated that mango fruit flies are much less abundant on Yap and Chuuk (67 flies/trap/day on Yap and 32 flies/trap/day on Chuuk) than on Pohnpei and Kosrae. Unfortunately, there are

[1] Regional Fruit Fly Project in the South Pacific. South Pacific Commission, Private Mail Bag, Suva, Fiji

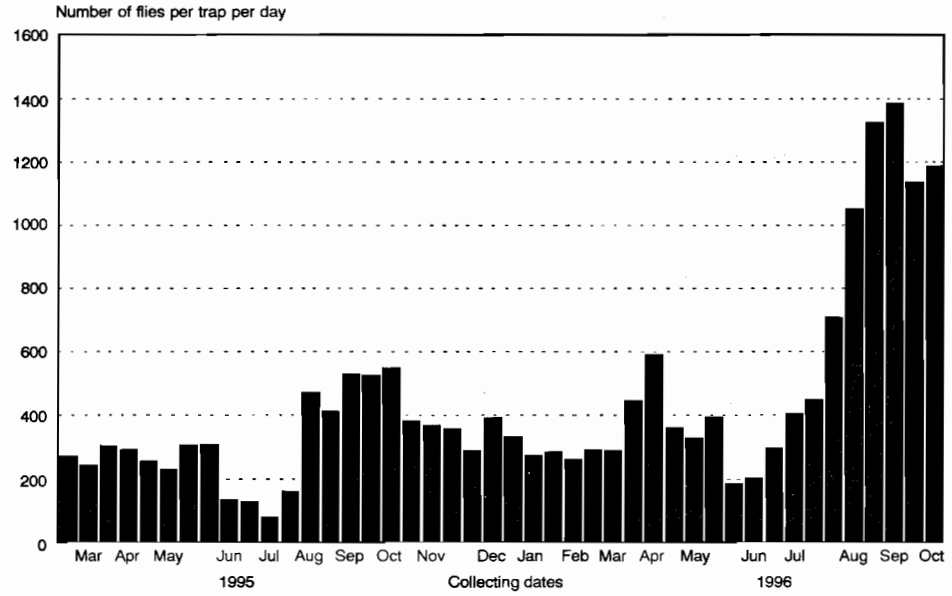


Figure 1. Bi-weekly catches of *Bactrocera frauenfeldi* by Cue-lure traps on Pohnpei. Means from eight traps, February 1995 to October 1996.

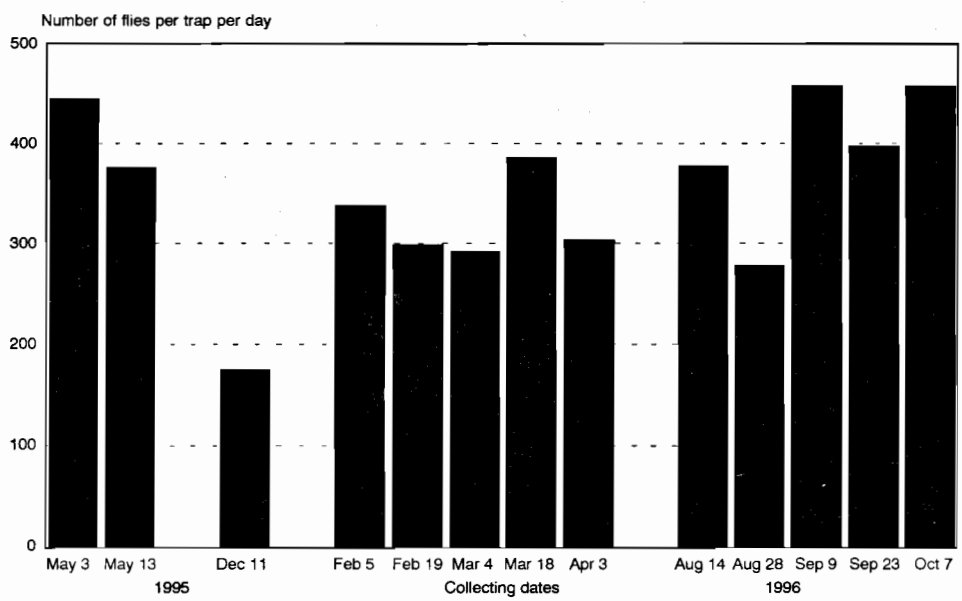


Figure 2. Bi-weekly catches of *Bactrocera frauenfeldi* by Cue-lure traps on Kosrae. Means from eleven traps.

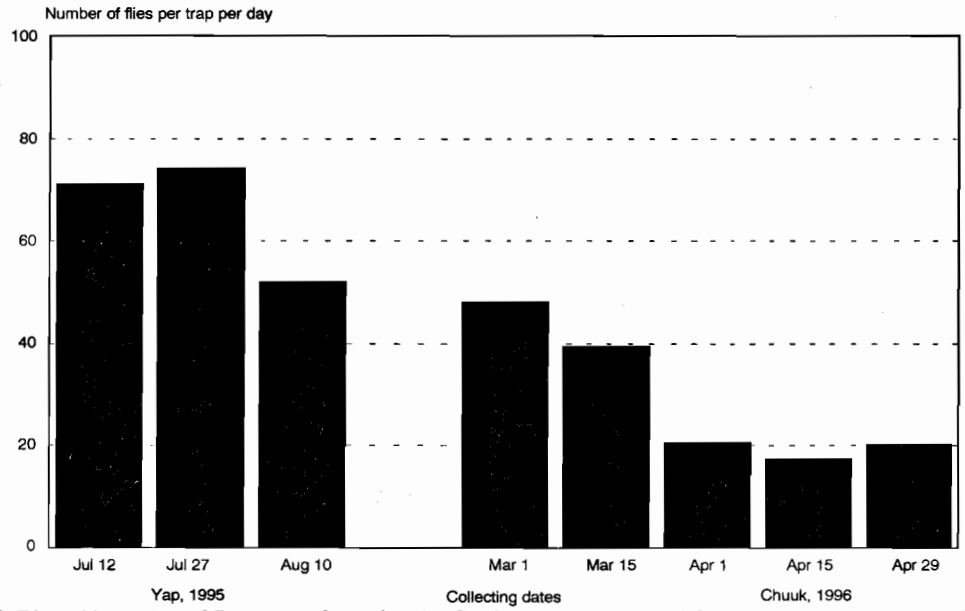


Figure 3. Bi-weekly catches of *Bactrocera frauenfeldi* by Cue-lure traps on Yap and Chuuk. Means from ten traps in 1995 (Yap) and twelve traps in 1996 (Chuuk).

insufficient data to provide a clear indication of seasonal abundance.

The two Pohnpei State outer atolls with continuous trapping had opposite situations. The three traps on Nukuoro atoll collected massive numbers of flies, a mean of 465 flies/trap/day. The four traps on Mokil atoll drastically reduced numbers of flies by male annihilation from 202 to 16.7 flies/trap/day in eight weeks. Numbers have since been maintained at a very low level, 7.4 flies/trap/day. Though there is no concrete evidence, farmers claim that, since the male trapping commenced, the breadfruit harvests have significantly improved.

Importance of Hosts

The host range for mango fruit fly in FSM is relatively well understood through host surveys initiated in January, 1995. More than 1100 samples of fruits and vegetables, covering 120 plant species, were collected in all FSM States. Thirty-one species of hosts have been so far recorded. Twenty-two host species for mango fruit fly were intensively sampled from different localities. Fruits were set up over moistened, sterilised sawdust to recover pupae. Each piece of fruit was set up in a separate container.

Results from these intensive surveys are detailed in Tables 1 and 2. Levels of infestation are expressed as numbers of fly pupae recovered from each fruit after at least two weeks of incubation in the laboratory. Data in the tables help appreciation of the importance of each host from different perspectives. Percentage infestation is a direct translation of economic losses caused by flies. Mean and maximum number of pupae recovered from infested fruits, with variations detailed in Table 2, are indications of levels of infestation. The mean number of pupae per kilogram of fruit and per fruit indicates the larval load carried by each host.

These studies have resulted in an evaluation of the importance of each fruit species as a host for mango fruit fly and, based on larval loads, the percentage of infestation. The major hosts of mango fruit flies are two varieties of guavas, tropical almonds (*Terminalia catappa*) and Polynesian chestnuts (*Inocarpus fagifer*). The larval loads of these hosts are more than 250 larvae per kg of fruits, more than 50% of the fruits are infested and fruits individually produce a mean of more than 15 larvae. These species are extremely common in FSM, especially on Pohnpei and Kosrae. Although not as abundant in FSM as guavas, tropical almonds and Polynesian chestnuts, other heavily infested hosts include Surinam cherries (*Eugenia uniflora*), Indian laurel (*Calophyllum inophyllum*), *Mammea odorata*, *Terminalia carolinensis* and *T. samoensis*. Intermediate hosts, with 10 to 100 larvae per kg of fruits and more than 20% of fruits infested, are apples (*Syzygium aquaeum*, *S. javanica* and *S. malaccense*), *Ochrosia oppositifolia*,

Table 1. Assessment of damage levels for the major hosts of mango fruit fly.

Families	Hosts	No. of samples	No. of fruits	Weight kg	Per cent infestation	Max no. pupae in one fruit	Mean no. pupae/ infested fruit	Mean no. pupae/kg infested fruit	Mean no. pupae/kg fruit (total)
Anacardiaceae	*Mangifera indica*	8	172	22.73	8.1	18	8.1	52.4	5.0
Annonaceae	*Annona glabra*	6	77	11.37	26.0	79	12.8	93.9	22.4
Annonaceae	*Annona muricata*	17	32	36.20	28.1	17	4.9	4.0	1.2
Apocynaceae	*Ochrosia oppositifolia*	3	33	2.04	33.3	37	14.9	258.3	80.4
Caesalpinaceae	*Inocarpus fagifer*	10	207	20.30	56.0	291	49.3	400.8	281.8
Combretaceae	*Terminalia carolinensis*	2	51	1.05	45.1	33	7.8	393.6	164.6
Combretaceae	*Terminalia catappa*	11	252	10.61	68.7	66	15.5	349.5	253.0
Combretaceae	*Terminalia samoensis*	1	51	0.11	88.2	6	2.7	1237	1091
Guttiferae	*Calophyllum inophyllum*	5	158	3.56	22.8	78	17.9	767.3	173.3
Guttiferae	*Mammea odorata*	1	16	1.06	25.0	114	43.8	648.2	165.9
Lauraceae	*Persea americana*	1	7	2.51	57.1	50	32.5	93.3	51.8
Malpighiaceae	*Malpighia glabra*	26	629	3.34	3.7	2	1.0	200.0	7.2
Moraceae	*Artocarpus altilis* (1)	60	311	427.68	37.3	266	28.1	19.4	7.4
Myrtaceae	*Eugenia uniflora*	11	392	1.84	60.7	7	1.6	353.4	210.9
Myrtaceae	*Psidium guajava* (2)	12	262	17.67	91.2	179	31.7	580.0	437.7
Myrtaceae	*Psidium guajava* (3)	5	77	4.21	85.7	69	25.1	434.1	393.8
Myrtaceae	*Psidium guajava* (4)	3	45	1.29	31.1	9	5.2	173.8	56.6
Myrtaceae	*Syzygium aquaeum*	10	253	4.33	51.4	7	2.5	135.1	73.4
Myrtaceae	*Syzygium javanicum*	9	220	10.18	38.2	14	2.6	55.6	21.3
Myrtaceae	*Syzygium malaccense*	4	64	4.38	43.8	15	4.8	69.2	30.9
Oxalidaceae	*Averrhoa carambolae*	13	236	34.43	17.8	12	3.1	16.2	3.8
Rubiaceae	*Guettarda speciosa*	1	36	0.32	41.7	12	4.2	472.1	196.9
Rutaceae	*Citrus reticulata* (5)	10	187	15.78	20.3	31	4.3	46.9	10.0
Rutaceae	*Citrus sinensis*	27	394	101.92	4.0	30	5.0	20.4	0.7

1. Seedless. 2. Large with pink flesh. 3. Large with white flesh. 4. Small with pink flesh. 5. Satsuma tangerines.

avocadoes (*Persea americana*), pond apples (*Annona glabra*) and one variety of guavas. Breadfruits and soursops are considered as intermediate hosts because of their low larval loads due to large fruit size. Among the minor hosts are some of the most economically important fruits grown in FSM, for example, mangoes (*Mangifera indica*), carambolas (*Averrhoa carambolae*), tangerines (*Citrus reticulata*), oranges (*C. sinensis*) and acerola (*Malpighia glabra*).

Discussion

Results from host surveying and damage assessments provide several answers to explain the exceptionally large numbers of flies collected in traps on Pohnpei and Kosrae Islands. Firstly, most of the major hosts of mango fruit fly, e.g. guavas, *Terminalia* spp, *Inocarpus*, *Syzygium* spp, breadfruits and *Calophyllum*, are extremely common on both islands, especially in urban and agroforestry areas on Pohnpei and along the coast on Kosrae. This very high host concentration is analogous to a monoculture situation that favours a continuous build-up of fly populations. Generally, less abundant host trees on Yap and Chuuk account for lower numbers of trapped flies. Secondly, most of the major host trees, except for breadfruits, bear very large numbers of small fruits. Their high fruit loads together with uneven ripening guarantee ideal conditions as breeding grounds for thousands of fruit fly larvae on each tree. Thirdly, most of the major hosts produce fruits all year around and their main fruiting seasons overlap, thus sustaining very large fly populations all year around. Figure 4 illustrates, for Pohnpei Island, the fruiting seasons for 10 host species.

Because of the abundance of fruit trees, Micronesians do not harvest and consume all fruits, especially during the main harvest seasons. A large proportion of the fruits becomes over-ripe on the trees, fall to the ground and are left to rot. This provides ideal breeding grounds for flies. Also, there seems to be little competition for food. For mango fruit fly, being the only Dacine fruit fly species present in FSM, there is no interspecific competition. Likewise, there is no evidence of intraspecific competition. Large numbers of fly larvae can develop and reach maturity in individual host fruits (Table 2). Maximum numbers of pupae recovered from individual fruits of the major hosts were 179 in one guava fruit, 291 in one *Inocarpus* and 66 in one

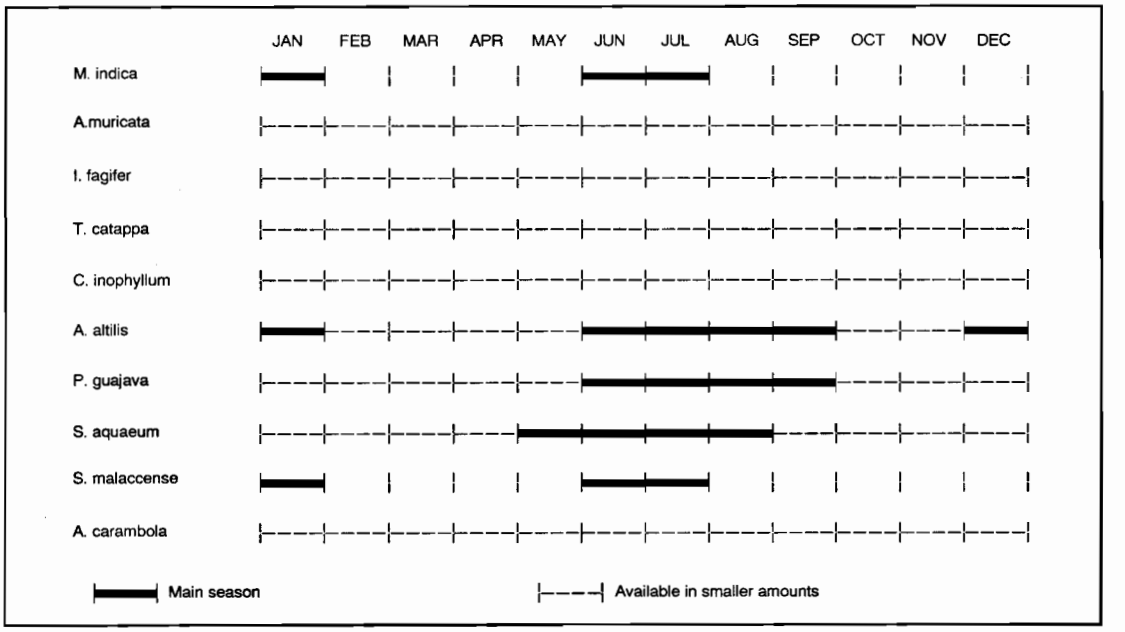


Figure 4. Fruiting seasons of the main hosts of mango fruit fly on Pohnpei Island. (Source: Pohnpei State Division of Agriculture).

Table 2. Assessment of levels of infestation for the major hosts of mango fruit fly, as a percentage of individual fruits yielding 1 to 300 fly pupae.

Hosts	Percent fruits infested	Percent of fruits with numbers of pupae in each range below									
		1–5	6–10	11–20	21–30	31–40	41–50	51–100	101–150	151–200	201–300
Mangifera indica	8.1	4.0	0.6	3.5	—	—	—	—	—	—	—
Annona glabra	26.0	14.3	1.3	5.2	3.9	0.0	0.0	1.3	—	—	—
Annona muricata	28.1	15.6	9.4	3.1	—	—	—	—	—	—	—
Ochrosia oppositifolia	33.3	9.1	9.1	3.0	6.0	6.0	—	—	—	—	—
Inocarpus fagifer	56.0	9.2	4.8	12.1	2.4	2.4	5.8	11.6	3.4	2.9	1.4
Terminalia carolinensis	45.1	27.5	3.9	7.8	3.9	2.0	—	—	—	—	—
Terminalia catappa	68.7	23.4	11.9	13.9	6.7	6.0	4.8	2.0	—	—	—
Terminalia samoensis	88.2	82.3	5.9	—	—	—	—	—	—	—	—
Calophyllum inophyllum	22.8	8.2	5.1	3.2	0.6	1.9	0.6	3.2	—	—	—
Mammea odorata	25.0	12.4	0.0	0.0	0.0	0.0	0.0	6.3	6.3	—	—
Persea americana	57.1	0.0	14.3	0.0	14.3	0.0	28.5	—	—	—	—
Malpighia glabra	3.7	3.7	—	—	—	—	—	—	—	—	—
Artocarpus altilis (1)	37.3	13.5	6.1	5.8	2.6	1.0	2.2	3.5	1.0	0.6	1.0
Eugenia uniflora	60.7	60.2	0.5	—	—	—	—	—	—	—	—
Psidium guajava (2)	91.2	11.5	7.6	18.7	16.4	13.3	8.0	13.0	1.9	0.8	—
Psidium guajava (3)	85.7	7.8	11.7	18.2	15.6	20.8	3.8	7.8	—	—	—
Psidium guajava (4)	31.1	20.0	11.1	—	—	—	—	—	—	—	—
Syzygium aquaeum	51.4	49.8	1.6	—	—	—	—	—	—	—	—
Syzygium javanica	38.2	35.0	2.7	0.5	—	—	—	—	—	—	—
Syzygium malaccense	43.8	28.2	12.5	3.1	—	—	—	—	—	—	—
Averrhoa carambolae	17.8	15.3	2.1	0.4	—	—	—	—	—	—	—
Guettarda speciosa	41.7	30.6	8.3	2.8	—	—	—	—	—	—	—
Citrus reticulata (5)	20.3	14.5	3.8	1.6	0.5	—	—	—	—	—	—
Citrus sinensis	4.0	3.3	0.0	0.0	0.7	—	—	—	—	—	—

1. Seedless. 2. Large with pink flesh. 3. Large with white flesh. 4. Small with pink flesh. 5. Satsuma tangerines

Terminalia. These figures are particularly revealing for *Inocarpus* and *Terminalia*, where only the outer layer of the fruit is consumed.

No parasitoids have been recovered from the fruit samples collected and processed through the rearing laboratory. This population control factor is entirely lacking in FSM. The large populations of mango fruit flies and the widespread abundance of host trees will therefore make control of flies by bait spraying a very difficult task unless area control is considered and rigorously applied. It is fortunate, though, that some of the hosts targeted for commercial exports from FSM are minor hosts (oranges, tangerines, mangoes) or not hosts (bananas, limes). The most immediate recommendation would be to attempt to introduce and establish a natural parasitoid wasp species, *Fopius arisanus* (Braconidae), in the hope of reducing fruit fly populations to levels that are more manageable by bait spraying.

Acknowledgements

The authors thank the Kosrae, Chuuk and Yap State quarantine and extension agents and Nukuoro, Sapwafik and Mokil outer island extension agents for maintaining and collecting flies from traps. The assistance of M. Martin (Pohnpei State Extension Agent) and E. Ioannis, R. Samuel, K. Diopoulos and J. William (College of Micronesia, Land Grant Program) in the field and the laboratory on Pohnpei, is greatly appreciated.

Bactrocera paraxanthodes Drew and Hancock — an example of how host records and attractant responses contribute to taxonomic research

R.A.I. Drew[1], A.J. Allwood[2] and D. Tau[3]

Abstract

Bactrocera xanthodes (Broun) was described in 1905 based on specimens bred from fruit imported into New Zealand from Suva (Fiji), Tonga and Rarotonga (Cook Islands) (Brown 1905). It is classified as a major fruit fly pest species in the South Pacific region because of its ability to inflict heavy crop losses and the trade restrictions applied against crops grown in some countries due to its presence. Morphologically, *B. xanthodes* is a unique species, possessing a transparent shining orange-brown surface on the thorax and abdomen without dark markings, unusual yellow patterns, an unusual scutellum pointed at the bases of the two apical scutellar bristles and a bristle on the postpronotal lobe.

During the Regional Fruit Fly Project (RFFP) and ACIAR projects, field studies revealed some unusual male lure responses and fruit infestation records among populations believed to be *B. xanthodes*. Consequently, taxonomic studies were undertaken to define the various populations especially because of the international trade restrictions imposed against commodities suspected of being *B. xanthodes* hosts. An overview of these studies and results is presented in this paper.

Geographic Distribution, Host Fruit and Male Lure Records of *B. xanthodes*

THE entire *B. xanthodes*-like population in the South Pacific region was believed to be conspecific by Drew (1989) who listed its distribution as Fiji, Western Samoa, Tonga, Cook Islands and Vanuatu. As a result of the RFFP and ACIAR project field surveys, the known *B. xanthodes* geographic distribution has been expanded in some areas and negated in others, but this can only be confirmed through taxonomic studies designed to define sibling species.

The host fruit records reported by Drew (1989) were one wild (*Barringtonia edulis*) and seven edible/commercial (*Citrus* sp., granadilla, guava, papaya, pineapple, tomato, watermelon). The watermelon record is based on a reported recovery from over-ripe fruit in Tonga, December 1985, while the pineapple record must be very uncertain as it refers to some of the original type specimens in 1905 having been reared from this fruit. No adult fly specimens are in existence that can positively confirm these records. Some populations such as those in Vanuatu (D. Tau, personal observation) do not attack edible/commercial fruit.

While *B. xanthodes* is known to respond to methyl eugenol, some populations were observed not to respond to this or any other male attractant. For example, the population in Vanuatu does not respond to any lure (D. Tau, personal observation).

Taxonomic Research on the *B. xanthodes* Complex

The extensive field surveys carried out under the RFFP and ACIAR projects provided specimens from Cook Islands, American Samoa, Western Samoa, Tonga, Fiji, Vanuatu and Nauru. Specimens and information were also provided from New Caledonia, Wallis and Futuna by CIRAD-FLHOR

[1] Faculty of Environmental Sciences, Griffith University, Nathan Campus, Qld, 4111
[2] Regional Fruit Fly Project in the South Pacific, South Pacific Commission, Private Mail Bag, Suva, Fiji
[3] Department of Agriculture and Horticulture, Port Vila, Vanuatu

and Department of Agriculture and Forestry officers. Records of *B. xanthodes* occurring in Niue have not been confirmed due to an absence of specimens for study.

Morphological comparisons revealed that four distinct populations occur, as follows:

B. xanthodes (Broun) — see Drew (1989) for morphological definition.

B. paraxanthodes Drew and Hancock — separated by Drew and Hancock (1995) on the basis of possessing a pale broad costal band confluent with vein R_{4+5} and lateral black lines on the scutellum. It was described from New Caledonia, Vanuatu and Western Samoa. More recent data indicate that this species occurs only in New Caledonia. It has a possible weak attraction to methyl eugenol and does not breed in commercial fruit (R. Amice, pers. commun.)

B. sp. n. No. 1 (near *paraxanthodes*) — possesses a pale broad costal band confluent with vein R_{4+5}, a narrow transverse pale infuscation across the wing from costal band to hind margin and enclosing both cross veins. It has, to date, only been recorded from Western Samoa, does not respond to male lures and has not been recovered from edible/commercial fruit.

B. sp. n. No. 2 (near *paraxanthodes*) — possesses a short narrow costal band confluent with R_{2+3} and ending at extremity of this vein, a small dark fuscous spot at apex of wing (apex of cell r_{4+5}) and extremely pale diffuse colouration on costal margin between apex of costal band and the small apical spot. It is known only from Vanuatu, does not respond to male lures and has not been recorded in edible/commercial fruits.

In addition to the morphological differences, DNA studies have been conducted on specimens from Fiji, Tonga and Vanuatu (Hoeben et al. 1996). These studies have confirmed that the population in Vanuatu is distinct from *B. xanthodes*.

Conclusions

On current information, the *B. xanthodes* species complex consists of four sibling species based on morphological comparisons, host records, geographic distributions and DNA analyses. The species and their geographic distributions are listed in Table 1.

The South Pacific host fruit records for the four species are as follows:

B. xanthodes — 19 edible/commercial hosts; 9 wild hosts.

B. paraxanthodes — One wild host, *Schefflera* sp.

B. sp. n. No. 1 — One wild host, *Ficus* sp.

B. sp. n. No. 2 — Two wild hosts, *Barringtonia edulis* and *Passiflora suberosa*.

Although considerably smaller than the *Bactrocera dorsalis* complex in Southeast Asia (Drew and Hancock 1994), the species in the *B. xanthodes* complex are diagnosed on the basis of similar research methods and characters. The *dorsalis* complex species were identified on the basis of morphology, attractant records, host plant records, DNA studies, pheromone analyses and geographic distributions. It is now clear that throughout the subfamily Dacinae, especially in Southeast Asia and the Pacific region, there are a large number of complexes of sibling species. Many of these still have to be researched and this is essential as most groups contain one or a few economic species.

Significance of this Research

International trade restrictions placed on fresh horticultural commodities suspected of being hosts of *B. xanthodes* now have to be reassessed. It is now known that *B. xanthodes*, the only pest species in the complex, does not occur in Vanuatu and New Caledonia. Only non-pest sibling species occur in these countries and consequently they should be able

Table 1. Distribution of *B. xanthodes* complex in the South Pacific region.

	B. xanthodes	*B. paraxanthodes*	sp. n. No.1	sp. n No. 2
Wallis and Futuna	✓			
Cook Islands	✓			
American Samoa	✓		?	
Western Samoa	✓		✓	
Tonga	✓			
Fiji	✓			
New Caledonia		✓		
Vanuatu				✓
Nauru	✓			
Niue	?			

to export cucurbit crops without having to apply a specific market access technology. More intensive host fruit surveys are still needed in some countries in order to complete the research on the *xanthodes* complex.

References

Broun, T. 1905. Descriptions of three species of fruit flies. Bull. Dep. Agric. NZ, 4: 1–6.

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanian Regions. Memoirs of the Queensland Museum, 26: 1–521.

Drew, R.A.I. and Hancock, D.L. 1994. The *Bactrocera dorsalis* complex of fruit flies (Diptera: Tephritidae: Dacinae) in Asia. Bulletin of Entomological Research, Supplement No. 2, 68 p.

Drew, R.A.I. and Hancock, D.L. 1995. New species, subgenus and records of *Bactrocera* Macquart from the South Pacific (Diptera: Tephritidae: Dacinae). Journal of the Australian Entomological Society, 34: 7–11.

Hoeben, P., Daniel, L.J., Jing Ma and Drew, R.A.I. 1996. The *Bactrocera (Notodacus) xanthodes* (Broun) Species Complex (Diptera: Tephritidae): Comparison of 18S r RNA Sequences from Fiji, Tonga and Vanuatu specimens suggest two distinct strains. Australian Journal of Entomology, 35: 61–64.

Seasonal Abundance of Fruit Flies in New Caledonia

R. Amice[1] and F. Sales[2]

Abstract

The New Caledonia fruit fly research program started in 1994 includes a trapping system and host fruit surveys. The trapping system comprises 41 sites and 120 traps using Cue-lure, methyl eugenol and Trimedlure. The fruit survey has resulted in the collection of 900 samples in the past two years not only from the most important economic fruit but also from a significant range of other cultivated or wild fruits.

Results from these studies show that the most important factors influencing seasonal abundance of fruit flies are temperature, rainfall and host fruit availability. Low temperatures during the cool season are detrimental to fruit fly activity. The hot, dry season also has a negative effect on fruit flies.

THE first recording of fruit flies in New Caledonia was by Cochereau (1970). The current fruit fly research program is funded by the New Caledonia Department of Agriculture and started in 1994. It is conducted by the Pocquereux Research Station, part of CIRAD-FLHOR (Department of Fruits and Horticulture). In fact, some work on fruit flies had already been done by CIRAD from 1990 to 1993 (Anon 1996).

Two components of the program were set up to provide information on the variations of populations of fruit flies and also on their geographic distribution, host range or rates of infestation. These components include a trapping system based on lure traps and a fruit survey of commercial and wild fruit hosts. This paper reports on data obtained from the trapping system and fruit surveys. The seasonal abundance of fruit flies is presented in relation to temperature, host availability and rainfall.

Trapping System

At the end of 1995, the trapping system comprised 41 sites and approximately 120 traps. Seven new sites were added in 1996 in the Nouméa region. Each site is equipped with three Lynfield traps using the three major attractants: Cue-lure, methyl eugenol and Trimedlure. The location of the trap sites is as follows:

Nouméa and suburbs	9
West Coast	22
East Coast	3
Loyalty Islands	7

All traps are cleared at two-week intervals. Lure is filled monthly and cotton wicks changed at two-month intervals. Insecticide (Dichlorvos plates) is also replaced at two-month intervals.

Fruit Surveys

Surveys of commercial and wild host fruits have been carried out since 1990 by the Pocquereux Fruit Research Station. A more intensive collecting was conducted from the second half of 1994. In the past two years, 900 samples have been collected. Fruit samples have been processed identically to those of the Regional Fruit Fly Project:

- filing data and record sheets;
- counting and weighing fruits;
- preparing botanical samples (when needed for wild hosts);
- keeping fruits in incubation for two weeks;
- sieving pupae and putting them in containers for adult emergence;
- counting and identifying adult flies.

Samples of the most important economic fruits have been collected, such as mango, citrus, guava,

[1] Direction de l'Agriculture et de la Foret, B.P. 256, Noumea Cedex, New Caledonia
[2] CIRAD-FLHOR, Station de Recherches Fruitières de Pocquereux, B.P. 32, La Foa, New Caledonia

peach, Annonaceae, Solanaceae and also of common fruits like *Terminalia catappa*, Rose Apple (*Syzygium jambos*). A significant range of native fruits have also been sampled.

A total of about 45 botanical families have been sampled.

Results and Discussion

Trapping data

Data have been collected from traps since 1993 and presented up to the end of 1995. Figures 1 and 2 show the number of flies collected and mean maximum and minimum temperatures. These figures illustrate two regions of different climates and habitats. Figures 3, 4, 5, 6 show data obtained from several regions of New Caledonia. All figures show a marked difference between the fruit fly captures of the cool season and those of the hot and rainy season. In some cases like in La Foa or in the Poya to Voh region (West Coast), the levels of captures are very low during the cool season and very high during the first three months of the year. In Nouméa, the captures show a more regular aspect. These results can be explained by several factors:

Temperature

The New Caledonia climate is characterised by a cool season during which minimum temperatures can be less than 10°C in some areas like La Foa. These low temperatures have a strong effect on fruit fly populations as shown in Figures 1 and 2. Nouméa is located on the coast and has a warmer climate than La Foa which is situated in a valley where cool nights are common. It seems that a threshold of 17–18°C in the minimum temperatures can be related to low populations of fruit flies. This can explain that in Nouméa, fruit fly populations stay all year round at a rather high level, while in La Foa a strong seasonality is observed.

Rainfall

The New Caledonia climate is typically subtropical in having a hot and rainy season from January to March and a dry season from September to November. The cool season shows a slight rise in rainfall after a stop in May. While rainfall has not been plotted in the figures, it is evident that the rainy season associated with the high temperatures of the summer is the primary determinant of the sudden increase of fruit fly populations in the first part of the

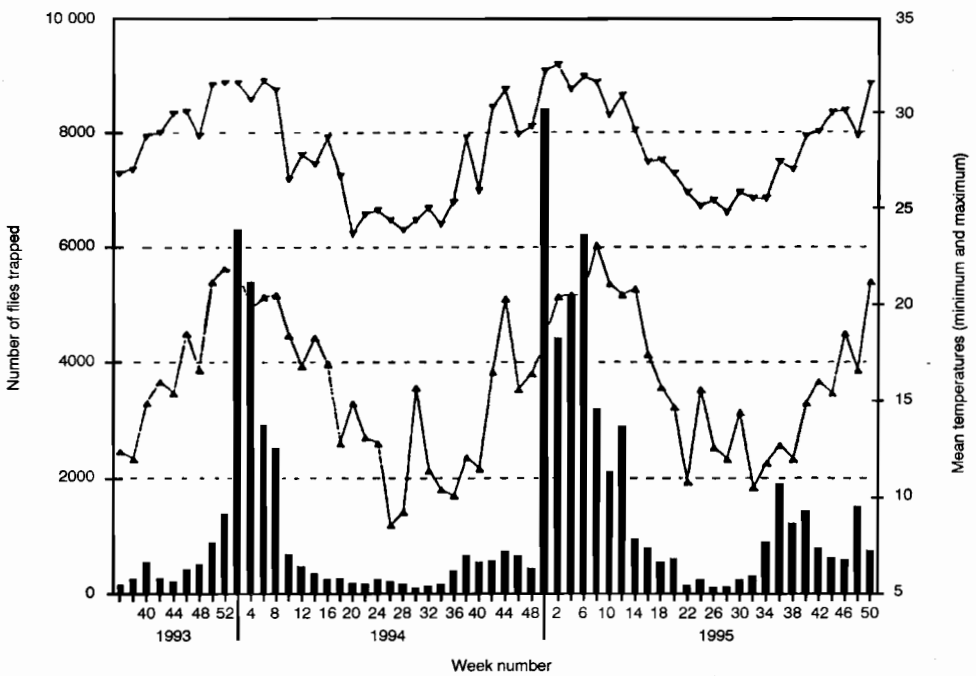


Figure 1. Fruit flies trapped from September 93 to December 95 (number of traps: 21). Town of Noumea.

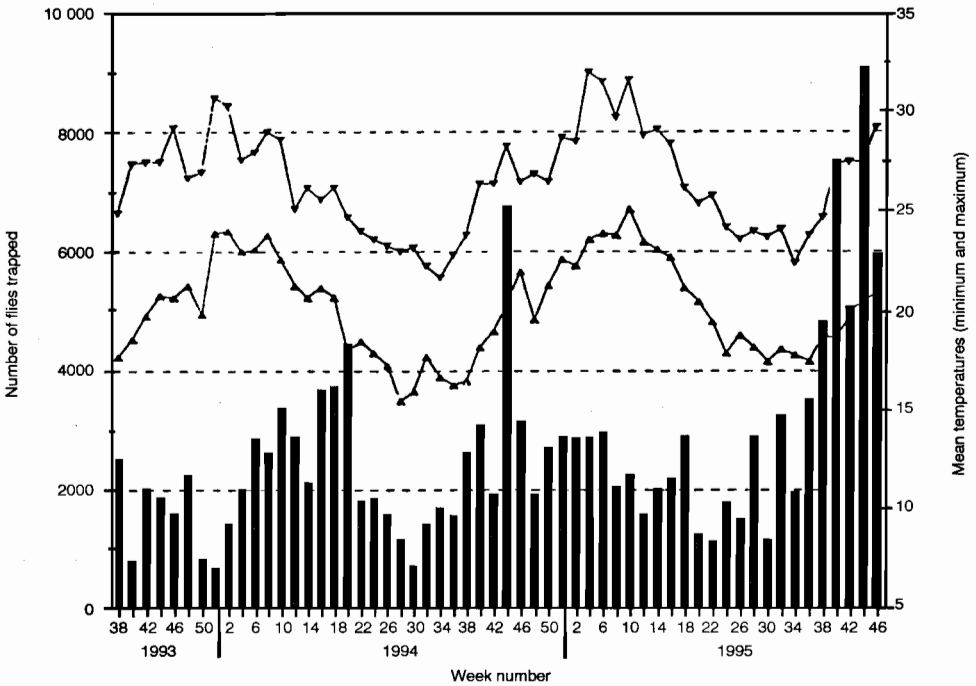


Figure 2. Fruit flies trapped from September 93 to December 95 (number of traps: 12). Region of La Foa.

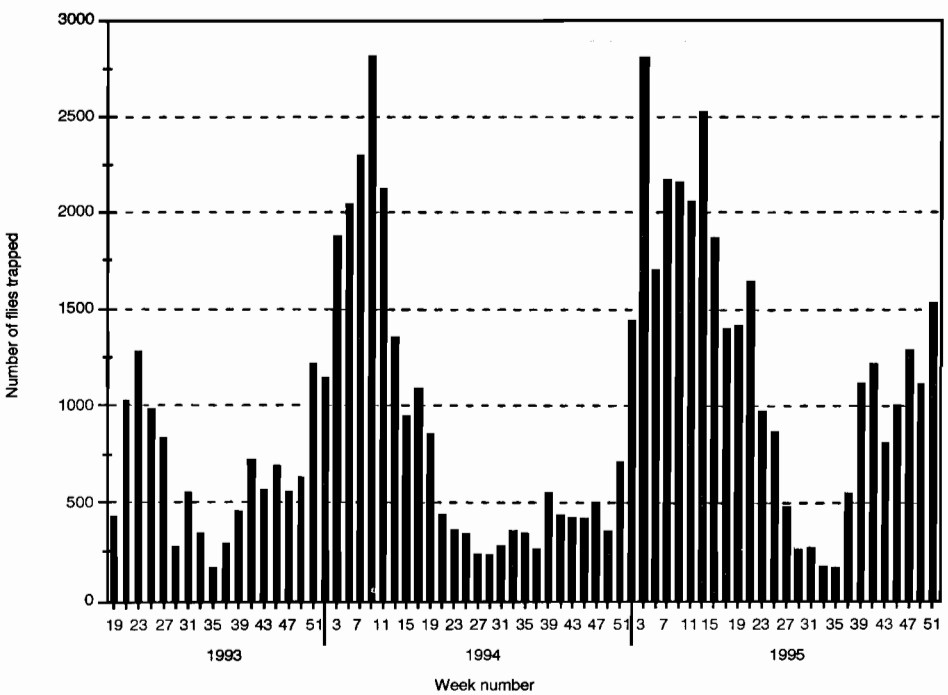


Figure 3. Fruit flies trapped from May 93 to December 95 (number of traps: 24). Region of Mont Dore to Boulouparis (South West).

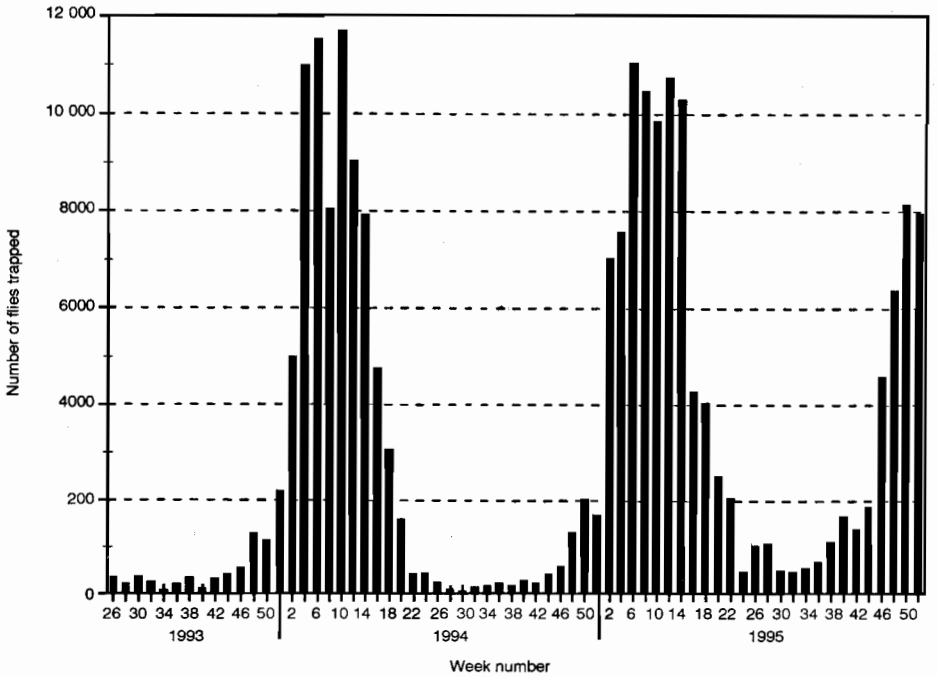


Figure 4. Fruit flies trapped from June 93 to December 95 (number of traps: 12). Region of Poya to Voh (West Coast).

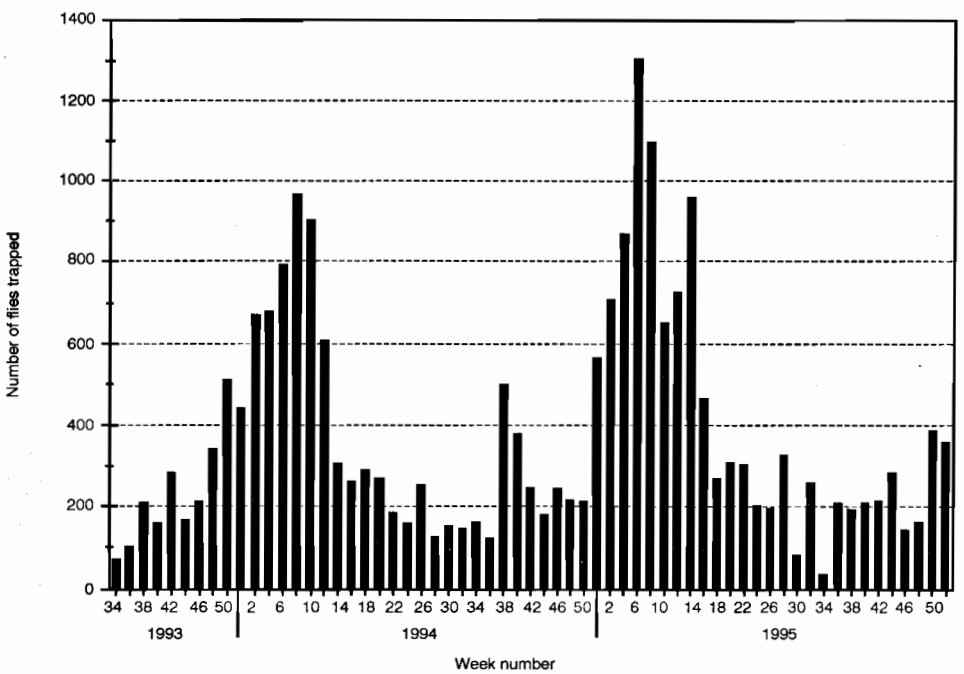


Figure 5. Fruit flies trapped from August 93 to December 95 (number of traps: 9). Region of Houailou to Poindimié (East Coast).

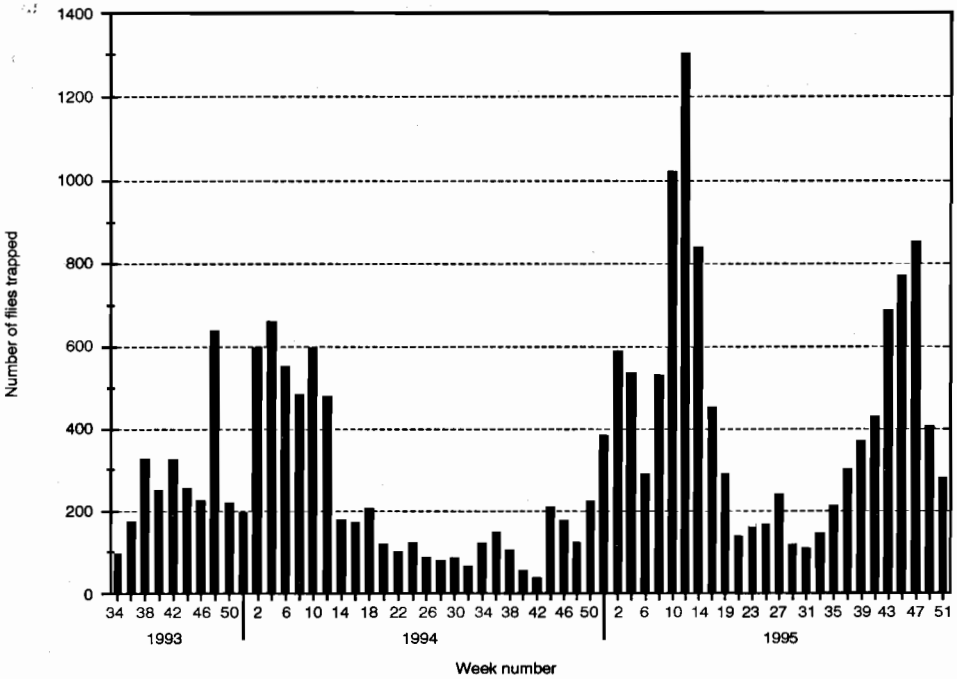


Figure 6. Fruit flies trapped from August 93 to December 95 (number of traps: 9). Region of Tontouta Airport.

year. The peaks in fruit fly populations shown in Figures 1, 3, 4, 5 and 6 coincide with periods of high rainfall. Native fruit flies are probably adapted to respond rapidly to favorable conditions associated with temperature and rainfall.

Fruit surveys

As the intention of the fruit surveys has been primarly the definition of fruit flies' host range, it is not easy to detect reliable variations of population through fruit surveys. However, a sampling was done on peach at Pocquereux Station in 1994.

This survey shows a tendency for higher fruit fly populations towards the end of the peach season, which can be explained by the building up of fruit fly populations through the continuous availability of a highly attractive fruit and also by a rise in temperature during summer.

Host fruit availability

An interesting piece of information gathered from fruit surveys is the host fruit availability during the year. Table 1 indicates availability of common fruit hosts in New Caledonia.

Table 1. Seasonality of fruits in New Caledonia.

Fruit	J	F	M	A	M	J	J	A	S	O	N	D
Mango	■	■	■			■	■	■	■	■	■	■
Citrus	■	■	■	■	■	■	■	■	■	■	■	■
Avocado			■	■	■	■	■					
Peach	■								■	■	■	■
Guava	■	■	■	■	■	■	■	■	■	■	■	■
Breadfruit			■	■	■							
Jackfruit	■							■	■	■	■	■
Syzygium malaccense	■	■	■									
S. jambos	■	■	■									
Terminalia catappa	■	■	■	■	■	■	■	■	■	■	■	■

As expected, many fruits are available early and late in the year corresponding with the hot season. On the other hand, only citrus fruits, guava and *T. catappa* are commonly found during the cool season. This is also true for wild hosts which are mainly found during the hot season.

Host fruit availability certainly plays an important role in the seasonal abundance of fruit flies. The

rather steady fruit fly populations encountered in Nouméa are probably due to the wide range of host fruits available throughout the year. The highly dominant species in Nouméa and other urban areas is *B. tryoni* which has a wide host range. Most endemic fruit fly species have a narrow host range which restricts them to specific habitats (generally native forests). *B. psidii* and *B. curvipennis* can rely on several common fruits to maintain their populations such as guava, mango, *Syzygiums* and *Terminalia catappa*. Being the most adaptable species *B. psidii* develops high populations during the summer outside the habitats favored by *B. tryoni*. La Foa region is a good example.

Conclusion

Fruit fly populations show strong seasonal variations in most regions of New Caledonia except in Nouméa where specific conditions reduce the adverse climatic effects.

Two very important factors influencing fruit fly populations are temperature and rainfall. Low temperatures experienced during the cool season (June, July, August) maintain very low populations. The increase of temperature in summer is responsible (when moisture is available) for high populations.

Rainfall is in many regions the factor which apparently triggers a rapid increase of fruit fly populations in the first three months of the year. The decrease of rainfall and temperature in May is correlated with a quick decrease of fruit fly populations.

Host fruit availability is also an important contributor to seasonal abundance of fruit flies (Drew and Hooper 1983, Drew et al 1984). Most fruits are available during summer in natural or rural habitats. In Nouméa where many fruit hosts occur, fruit fly populations are maintained at a relatively high level throughout the year.

References

Anon. 1996. Station de recherches fruitières de Pocquereux Rapport d'Activité 1995–1996. CIRAD-FLHOR. 45–53.

Cochereau, P. 1970. Les mouches des fruits et leurs parasites dans la zone Indo-Australo-Pacifique et particulièrement en Nouvelle-Calédonie. Cah. ORSTOM, Sér. Biol., n° 12: 15–50.

Drew, R.A.I. and Hooper, G.H.S. 1983. Population studies of fruit flies (Diptera: Tephritidae) in Southeast Queensland. Oecologia (Berlin), 56: 153–159.

Drew, R.A.I., Zalucki, M.P. and Hooper, G.H.S. 1984. Ecological studies of Eastern Australian fruit flies (Diptera: Tephritidae) in their endemic habitat. I Temporal variation in abundance. Oecologia (Berlin) 64: 267–272.

Biology of Melon Fly, with special reference to Solomon Islands

R.G. Hollingsworth[1], M. Vagalo[2] and F. Tsatsia[3]

Abstract

The melon fly *Bactrocera cucurbitae* (Coquillett) is one of the world's most serious pests of vegetable crops, particularly plants in the family Cucurbitaceae. It commonly infests immature fruits and flowers; stems and roots of host plants can also be attacked. It is remarkable for rapid development of larvae, and the long life-span and dispersal ability of adults. Following dispersal to new areas, adults reside in areas where cucurbit crops are cultivated, or in areas of short vegetation where wild cucurbit hosts are common. Melon fly was first detected in the Solomon Islands in 1984. Spreading from Western Province, it is now found in six of the country's nine provinces. Melon fly was first detected on Guadalcanal in November 1995 in the Honiara area. A field study in this area revealed that catches of melon fly in Cue-lure traps were low but stable. The fruit of a wild cucurbit vine was the most important melon fly host in the town area. Cucumber was the only other host recorded. No melon flies were reared from tomato or papaya. There is a plan to introduce a parasitoid, *Psyttalia fletcheri* (Silvestri), from Hawaii to reduce populations of this pest.

THE melon fly *Bactrocera cucurbitae* (Coquillett) is possibly the world's worst fruit fly pest of vegetable crops, particularly cucurbits. It is widely distributed in Asia, where it is endemic, also in Mauritius and Réunion (Indian Ocean), in Egypt, Kenya, and Tanzania (Africa) and in the Pacific. In the Pacific, it is found in the following places (followed by the date of first detection): Hawaii (1895), Guam (1936) and several other islands in the Marianas group, throughout New Guinea and the Bismarck Archipelago (1980), Nauru (1982) and in six of the nine provinces in the Solomon Islands by 1995 (Waterhouse 1993; Drew et al. 1982; Drew 1989; Eta 1985 and authors' unpublished data).

B. cucurbitae primarily infests cucurbit crops (e.g. cucumber *Cucumis sativus*, watermelons *Citrullus lanatus*, squash and pumpkin (varieties of *Cucurbita pepo*). However, it is recorded from 125 plants, including members of families not related to Cucurbitaceae (White and Elson-Harris 1992). Non-cucurbit hosts include: quince (*Cydonia oblonga*) and tomato (*Lycopersicon esculentum*) (Pakistan); pummelo (*Citrus maxima*), yard-long bean (*Vigna unguiculata*), and garden bean (*Phaseolus vulgaris*) (Malaysia); jackfruit (*Artocarpus heterophyllus*) and water apple (*Syzygium samarangense*) (South-east Asia and Borneo); limeberry (*Triphasia trifolia*) (Marianas); avocado (*Persea americana*), common fig (*Ficus carica*), granadilla (*Passiflora* sp.), Hinds' walnut (*Fuglans hindsii*), mango (*Mangifera indica*), papaya (*Carica papaya*), peach (*Prunus persica*), sweet orange (*Citrus sinensis*), tree tomato (*Cyphomandra crassicaulis*), buds of *Sesbania grandiflora*, and stems of kai choy (a variety of *Brassica juncea*) (Hawaii). This list excludes hosts for which additional confirmation is required (White and Elson-Harris 1992).

In Hawaii, melon fly is a serious pest of watermelon, cantaloupe, pumpkin, squash, cucumber, tomato, capsicum, beans and passion fruit (Harris and Lee 1989 as cited in Waterhouse 1993). In common with some other species in the subgenus *Bactrocera* (*Zeugodacus*), it sometimes infests flowers, stems, or roots in addition to fruits. Favoured wild hosts of melon flies in Hawaii and in other parts of the Pacific are melons in the genus *Momordica*.

[1] United Nations volunteer entomologist
[2] Senior entomologist
[3] Assistant research officer
Dodo Creek Research Station, PO Box G13, Ministry of Agriculture and Fisheries, Honiara, Solomon Islands

Although the host record for melon fly is extensive, it should be remembered that cucurbit crops (and tomato, in Hawaii) are by far the most common commercial hosts. In the South Pacific region, melon fly has been recorded from cucumber, marrow (a variety of *Cucurbita pepo*), pumpkin, watermelon, and snake gourd (White and Elson-Harris 1992; Bateman 1989). In the Solomon Islands, melon fly was reared from papaya in 1994, but this record must be treated with caution, as the fruit sample was transported to the lab in the same bag with melon fly-infested snake gourd. In the Honiara area (Guadalcanal), melon fly has been reared from only two hosts: cucumber and the fruit of a wild cucurbit vine, *Coccinea grandis*, which is commonly found growing on fences in the town area.

Biology and Behavior of Melon Fly

The developmental biology and behavior of melon fly have been reviewed by Waterhouse (1993). Eggs hatch in a little over 24 hours. Larval and pupal development under optimal conditions is rapid in relation to many other fruit fly species. Time from egg to pupation is about 5 days in zucchini, and the pupal period is about 7 days. The pre-oviposition period is 11-12 days, and mating occurs at dusk. Females lay 1–40 relatively large eggs in selected fruits. Females use no marking pheromones to discourage oviposition by other female melon flies. During its lifetime, a female may lay more than 1000 eggs. Females are long-lived, normally up to 150 days, but living from 240 to 460 days under cool conditions. Shortly after emergence, adults typically disperse to new areas. Long-range dispersal can be triggered in unfavorable habitats. In the Marianas, long-range dispersal up to 65 km has been documented. In Japan, melon flies migrated 265 km over open water (Waterhouse 1993). After dispersal, female melon flies move into cucurbit fields during the day to oviposit, returning to surrounding vegetation before nightfall. Egg-laying peaks occur in the morning and afternoon (Nishida and Bess 1957 as cited in Waterhouse 1993).

Melon fly catches in traps are usually concentrated in crop production areas (in the vicinity of host plants) and in areas of short vegetation where wild cucurbit hosts flourish. Melon fly catches in forested areas are usually very low (Vargas et al. 1989; Vijaysegaran and Osman 1992; Johnson 1988).

Biological Control

Psyttalia fletcheri, a braconid wasp, was introduced from India to Hawaii in 1915–1916 for the control of melon fly. It proved a remarkable success, parasitising up to 100% of melon fly larvae in wild *Momordica* melons, and up to 50% of larvae in commercial crops. However, by the early 1950s, the level of parasitisation in *Momordica* fruits was less than 50%, and parasite recovery in commercial fruits was virtually nil (Waterhouse 1993). Nishida (1955) (as cited in Waterhouse 1993) suggested a decrease in the amount of uncultivated land where *Momordica* grew might have disrupted biological control by *P. fletcheri*.

The authors hope to import *P. fletcheri* from Hawaii to the Solomon Islands in early 1997 for release of melon fly in the Honiara area and at selected sites in Western Province. In preparation for this, a colony of melon fly has been established in Honiara.

History of Melon Fly Detection and Spread in Solomon Islands

Melon fly was first detected in Solomon Islands in 1984, in Maliae village (Shortland Islands group) (Eta 1985). Presumably melon fly arrived in Western Province from adjacent Bougainville (PNG). In early 1985, melon fly was eradicated from Maliae village via an intensive protein bait spray program lasting 3½ months. Although the operation was a technical success, a trapping survey conducted during the same year revealed that melon fly was already established on Kolombangara and Ghizo Islands in Western Province, and in northern Choiseul. In response, the Solomon Islands government requested the assistance of US AID, who brought in Dr Victor Johnson to direct a nation-wide survey for melon fly using Cue-lure traps. Johnson (1988) found that melon fly infestation was general in Western Province, and also on Choiseul Island. No catches of melon flies were made on islands to the southeast. However, by March 1988, melon fly was detected in Isabel, a large island directly southeast of Choiseul (Williams et al. 1990). Melon fly was detected in Central Province (Russell Islands) in 1994, and in Malaita and Guadalcanal by 1995. As of October 1996, melon fly is known to be present in all but three of the nine provinces of Solomon Islands. These three provinces include Rennell/Bellona, Makira, and Temotu. The orderly pattern of melon fly spread through the Solomon Islands chain (from northwest to southeast) suggests that melon fly is moving between islands without the aid of humans. Except for the islands of Temotu Province, all major islands in the Solomons are less than 75 km from their nearest neighbours. Given the remarkable dispersal ability of the melon fly (reportedly up to 265 km), it seems likely that melon fly will eventually

spread to all provinces except Temotu (400 km to the east of Makira Province).

Melon fly was detected in Honiara (Guadalcanal) in November 1995, via the collection of ripe fruit of *Coccinea grandis*. Protein bait spraying within the infested area (about 6 km^2) was carried out for several months beginning in December 1995. Bait spraying was abandoned in early February 1996, following a majority decision by members of the Coordinating Committee of the Regional Fruit Fly Project not to pursue a full-scale eradication program. Reasons for not attempting eradication included considerations of cost and the probability of reintroduction of melon fly from other provinces.

Hosts and Pest Status of Melon Fly in Solomon Islands

In his 1988 report, Johnson (1988) stated that the only fruits serving as hosts for melon fly in Western Province were cucumber, snake gourd, immature watermelons and immature pumpkins. According to Johnson, the presence of melon fly caused many villagers to give up cucurbit cultivation. In Gizo, where cucurbit cultivation had been abandoned, melon fly trap catches averaged about 25 flies per week. By contrast, at a mission training school on Kolombangara Island, Johnson collected >500 melon flies over a 5-day period.

Johnson wrote that a 'knowledgeable local botanist' informed him that the only wild cucurbit in the Solomons was a variety of bitter melon, apparently introduced by the Chinese, found chiefly in the Honiara town area. No mention was made of another cucurbit vine, *Coccinea grandis*, now very common on fences in the Honiara town area. This smooth-skinned fruit is similar in general shape to cucumber, but smaller. Mature fruits are usually 6–8 cm in length. When ripe, fruits and flesh are bright red. Fruit collection records show it is a very good host for melon fly.

Dr C. Williams, a former entomologist at Dodo Creek Research Station in Guadalcanal, made a two-week tour of Western Province in 1989 to gather some first-hand information about the pest status of melon fly. Williams noted that trap catches of melon flies were low except where flies multiplied on nearby cucurbit plantings. Melon fly attack was low on cultivated cucurbits in thinly populated areas. However, in an area of intensive cucurbit production on Kolombangara Island, a high percentage of cucurbits were infested. Average attack levels at eight garden/homestead sites ranged from 7% to 70% (Williams et al. 1990). No melon flies were recovered from citrus, Malay apple, carambola, papaya, long bean, tomato or eggplant (Williams et al. 1990).

Observations in an isolated area in Western Province during 1996 agree with the findings of Williams et al. (1990) that melon fly populations are low in areas where cucurbit hosts are not available. The authors first visited St. Dominic's Rural Training Centre at Vanga Point (Kolombangara) in March. Although large areas were in cultivation, none of the cucurbit plants in the area had fruits. During the year, melon fly populations gradually increased, apparently in response to availability of cucurbit fruits. Infested cucurbit fruits were found in June, and soon after, the authors began collecting melon flies from Cue-lure traps. By the end of September, the melon fly population was very high at Vanga Point, as evidenced by the high proportions of melon flies in traps (about 95% melon fly, 5% mango fly). Observations at Vanga Point suggest that farmers in isolated areas should be able to escape melon fly problems by practicing a host-free period.

Since April 1996, melon fly populations have been monitored in the Honiara area via seven Cue-lure traps (500 metres apart along a transect line). Traps were cleared every two weeks, at which time representative samples of mature and ripe fruits in the immediate area were collected, counted, and weighed. Fruits were set up on sawdust to rear any fruit flies infesting the fruits. Melon flies were reared only from cucumbers and the fruit of a wild cucurbit vine (previously mentioned) (Table 1). No melon flies were reared from tomatoes or papaya. The fruit from the wild cucurbit species was by far the most important host of melon fly in the Honiara area. The amount of ripe fruit sampled every two weeks from wild cucurbit plants is a rough index of the amount of fruit locally available for melon fly reproduction. In Figure 1, the total weight of fruit samples from seven sampling sites is plotted over time, together with the number of melon flies caught in Cue-lure traps at these same locations. The results suggest that fluctuations in melon fly populations follow fluctuations in fruit availability with a lag time of about four weeks. This lag is expected due to time required for development of melon flies from eggs to adults (about two weeks) plus another 10–11 days before male flies reach sexual maturity (at which time Cue-lure would be most attractive). This study shows the importance of this wild cucurbit species for sustaining melon fly populations in the Honiara area. This host plant may be present in other Pacific countries where melon fly is absent. If so, quarantine personnel should consider increasing quarantine surveillance activities in areas where this plant grows.

Table 1. Fruit collections made in the Honiara area between April and September 1996 to determine the main hosts of melon fly. Fruits were collected at two week intervals at seven sites, within the immediate vicinities of Cue-lure traps.

Fruit	No. fruits	Total wt. (g)	No. samples	No. samples with fruit flies	Fruit fly species	Total no. flies
Wild cucurbit	547	5932	53	28	*Bactrocera cucurbitae*	569
Cucumber	9	1378	4	2	*Bactrocera cucurbitae*	7
Mango	16	2225	6	3	*Bactrocera frauenfeldi*	90
Papaya	14	3781	13	6	*Bactrocera frauenfeldi*	232
Guava	28	640	6	2	*Bactrocera frauenfeldi*	33
Tomato	30	859	3	0		
Capsicum	15	305	3	0		

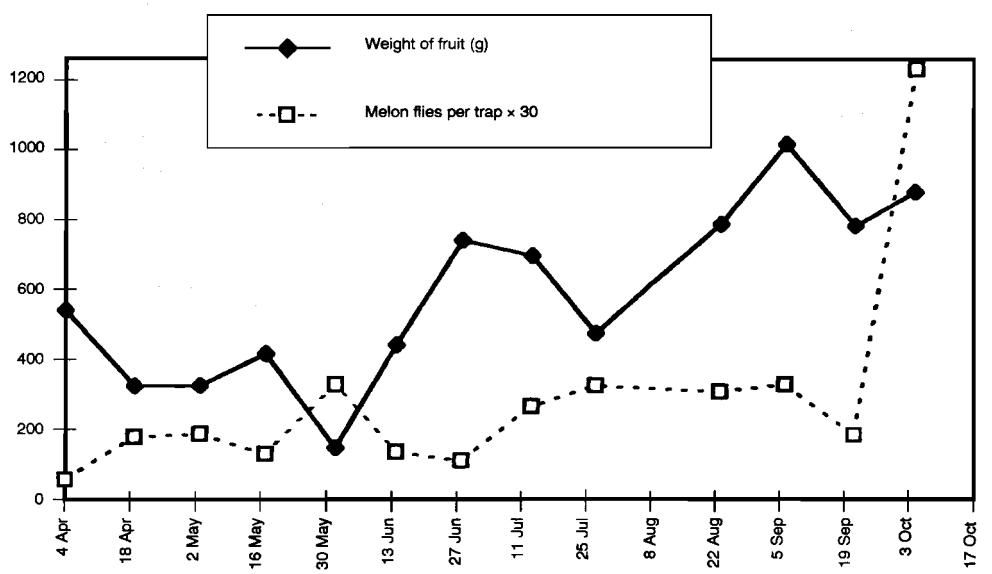


Figure 1. Average number of melon flies in seven Cue-lure traps and sample weights for wild cucurbit fruits collected every two weeks in the Honiara area.

References

Bateman, M.A. 1989. A report on the tropical fruit flies of the South Pacific region. South Pacific Commission, Plant Protection Service. 32 p.

Eta, C.R. 1985. Eradication of the melon fly from Shortland Islands, Western Province, Solomon Islands (special report). Solomon Islands Agricultural Quarantine Service, Annual report. Ministry of Agriculture and Lands, Honiara, 14–23.

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanean regions. Memoirs of the Queensland Museum, Brisbane, Australia, 26: 1–151.

Drew, R.A.I., Hooper, G.H.S. and Bateman, M.A. 1982. Economic fruit flies of the South Pacific region. 2nd edition. Department of Primary Industries, Brisbane, Queensland.

Harris, E.J. and Lee, C.Y. 1989. Influence of bitter melon, *Momordica charantia* L. (Cucurbitaceae) on distribution of melon fly, *Dacus cucurbitae* Coquillet (Diptera: Tephritidae) on the island of Molokai, Hawaii. Proceedings of the Hawaiian Entomological Society 29: 49–56.

Johnson, V. 1988. Survey of melon fly in the Solomon Islands, final report. Internal report, Agricultural Quarantine Service, Solomon Islands Goverment.

Nishida, T. 1955. Natural enemies of the melon fly, *Dacus cucurbitae* Coq. in Hawaii. Annals of the Entomological Society of America, 48: 171–178.

Nishida, T. and Bess, H.A. 1957. Studies on the ecology and control of the melon fly Dacus (Strumeta) cucurbitae. Hawaii Agricultural Experiment Station, University of Hawaii Technical Bulletin 34: 1–44.

Vargas, R.I., Stark, J.D. and Nishida, T. 1989. Abundance, distribution, and dispersion indices of the oriental fruit fly and melon fly (Diptera: Tephritidae) on Kauai, Hawaiian Islands. Journal of Economic Entomology 82: 1609–1615.

Vijaysegaran, S. and Osman, M.S. 1992. Fruit flies in Peninsular Malaysia: their economic importance and control strategies. Technical Bulletin of the Food and Fertilizer Technology Center of the Asian and Pacific Council, Taipei City, Taiwan, 8–14.

Waterhouse, D.F. 1993. Biological control: Pacific prospects. Supplement 2. Australian Centre for International Agricultural Research, Canberra. Monograph No. 20, 138 p.

White, I.M. and Elson-Harris, M.M. 1992. Fruit flies of economic significance: their identification and bionomics. CAB International (Wallingford, Oxon, UK) with the Australian Centre for International Agricultural Research. 601 p.

Williams, C., Vagalo, M., Tsatsia, F. and Pauku, R. 1990. Entomology section report 1987–1990 (Dodo Creek Research Station). Internal report of the Research Division, Ministry of Agriculture and Lands, Solomon Islands.

Laboratory-rearing Techniques for Tephritid Fruit Flies in the South Pacific

G.P. Walker[1], E. Tora Vueti[1], E.L. Hamacek[2] and A.J. Allwood[3]

Abstract

Laboratory colonies of 15 economically important species of multi-host fruit flies (Diptera: Tephritidae) have been established in eight South Pacific island countries for the purpose of undertaking biological studies, particularly host status testing and research on quarantine treatments. Laboratory rearing techniques are based on the development of artificial diets for larvae consisting predominately of the pulp of locally available fruits including pawpaw, breadfruit and banana. The pawpaw diet is the standard diet and is used in seven countries for rearing 11 species. Diet ingredients are standard proportions of fruit pulp, hydrolysed protein and a bacterial and fungal inhibitor. The diet is particularly suitable for post-harvest treatment studies when larvae of known age are required. Another major development in the laboratory rearing system is the use of pure strains of *Enterobacteriaceae* bacterial cultures as important adult-feeding supplements. These bacterial cultures are dissected out of the crop of wild females, isolated by sub-culturing, and identified before supply to adults on peptone yeast extract agar plates. Most species are egged using thin, plastic receptacles perforated with 1 mm oviposition holes, with fruit juice or larval diet smeared internally as an oviposition stimulant. Laboratory rearing techniques have been standardised for all of the Pacific countries. Quality control monitoring is based on acceptable ranges in per cent egg hatch, pupal weight and pupal mortality. Colonies are rejuvenated every 6 to 12 months by crossing wild males with laboratory-reared females and vice versa. The standard rearing techniques, equipment and ingredients used in collecting, establishment, maintenance and quality control of these fruit fly species are detailed in this paper.

In laboratory rearing of tephritid fruit flies, the technical breakthrough that allowed high yields of pupae from larval diets was the introduction of dehydrated plant materials (i.e. carrot powder) and dry yeasts (Tsitsipis 1989). In Hawaii, the mass rearing programs for fruit flies have been based on the use of protein hydrolysate to promote egg production and on low cost, nutritious larval diets. These developments have made it possible to obtain high reproduction rates under controlled environments. However, in many instances insect quality has declined when increased numbers are produced (Vargas 1989), for example, when many millions of flies are required for eradication programs.

In 1990, the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project (RFFP) commenced in the South Pacific. A major objective was to undertake biological studies on the economically important multi-host species of fruit flies (Diptera: Tephritidae), particularly research on host status testing and quarantine treatments for locally produced fruits and vegetables. For these studies, a prerequisite was the supply of good quality fruit fly of specific life stages.

In the past six years, laboratory colonies of 15 economically important species have been established (Table 1). One or more of these species are maintained in each of eight South Pacific island countries. Seven of these countries are participants in the RFFP-Cook Islands, Fiji, Tonga, Western Samoa, Solomon Islands, Vanuatu and Federated States of Micronesia (FSM). The other country involved in

[1]Ministry of Agriculture, Fisheries and Forests, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2]Queensland Department of Primary Industries, Plant Protection Unit, 80 Meiers Rd, Indooroopilly, 4068, Queensland, Australia
[3]Regional Fruit Fly Project, South Pacific Commission, Private Mail Bag, Suva, Fiji

this type of research is New Caledonia. The emphasis while maintaining these colonies was low cost, simplicity and the use of local materials wherever possible. The basis of this has been the development of good quality artificial larval diets for which the major ingredient has been locally available fruits. The pawpaw diet is the standard diet and is used in seven countries for rearing 11 species. The diet is particularly suitable for post-harvest treatment studies when larvae of known age are required.

Table 1. Tephritid fruit fly species reared on artificial diets in the South Pacific.

Country	Fruit fly species	Artificial diet
Cook Islands	*Bactrocera melanotus* (Coquillett)	Pawpaw
Cook Islands	*B. xanthodes* (Broun)	Pawpaw
Fiji	*B. passiflorae* (Froggatt)	Pawpaw
Fiji	*B. xanthodes*	Pawpaw
Western Samoa	*B. kirki* (Froggatt)	Pawpaw
Western Samoa	*B. xanthodes*	Pawpaw
Tonga	*B. facialis* (Coquillett)	Pawpaw
Tonga	*B. kirki*	Pawpaw
Tonga	*B. xanthodes*	Pawpaw
New Caledonia	*B. tryoni* (Froggatt)	Banana
New Caledonia	*B. psidii* (Froggatt)	Banana
New Caledonia	*B. curvipennis* (Froggatt)	Banana
New Caledonia	*B. umbrosa* (Walker)	Potato/carrot
Federated States of Micronesia	*B. frauenfeldi* (Schiner)	Pawpaw
Solomon Islands	*B. cucurbitae* (Coquillett)	Pawpaw
Solomon Islands	*B. frauenfeldi*	Pawpaw
Solomon Islands	*B. umbrosa*	Breadfruit
Solomon Islands	*Dacus solomonensis*	Whole fruit
Vanuatu	*B. trilineola* (Drew)	Pawpaw
Vanuatu	*B. minuta* (Drew)	Pawpaw
Vanuatu	*B. paraxanthodes* (Drew)	Pawpaw
Vanuatu	*B. quadrisetosa* (Drew)	Pawpaw
Vanuatu	*B. umbrosa*	Breadfruit

Another major development in producing high quality fruit fly colonies in these countries is the use of pure strains of bacterial cultures (family *Enterobacteriaceae*) as important adult-feeding supplements. Drew and Lloyd (1989) consider that bacteria comprise proteinaceous food for adult fruit flies and probably larvae. The 'fruit fly type' bacteria are isolated by dissecting out the crops from wild females, sub-cultured and routinely fed to caged adults. These two new developments — the use of a larval diet consisting mainly of raw fruit pulp and *Enterobacteriaceae* as adult food — have proven to be extremely successful. Healthy colonies have been maintained in Fiji for more than five years with little difficulty. The colonies are rejuvenated every 6 to 12 months by the incorporation of wild flies to ensure laboratory colonies are genetically similar to wild populations.

Systematic measures of quality of the laboratory colonies have been implemented because, as Boller et al. (1981) comment, to produce the required quality of fly the average and variation in production and performance criteria must be monitored in the laboratory. Leppla (1989) maintains that the value of insect colonies depends on the conditions under which they are established and the precision with which they are managed.

This paper describes the rearing facilities and standard techniques that have been developed for the economically important fruit fly species in these subtropical, small island countries and are predominately based on work in Fiji and Cook Islands from 1990. The techniques include collecting, establishing, maintaining and monitoring the quality of these multi-host species for research when laboratory colonies capable of laying about 30 000 eggs in 5–6 hours are required.

Collecting

Vigorous fruit fly colonies of the economic species present in a region are best established by collecting as many individuals from as many different hosts and habitats as possible because, as Mackauer (1976) comments, the evolutionary potential of a laboratory population is essentially determined when the breeding stock is isolated from the field. This can be achieved by collecting as many ripe host fruits and vegetables as possible and setting up as for collection of pupae (see later) with drainage for wet fruit to prevent larvae from drowning. Collections at different times of the day and year are also recommended (Leppla 1989). Resultant pupae should be placed in a small emergence cage containing water and sugar and emerging adults identified and transferred to a separate culturing cage as they emerge. This process will eliminate other insects that may emerge from the fruit, including other fruit fly species and possible parasitoids. Every effort must be made to minimise mortality during this process.

Establishment

The major population bottleneck in laboratory rearing usually occurs within three to five generations of the collections being established, particularly the first generation (Leppla 1989). To preserve the genetic variability of the colony every effort must be made to minimise this mortality. High mortality can be avoided by not overcrowding the flies, which causes stress-related mortality, by providing excess food and by avoiding temperatures above 30 °C. In

the initial stages of establishment it is better to use small cages (about 20 × 35 × 25 cm) and combine as many adults from different hosts or habitats together, after identification of the fruit fly species, to maximise the number of males and females reproducing, yet avoiding overcrowding. Adults of similar age (within 2–3 weeks) should be combined in the same cage and as the numbers are increased into the 100s, all the adults should be transferred to larger cages (50 × 50 × 50 cm). Colonies should be increased to 5–6 large cages for each species required for research purposes, with each cage containing 5000–10 000 flies.

Whole fruit rearing

If a good diet has not yet been developed for the species being reared, or adult numbers collected from the field are low, whole fruit may be used to establish the colony. This alternative requires collecting preferred host fruit before it is infested (e.g. pawpaw before colour break) or protecting fruit to ensure it is not infested before use. The whole-fruit egging system requires spiking the fruit with a number of small 1 mm holes (number depends on the number of females and size of fruit) and ensuring sufficient fruit for each larva (2 g per larva). One female may oviposit 10–50 eggs in 24 hours so enough weight of fruit must be provided to sustain the possible number of larvae. Fruit should be set up with drainage to ensure larvae do not drown in liquid.

Maintenance

Maintaining viable fruit fly colonies is a matter of careful rearing, diligent monitoring of quality control, and periodic strain restoration or replacement (Leppla 1989). Leppla also notes that colonies evolve rapidly and then remain relatively stable if rearing techniques are not changed. Rossler (1975) considered that replenishment of a Medfly colony was possible and preferable to total replacement, while Leppla (1984) commented that the success of strain maintenance strategies (i.e. the frequency and degree of restoration or replacement) depended on the quality of the mass production system.

There is severe selection pressure during laboratory mass-rearing with consequent rapid adaptation of fruit flies to artificial rearing regimes. To ensure the colony remains biologically similar to the wild populations, the colonies are regularly rejuvenated by crossing wild males exclusively with laboratory-reared females and at the same time crossing the wild females with laboratory-reared males every 6 to 12 months. This is a labour intensive task but it is an integral part of rearing maintenance. Field collected host fruit are set up as for collecting and adult males aspirated out daily and placed in a cage containing only laboratory females and vice versa. Adult density is maximised to promote mating (without overcrowding). All new cages are set up with the progeny of these two cages with flies from older cages discarded once a healthy, 'new' colony is achieved (at about three cages, each with 5000 adult flies).

The details of technical aspects of laboratory rearing are described below and are based on methods mainly undertaken in Fiji but which are used for most of the fruit fly species listed in Table 1.

Requirements and Procedures for Different Life Cycle Stages

Rearing facilities

The maintenance of fruit fly laboratory colonies requires a secure area (room or building) with natural lighting although facilities should be supplemented with artificial lighting, usually in the form of 1 or 2 banks of fluorescent tube lighting. Artificial lighting should be attached to a time switch to ensure a 'natural' dawn and dusk, which is important for mating of most species. Thus, lights should turn on about one hour after dawn and turn off one hour before dusk. *B. kirki* in Tonga, however, responds better to longer days and very strong lighting. Some species mate during the day (e.g. *B. melanotus* and *B. psidii*) and perform better under natural light (G. Clare, pers. comm.).

The area must be secure from outside agents such as rats, and all efforts should be made to restrict ants and *Drosophila* species (vinegar flies) from the rearing room, thus fine insect screening should cover all windows and entrances. The internal area must have large benches that are ant-proof, which is usually achieved by placing water or oil traps under the bench stands. The whole area must be completely free of pesticide contamination or spray drift at all times. The area should have a temperature range of about 25–28 °C. This may require air conditioning especially if temperatures exceed 30 °C. Some countries require heating in winter to maintain an optimum temperature range.

Adults

Colonies should consist of 5–6 cages each containing 5000–10 000 adults of known age and quality. Eggs are laid after an initial pre-oviposition period of 2–4 weeks, depending on the species. After this period, eggs may be collected by allowing females to oviposit into fruit or artificial domes. At the peak of

production (weeks 4–7) good cages should produce 50 000 eggs in a 24-hour period and support egging three times weekly. These eggs must be produced without affecting normal colony maintenance requirements. Cages are discarded when there is significant mortality, usually after about 8–9 weeks.

Cages

Large colony cages (approx. 50 x 50 x 50 cm) can be made using frames of aluminium rod lengths with small, drilled plastic corners, or alternatively by using PVC water piping. These materials are relatively cheap, easy to clean and are also easy to dismantle and transport if required. Synthetic gauze used as a cage cover should have mesh holes small enough to keep ants and *Drosophila* out. The cage cover is sewn with an extended open sleeve on one side to allow easy access.

Adult food

Adult fruit flies can survive on sugar and water alone and this should be supplied in cages as the adults emerge. Water is supplied using a sealed container with a sponge wick and sugar is made available in granulated form on tissue which absorbs any excess moisture. At least two water and sugar sources should be continuously available in each cage. Water sources should be cleaned and replaced weekly.

Protein for adults

A few days after emergence, the females require a source of protein for egg maturation, and this is supplied in the form of enzymatic yeast hydrolysate. Hydrolysed yeast and sugar is normally mixed in a ratio of 1:3 with a minimum of water to make a thick paste which is plastered onto cards. A number of these cards are hung from the top of the cage, ensuring that the adults do not get trapped in the sticky mixture. Adults may perform better with extra nutrients and these can be supplied in the form of mineral (e.g. Wessons salts) and vitamin mixes (e.g. Vanderzant general insect vitamin mix) or added protein (e.g. dried egg yolk).

Bacteria for adults

Bactrocera species of fruit flies have a specific group of bacteria (family Enterobacteriaceae) associated with them which are important for both adult and larval development and are supplied to adult cages. A number of bacteria species are used in the region, but the one most commonly associated with the fruit fly species reared in the South Pacific is *Klebsiella oxytoca*. The bacterium is isolated by dissecting out the crop of wild female flies. Male flies are also a source of this bacterium, as are larvae in fruit which yielded a pure culture in Tonga (GPW, pers. observ.). Crop contents are smeared onto sterilised peptone yeast extract (PYE) agar plates and the bacteria sub-cultured until a pure culture is obtained (details on preparing agar plates and smearing techniques may be found in Walker and Hamacek 1992). This culture must be checked for purity and identified by a microbiologist before being sub-cultured again onto PYE agar plates for feeding to adult flies. The agar plates, with at least two days of bacterial growth, are supplied twice weekly to new cages by inverting the plates on top of the cages and loosening the agar so that it drops onto the cage cover. Adult dissections and bacterial smears should be undertaken in sterile conditions and utensils sterilised with ethyl alcohol or by flaming.

Eggs

Eggs are collected after the pre-oviposition period by placing artificial or fruit dome egging devices in cages where flies are about 3–7 weeks old.

Fruit domes

Fruit domes are produced by cutting the fruit in half and piercing the skin with a 1 mm diameter needle 30–100 times, depending on the size of the fruit and the number of females in the cage. The flesh is scooped out leaving as little flesh as possible on the skin. Domes are washed and sealed onto a petri dish or equivalent with moistened filter paper to prevent flies from entering the dome. Wet filter paper should be placed inside to keep the domes as moist as possible.

Artificial domes

Various artificial egging devices have been developed locally, but most consist of a thin plastic receptacle perforated with oviposition holes and containing a natural oviposition stimulant. Preparation of this device is a standard procedure. Small (1 mm) holes should be punctured in the sides of the receptacle. Host fruit pulp or larval diet should then be smeared onto the inside of the container. Juice is pushed through the holes and then excess material inside the container wiped away. The container should be sealed onto a petri dish with moist tissue. Wet tissue or sponge should be placed inside the artificial dome to maintain maximum humidity. The eggs must **never** become dry. Diluted host fruit juice (10:1, water:juice) saturated into cellulose sponge placed inside the dome may improve oviposition (Vargas et al. 1993).

Collecting and counting eggs

Eggs are collected by washing out the dome with water using a hand sprayer, or if using fruit domes, washing and then teasing egg bundles out of flesh with a scalpel or probe, or squeezing flesh gently with soft forceps. Egg numbers are estimated volumetrically by counting a measured sub-sample of eggs (e.g. one drop or a marked volume on a pipette) on moistened black filter paper.

Egg hatch test

An egg hatch test should be set up whenever egging is undertaken. At least 100 eggs are pipetted onto moistened black filter paper and held in a petri dish sealed in an air-tight container. Eggs must remain moist at all times. Percentage egg hatch is recorded after about three days.

Egg/diet ratio and seeding diet

Eggs should be dispensed onto diet at a known ratio of numbers of eggs to weight of diet to ensure an excess of food for the larvae. This ratio should be 2 eggs per 1 g of diet when establishing colonies, but the ratio may be adjusted after adequate studies to determine the optimum ratio. An optimum rate is one that does not affect the quality of flies while minimising underutilised (wasted) diet. Eggs can be pipetted directly onto the diet surface. The eggs must remain moist and they should be evenly distributed over the diet. Eggs with fruit residues from the domes placed on diet may lead to mould growth on the diet surface so eggs should be rinsed several times to remove contaminants (e.g. bits of fruit pulp). Eggs can be surface-sterilised in 0.025% NaClO for about 5 minutes, after which they must be immediately triple-rinsed in fresh water.

Larvae

Use of whole fruit

Whole fruit are used when the artificial diets available are not suitable for the particular species or when an artificial rearing system is still under development. Whole host fruit may be used when, and if, fly numbers are very low.

Artificial diets

It is essential to develop inexpensive diets that are nutritionally suitable for larval development, contain ingredients that are continuously available, are of known quality and free of any pollutants. The bulk of effort expended in improving tephritid fruit fly rearing world-wide has been directed at the development of larval diets. Virtually all artificial larval diets used world-wide have common characteristics. They normally include water, microbial inhibitors, sources of protein, carbohydrate and lipid, plus vitamins, salts, minerals and sterols. The two other ingredients usually added to fruit fly larval diets are a bulking agent and an agent for adjusting pH. In Hawaii, wheat millfeed standard diets have been used for *Bactrocera dorsalis* (Oriental fruit fly), *Ceratitis capitata* (Medfly) and *Bactrocera cucurbitae* (melon fly) and an improved diet based on bran has been developed for rearing *Bactrocera latifrons* (Vargas et al. 1993) (see Table 2).

Initial developments of the diets for the South Pacific were carried out in the Cook Islands by E. Hamacek and in Fiji by Hamacek and RFFP staff. The initial bulking agent used was cassava in the Cook Islands and then sugarcane bagasse in Fiji. Pawpaw is now the main ingredient used because it is generally available all year and, if picked at colour

Table 2: Artificial fruit fly diets used in the Pacific (ingredients in grams).

Ingredient	Orient/ Med	Melon fly	Latifrons	Dried carrot	Pawpaw/ cassava	Pawpaw/ bagasse	Pawpaw	Breadfruit	Banana
Fruit pulp					1500	1500	1000	1000	886
Mill feed	500	1027							
Bran			140						
Carrot powder			50	470					
Cooked cassava					1500				
Sugarcane bagasse						150			
Sugar	230	242	20						
Torula yeast	64	117	35	150	125	80	53	53	111
Nipagin	2	3.67	1.6	15	12.5	4	2.6	2.6	2.5
Sodium benzoate	4	3.67							
HCl (conc.)		6.67		31.5					
Citric acid			35						
Water (mL)	1200	2500	750	3000+	400	250+		1000	

break, is not infested by fruit flies. Another advantage of using fresh fruit in the diet is that the pH requires no adjustment. The pH is normally held at 4–5.5 to deter bacterial and fungal contamination. The other ingredients are Torula yeast and Nipagin, which are standard ingredients in insect diets. Torula yeast is a standard source of protein in larval diets although Brewer's yeast (*Saccharomyces* spp.) may also be used. Nipagin (methyl *p*-hydroxy-benzoate), or sodium benzoate at 0.1% of the diet, are added to stem both bacterial and fungal development, deleterious to fruit fly larvae.

Variations in the quality of the bulking agents, cassava and sugarcane bagasse used in the Cook Islands and Fiji led to unreliable data in larval developmental studies, and together with difficulties in extraction of larvae from these diets led to futher development work on the diet. Researchers working in the Cook Islands (RFFP staff and G. Clare) discovered that storing the other ingredients (pawpaw, Torula yeast and Nipagin) after mixing without the bulking agent at 4 °C for at least 24 hours led to gelling of the ingredients. Excess water produced in this gelling process could be decanted off, producing a diet from which larvae could be easily extracted using a sieve under running water. This, now standard diet has been further developed by substituting pawpaw with other available fruits, particularly breadfruit (used in Fiji, Solomon Islands and Vanuatu) and banana in New Caledonia (Lemontey and Mademba-Sy 1995).

The range of diets used in the eight different South Pacific island countries for various fruit fly species are given in Table 1 and ingredients are shown in Table 2. The standard diet, either with pawpaw, breadfruit or banana as the main ingredient, is used for all species in all countries except *B. umbrosa* in New Caledonia, which is reared on dried potato/carrot diet (G. Clare, pers. comm.). This species is reared on breadfruit diet in the Solomon Islands and Vanuatu. The standard diet is simple to make and stores well in the fridge but loses some quality if frozen (Clare, pers. comm.). The two main problems with these diets are the threat that the fruit may be contaminated by pesticides, or that they may contain wild fruit fly eggs or larvae. It is essential to ensure that fruit are not infested by picking them at the appropriate stage or protecting them by bagging. Pawpaw is picked at colour break and breadfruit and banana are picked at the mature green stage, about one week before use. All of the fruits are then carefully stored to prevent insect infestations and allow natural ripening.

Other standard diets may be used, and examples of these are given (Table 2). In New Caledonia researchers were having difficulty mass-rearing *B. umbrosa*. However, a suitable diet was developed by Clare based on potato and carrot. The use of carrot for fruit fly larval diets is well known, with dried carrot diet (Table 2) the most commonly used diet in small-scale rearing around the world. There is evidence that carotene (from carrot) is an important feeding stimulant which promotes growth, particularly during early larval development (Fay 1989). Water is also very important, both for minimising the effects of metabolic heat build-up during the final stages of larval development (Hooper 1978) and in affording greater access to nutrients. There are indications that *B. cucurbitae* needs a diet of higher moisture content than some other species. The standard diets used in the South Pacific that are based on natural fruit pulp have a naturally high water content but the addition of a little water is sometimes necessary for the right consistency when using fruit that are not fully ripe.

General preparation of fruit diets

All ingredients must be thoroughly mixed, particularly the Nipagin. This is achieved by mixing the Nipagin, dissolved in a little warm water if necessary, and yeast to small quantities of fruit. Use a blender if available. The diet is stored at 4 °C for at least 24 hours which allows the mixture to gel prior to decanting off excess water before use. Check pH is 4.0–5.5 with litmus paper. Concentrated hydrochloric acid (HCl) (0.5–3.55%) or citric acid can be used to increase acidity if required.

Larval trays and storage containers

Larvae may be reared in various shallow trays or dishes containing the diet. Diet thickness is an important factor as the greater the surface area to volume ratio the greater the likelihood of metabolic heat dissipation (Fay 1989). However, thin diet is prone to drying. Diet (500–800 g) is spread onto a shallow tray at a thickness of 3–5 cm. Diet trays with eggs are placed in plastic containers with tight-fitting lids sealed with tape and labelled. The lid must have a large ventilation hole covered with fine insect screen to keep *Drosophila* out. Ventilation is important for efficient gas and heat exchange. However, during the first 3–4 days the vent should be sealed to ensure high humidity for good egg hatch and prevent the entry of light which may promote excess yeast growth on the diet surface.

Pupae

Pupating substrate

Larvae enter a post-feeding stage and commence 'popping' or 'jumping' out of the diet trays. These larvae must be allowed to pupate in a moist substrate, normally a layer (>1 cm thick) of moistened, sterilised, untreated sawdust placed in the bottom of the holding container about 2 days before 'jumping' begins. Thoroughly washed sand or fine vermiculite may also be used as a pupating substrate. Before use, the sawdust should be sieved to retain only fine particles for easy pupal sorting. Sawdust or vermiculite must be heat-sterilised before use (120 °C for at least 2 hours).

Collection and storage conditions

Pupae are collected when at least a few days old by gentle sieving, and stored in moistened sawdust for eclosion. A small container should be layered with 1 cm of moist sawdust, pressed down. Pupae are then added and lightly covered with more moistened sawdust. Pupae should be held at about 25–28 °C or the same temperature as for larvae. Relative humidity should in the 70–80% range, high enough to prevent pupal water loss but not so high as to allow free water or inducement for mould. Pupae are normally placed in new cages 2–3 days before eclosion.

Quality Control and Recording Procedures

Quality control of mass-reared insects is divided commonly into two categories:

(1) production quality control where the parameters of rearing are addressed and which include such items as diet ingredients and environmental conditions; and
(2) product quality control where the insects produced are evaluated (Calkins 1989).

Production quality control in the South Pacific rearing system includes standardising the use and storage of materials and ingredients, monitoring production processes and ensuring facility and equipment maintenance. For monitoring purposes, all rearing cages are labelled with date, species and cage number, and all rearing containers with relevant informaton, e.g. weight of diet, number of eggs, diet type, date, and fruit fly species. Information on room temperatures is essential and relative humidity recording is also useful. All unusual observations should be noted along with any deviations from normal practice, e.g. diet wetness, growth on diet surface, abnormal condensation in larval diet container. These comments may help identify the source of any problems found later with quality of flies or pupae.

In the second category, product quality control, the quality of the fruit fly rearing system can normally be assessed at the pupal stage and can be correlated to pupal size (Fay 1989). However, pupal weight changes over time so that comparisons should be made with equal-aged pupae. Other simple tests of quality include percentage adult emergence (or percentage pupal mortality), percentage flight ability and percent survival (Boller et. al. 1981). Records should be kept of colony progress so that any anomalies associated with rearing processes can be identified and overcome (Fay 1989). Generation number, daily egg production, per cent egg hatch, ratio of numbers of eggs to weight of diet, larval duration and pupal recovery should all be recorded. Significant adult mortality in cages only 3–4 weeks old, or high numbers of flightless adults, are indicators that there is a problem with the laboratory colony.

Quality assurance monitoring in the South Pacific is based mainly on the pupal stage (weight and mortality) and egg hatch (see below). There are variations between individual fruit fly species in any country and between the same species in different countries but there is a range that indicates a colony is healthy. Checks on these variables are conducted continuously and recorded for future reference. Variations in performance in biological studies are normally preceded by indications in these regular checks that there is a problem in the rearing system. Details on guides to quality control and fault-finding guidelines can be found in Walker and Hamacek (1992).

Records used for quality assurance monitoring in the South Pacifc include:

- percentage egg hatch — should be >70%, 75–95% ideal (using >100 eggs);
- pupal weight — should be regular for same aged pupae (using 100 pupae);
- pupal mortality should be <10% (using 100 pupae);
- pupal recovery from number of eggs hatched should be >60%;
- adult recovery from eggs should be 45–50%.

Laboratory Hygiene

Rearing facilities should have a high standard of hygiene to minimise the risk of bacterial contamination. *Bacillus* spp. and *Serratia marcescens* are known pathogens of fruit flies. All cage covers, frames and all containers used to hold eggs, larvae,

pupae and implements should be disinfected in 0.2% sodium hypochlorite (NaClO) and then well rinsed in fresh water (preferably three times) before re-using. Benches should be regularly cleaned with water or wiped down with 75% ethyl alcohol.

Conclusion

Vargas et al. (1993) state that fruit fly rearing may be conducted with either a relatively small volume of adults to promote relatively high egg production, or a very high adult volume to compensate for reduced egg production per unit volume. The rearing system described in this paper uses a small 'volume' of flies to produce a relatively large number of eggs with the emphasis on quality rather than quantity for various life stage studies. Adult cages are discarded after a relatively short egging period and the colonies rejuvenated frequently. The adults are fed standard protein sources, but are supplemented with 'fruit fly type' bacteria, which has led to good egg production and egg hatch for most species in most countries. Efficient egging devices have been developed in the South Pacific, similar to devices used in Hawaii, and larvae are fed a 'natural' diet based on locally available fruit producing high quality fruit fly life stages.

The laboratory rearing system described in this paper requires a relatively small amount of labour input when compared with some other laboratory insect rearing systems, and most aspects of the work are quite simple. However, it does rely on staff who are highly committed to this work and who have access to continuously available, uncontaminated local produce to achieve research results that can be duplicated with confidence.

Acknowledgments

The authors acknowledge the major contribution of the staff of the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project in the South Pacific (RFFP), particularly the governments and staff of countries participating in the RFFP, and the United Nations volunteer entomologists. The authors acknowledge the financial support of the Food and Agriculture Organisation of the United Nations (FAO), the Australian Agency for International Development (AusAID), the United Nations Development Programme (UNDP) and the South Pacific Commission (SPC); the support of the Australian Centre for International Agricultural Research and participating staff of the Queensland Department of Primary Industries; and the government of New Caledonia and research staff of CIRAD and Hort+Research, New Zealand.

References

Boller, E.F., Katsoyannos, B.I., Remund, U. and Chambers, D.L. 1981. Measuring, monitoring and improving the quality of mass-reared Mediterannean fruit flies, *Ceratitis capitata* (Wied.). I. The RAPID quality control system for early warning. Zeitschrift fur Angewandte Entomologie, 92: 67–83.

Calkins, C.O. 1989. Quality Control. In: Robinson, A.S. and Hooper, G., ed., Fruit flies: their biology, natural enemies and control, Elsevier, Amsterdam, 3B: 153–165.

Drew, R.A.I. and Lloyd, A.C. 1989. Bacteria associated with Fruit Flies and their Host Plants. In: Robinson, A.S. and Hooper, G., ed., Fruit flies: their biology, natural enemies and control, Elsevier, Amsterdam, 3B: 129–140.

Fay, H.A.C. 1989. Multi-host species of Fruit Fly. In: Robinson, A.S. and Hooper, G., ed., Fruit flies: their biology, natural enemies and control, Elsevier, Amsterdam, 3B: 129–140.

Hooper, G.H.S. 1978. Effects of larval rearing temperature on the development of the Mediterannean fruit fly, *Ceratitis capitata*. Entomologia Experimentalis et Applicata, 23: 222–226.

Lemontey, J.M. and Mademba-Sy, F. 1995. The Fruit Fly Research Programme in New Caledonia. Fruits, 49 (5–6): 421–427.

Leppla, N.C. 1984. Mass production of biological control organisms. In: King, E.G. and Leppla, N.C., ed., Advances and Challenges in Insect Rearing. Agric. Res. Serv., USDA, U.S. Government Printing Office, Washington, D.C., 292–294.

Leppla, N.C. 1989. Laboratory colonization of fruit flies. In: Robinson, A.S. and Hooper, G., ed., Fruit flies: their biology, natural enemies and control, Elsevier, Amsterdam, 3B: 91–104.

Mackauer, M. 1976. Genetic problems in the production of biological control agents. Annual Review of Entomology, 21: 369–385.

Rossler, Y. 1975. Reproductive differences between laboratory-reared and field-collected populations of the Mediterannean fruit fly, *Ceratitis capitata*. Annals of the Entomological Society of America, 68: 987–991.

Tsitsipis, J.A. 1989. Nutrition. In: Robinson, A.S. and Hooper, G., ed., Fruit flies: their biology, natural enemies and control, Elsevier, Amsterdam, 3A: 103–119.

Vargas, R.I. 1989. Mass production of Tephritid Fruit Flies. In: Robinson, A.S. and Hooper, G., ed., Fruit flies: their biology, natural enemies and control, Elsevier, Amsterdam, 3B: 141–151.

Vargas, R.I., Mitchell, S., Chiou-Ling Hsu and Walsh, W.A. 1993. Evaluation of mass-rearing procedures for *Bactrocera latifrons* (Diptera: Tephritidae). Journal of Economic Entomology, 86, 4: 1157–1161.

Walker, G.P. and Hamacek, E.L. 1992. Laboratory Rearing of Fruit Flies. Lecture 7. Third International Training Course on Understanding and Managing Fruit Flies. FAO/AIDAB/UNDP/SPC/Regional Fruit Fly Project.

Effectiveness of Various Artificial Larval Diets for Rearing *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* (Broun) in the Laboratory in Fiji

E. Tora Vueti[1], E.L. Hamacek[3], A. Kassim[2], G.P. Walker[4], A. Balawakula[1], L. Ralulu[1], L. Leweniqila[1] and D. Kumar[1]

Abstract

Laboratory colonies of *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* (Broun) were established at Koronivia Research Station, Fiji in 1991. Laboratory rearing of the two economically important species was a prerequisite to studies conducted on protein bait spray and quarantine treatment development. To increase the production of laboratory reared fruit flies for this research and also to have a substitute larval diet available, replicated comparisons of the effectiveness of larval diets were carried out using *B. passiflorae* and *B. xanthodes*. The diets compared were pawpaw/bagasse, dehydrated carrot and diets used for culturing Mediterranean fruit fly (*Ceratitis capitata* Wiedemann), Oriental fruit fly (*B. dorsalis* Hendel), melon fly (*B. cucurbitae* Coquillett) and *B. latifrons* (Hendel), pawpaw diet and breadfruit diet. *B. passiflorae* and *B. xanthodes* eggs seeded onto the various diets were allowed to develop into larvae, pupae and adults. The percentage egg hatch, number of pupae recovered, percentage pupal mortality, weight of 100 pupae, number of adults and percentage eclosion were used to determine the effectiveness of the diets. Results showed that pawpaw/bagasse and dehydrated carrot diets performed favorably for both species. The pawpaw diet currently used as standard larval diets for both species is the most readily available and easiest to use. Breadfruit diet was tested on *B. xanthodes* only and showed that it was a suitable substitute for the pawpaw-based diets. Other larval diets, cassava/pawpaw and banana diets, that have been developed and used in the South Pacific areas are also discussed in this paper. When pawpaw or breadfruit are not available, dehydrated carrot diet may be substituted for fruit-based larval diets.

DEVELOPMENT of larval diets for fruit flies (Tephritidae) has been carried out with the development of mass rearing of fruit flies. In 1949–1950, Finney pioneered development of practical rearing methods for Oriental fruit fly (*Bactrocera dorsalis* Hendel) and Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) and the carrot larval diet which was the basis of the development of other artificial larval diets. There has been tremendous progress in the development of larval diets over the years using bulking agents such as sugarcane bagasse or bran/wheat with the addition of ingredients that are required by fruit flies (Hooper 1978; Vargas 1989; Vargas et al 1993; Vargas et al. 1983; Vargas and Mitchell 1987; Walker and Hamacek 1992). Recent trapping and host fruit survey data have confirmed that *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* (Broun) are the economical fruit fly species in Fiji. Laboratory colonies of *B. passiflorae* and *B. xanthodes* were established at the Koronivia Research Station, Fiji in 1991. Increasing pressure on the fruit fly colonies brought about by the need to conduct biological studies, protein bait spray and quarantine treatment development resulted in a need to increase the numbers of *B. passiflorae* and *B. xanthodes*.

Laboratory colonies of fruit flies (Diptera: Tephritidae) established by the Regional Fruit Fly

[1] Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2] Regional Fruit Fly Project, South Pacific Commission, Private Mailbag, Suva, Fiji
[3] Queensland Department of Primary Industries, Indooroopilly, Brisbane, Australia
[4] Crop and Food Research, Mt. Albert Research Centre, Private Bag 92169, Auckland, New Zealand

Project (RFFP) in the South Pacific initially used pawpaw/bagasse as the basis for larval diet for species in the Cook Islands, Fiji, Tonga and Western Samoa. The pawpaw/cassava-based diet was developed in the Cook Islands in 1991 because sugarcane bagasse was not readily available. In 1992, the pawpaw diet was developed for *B. melanotus* (Coquillett) and *B. xanthodes* in Cook Island. This diet is currently the standard larval diet for laboratory colonies of fruit flies that have been established by RFFP. The banana diet was developed in Australia by Hamacek for *B. musae* (Tryon) in 1990. In New Caledonia, *B. umbrosa* is reared on dried carrot/potato diet (Clare unpubl. data). The constituents of various diets are described in Table 1.

A study on the comparison of larval diets was conducted in Fiji on *B. passiflorae* and *B. xanthodes* in 1992. The aim of this study was to ensure a suitable alternative diet to the pawpaw/bagasse or other fruit-based diets was available when the fruit based diets were not available, e.g., following natural disasters or disease outbreaks.

Materials and Methods

Larval diets

The larval diets compared were pawpaw/bagasse, dehydrated carrot and wheat based diets used for rearing Mediterranean and Oriental fruit fly, melon fly and *B. latifrons*. Data on pawpaw and breadfruit diets were taken from the laboratory rearing records. The constituents and pH of each diet used for the study is given in Table 2.

Eggs were collected from stock laboratory flies reared on pawpaw/bagasse-based diet at the Koronivia Research Station. Pawpaw domes and artificial egging devices were put into *B. xanthodes* and *B. passiflorae* cages, respectively, for 24 hours. The eggs were removed with water using a hand sprayer, batches of 200 eggs were placed on black filter paper in a petri dish which was placed in a colored plastic container. The percentage egg hatch was determined after 72 hours by counting the unhatched eggs and converting to a percentage egg hatch. Five hundred grams of each diet was put into 750 mL plastic containers and 1000 eggs were seeded onto the diet. Each diet container was moistened with water then put into four litre containers with fine gauze covering the ventilated lid of the container.

Paper cards were placed on top of the container for three days to allow maximum egg hatch to occur on diets and to ensure that there was minimal yeast growth on the surface of the diet. Sterilised, sieved sawdust was put into each four litre container after five days in preparation for pupation media. Each diet was replicated four times for *B. passiflorae* and *B. xanthodes* in a room maintained at 25 ± 2°C and 80 ± 9% relative humidity.

After 17 days, pupae were sieved from sawdust, counted and held in moist sawdust until eclosion.

Table 1. Artificial fruit fly diets used in the Pacific region.

Ingredients (g)	Diets								
	Pawpaw/ Bagasse	Dehydrated carrot	Medfly/ Oriental diet	Melon fly diet	*B. latifrons* diet	Pawpaw diet	Breadfruit diet	Pawpaw/ cassava	Banana diet
Nipagin	4	15	2	3.6	1.6	2.6	2.6	12.5	3.5
Torula yeast	80	150	64	117	35	53	53	125	25
Sodium benzoate	—	—	4	3.6	—	—	—	—	—
Sugar	—	—	230	242	20	—	—	—	—
Conc. HCl	—	31.5	—	6.6	—	—	—	—	—
Citric acid	—	—	—	—	35	—	—	—	—
Agar	—	—	—	—	—	—	—	—	20
Pawpaw	1500	—	—	—	—	1000	—	1500	—
Banana	—	—	—	—	—	—	—	—	350
Cassava (cooked)	—	—	—	—	—	—	—	1500	—
Breadfruit	—	—	—	—	—	—	1000	—	—
Dehydrated carrot	—	450	—	—	50	—	—	—	—
Sugarcane/bagasse	150	—	—	—	—	—	—	—	—
Mill feed	—	—	500	1027	140	—	—	—	—
Water (mL)	250+	3000 (hot)	1200	2500	750	optional	1000+	400	500 (hot)

Table 2. Constituents of larval diets used for *B. passiflorae* and *B. xanthodes* in Fiji.

Ingredients (g)	Diets				
	Pawpaw/bagasse	Dehydrated carrot	Medfly/Oriental diet	Melon fly diet	*B. latifrons* diet
Pawpaw	3550				
Nipagin	9.76	15	+	+	+
Torula yeast	189	150	+	+	+
Conc. HCl	—	31.5	—	+	—
Sugarcane bagasse	355	—	—	—	—
Dried carrot	—	450	—	—	—
Dry prepared bran diet	—	—	2000	2000	2000
Distilled water (ml)	700+	4400 (hot)	2762	3262	3262
pH	5.5	4	6	5.5	5

+ : Ingredients are present but amounts are not available. The bran/wheat based diets were already prepared for this test and supplied by the USDA Agricultural Research Service laboratories, Hilo, Hawaii. Water was added to the dry diets.

Table 3. Pupal weight, percentage pupal mortality and percentage adult emergence for *B. passiflorae* and *B. xanthodes* reared on pawpaw/bagasse, dehydrated carrot and wheat based diets.

Diet	Wt. of 100 pupae (g)		% pupal mortality		% adult emergence	
	B. passiflorae	*B. xanthodes*	*B. passiflorae*	*B. xanthodes*	*B. passiflorae*	*B. xanthodes*
Pawpaw/Bagasse	1.08	1.57	4.50	1.15	95.50	98.85
Dehydrated carrot	1.05	1.43	1.20	0.57	98.80	99.43
Medfly/Oriental diet	1.12	1.51	3.55	3.95	96.45	96.05
Melon fly diet	1.16	1.59	4.68	3.37	95.32	96.63
B. latifrons diet	1.12	1.61	5.80	4.15	94.20	95.85
Standard Error	± 0.01	± 0.01	± 0.57	± 0.57	± 0.62	± 0.62

Observations on the degree of dryness of each diet and yeast growth were made for each diet from day one. Pawpaw and breadfruit diets were also compared. Data were collected from the laboratory rearing records of *B. passiflorae* and *B. xanthodes* on these diets. Procedures of the method of rearing are discussed in the 'Laboratory rearing techniques for Tephritid fruit flies in the Pacific' paper by Walker et al. (these Proceedings).

Data collected for this study included percentage egg hatch, number of pupae and adults recovered, percentage pupal mortality, percentage adult emergence from pupae, weight of 100 pupae and duration of the life cycle.

Results

The comparisons of pawpaw/bagasse, dehydrated carrot and wheat-based diets were carried out using a factorial randomised design with four replicates and parameters assessed were percentage pupal mortality, weight of 100 pupae and percentage adult eclosion (Table 3). Fisher's F-test was conducted on the means of the above parameters and various transformations were carried out to normalise the data.

Laboratory rearing records were used to determine the performance of *B. passiflorae* and *B. xanthodes* larvae on pawpaw diet and *B. xanthodes* on breadfruit diet. No statistical analyses were carried out on the data from the laboratory rearing records. Data on the pawpaw diet were taken from laboratory rearing records of four generations of flies and from two generations for the breadfruit diet.

Discussion

The mean percentage egg hatch during these comparisons were 78% for *B. passiflorae* and 86 % for *B. xanthodes*. Laboratory rearing records over six years have shown that the mean percentage hatch of eggs of *B. xanthodes* on reared on pawpaw diet was 91%,

B. passiflorae was 93% and *B. xanthodes* on breadfruit diet was 96%.

The means of weight of pupae and percentage adult emergence from the five diets compared were not significantly different. The percentage pupal mortality for *B. xanthodes* reared on pawpaw/bagasse and dehydrated carrot diets was significantly less than that for bran-based diets. Also, the percentage pupal mortality for *B. passiflorae* reared on dehydrated carrot diet was significantly less than that for the other diets. However, in practical laboratory rearing terms, the small differences in pupal mortality would not be critical. In effect, all diets would be adequate for rearing *B. passiflorae* and *B. xanthodes*, based on the parameters used.

Observations on the degree of dryness of the diets and the extent of yeast growth were not measured quantitatively. However, it was observed that the moisture content of each diet was sufficient for the development of the first, second and third instars and pupal stage. Also, it was observed that larvae left the pawpaw/bagasse diet earlier (after 13 days) compared to the other four diets. The duration of egg to larvae exiting the pawpaw/bagasse diet was less than 20 days, bran-based diets around 20 days and dehydrated carrot diets more than 20 days. On the basis of duration of larval development, pawpaw/bagasse shows a slight advantage over the bran-based diets and dehydrated carrot diet. There was no yeast growth because of the limited light provided to the diets.

Laboratory rearing records have shown the effectiveness of pawpaw diet for the larvae of *B. xanthodes* and *B. passiflorae*. The mean weights of 100 pupae for *B. xanthodes* and *B. passiflorae* were 1.20 g and 0.97 g and the percentage recoveries of pupae were 86% and 88% reared on this diet respectively. Breadfruit diet was also used as larval diet for *B. xanthodes* only. Data indicated that the mean pupal weight was 1.37 g and percentage pupal recovery was 91%.

This study has shown various options for artificial larval diets for laboratory reared *B. passiflorae* and *B. xanthodes*. Firstly, suitable substitutes are available to the fruit-based diets (pawpaw/bagasse, pawpaw and breadfruit) when fruits are not available. The dehydrated carrot diet or one of the bran-based diets may be used as a substitute. Secondly, to increase the production of fruit flies in the laboratory to conduct studies on protein bait spray and quarantine treatment development, a readily available, cheap and easy to use diet is necessary. Pawpaw diet was developed by Kassim in the Cook Islands for this purpose.

Pawpaw diet is currently the standard larval diet used for most species in Fiji, Tonga, Western Samoa, Cook Islands, Federated States of Micronesia, Vanuatu and Solomon Islands. Finally, this study developed some laboratory techniques that have been adopted in laboratory rearing. For example, exclusion of light by covering the larval diet containers with paper cards reduces yeast growth and therefore promotes optimum egg hatch.

References

Hooper, G.H.S. 1978. Rearing larvae of the Queensland fruit fly, *Dacus tryoni* (Froggatt) (Diptera: Tephritidae), on a bran-based medium. Australian Entomological Society, 17: 143–144.

Vargas, R.I., Mitchell, S., Chiou-Ling Hsu and Walsh, W.A. 1993. Evaluation of mass rearing procedures for *Bactrocera latifrons* (Diptera: Tephritidae). Journal of Economic Entomology, 86, 4: 1157–1161.

Vargas, R.I. 1989. Mass production of tephritid fruit flies. In: Robinson, A.S. and Hooper, G., eds, Fruit flies: their biology, natural enemies and control, 3B: 141–151. Elsevier, Amsterdam.

Vargas, R.I. and Mitchell, S. 1987. Two artificial larval diets for rearing *Dacus latifrons* (Diptera: Tephritidae). Journal of Economic Entomology, 80: 6: 1337–1339.

Vargas, R.I., Chang, H. and Williamson, D.L. 1983. Evaluation of sugarcane bagasse larval diet for mass production of the Mediterranean fruit fly (Diptera: Tephritidae) in Hawaii. Journal of Economic Entomology, 76: 1360–1362.

Walker, G.P. and Hamacek, E.L. 1992. Laboratory rearing of fruit flies. In: Third International Training Course on Understanding and Managing Fruit Flies in the Tropics, University of the South Pacific, Suva, Fiji, November, 1992. Lecture No. 7.

Rearing Techniques for *Dacus solomonensis* and *Bactrocera cucurbitae* in Solomon Islands

F. Tsatsia[1] and R.G. Hollingsworth[1]

Abstract

Dacus (Callantra) solomonensis Malloch is known to occur only in Solomon Islands and Bougainville. There is no published information about its life history. It is a major pest of snake gourd, attacking both mature and immature fruits. Cucumber (*Cucumis sativus*) and pumpkin (*Cucurbita* spp.) are also hosts.

A small colony of *D. solomonensis* was begun in March 1996 using pupae obtained from snake gourd. Colony size was increased using whole fruits of snake gourd for egging. Eggs have also been obtained using pumpkin domes. At 25 °C, eggs hatched in about 46 hours. Durations of larval and pupal stages were 12 and 9 days, respectively. Larvae tolerate wet conditions, sometimes pupating inside the skin of snake gourd. This occurs both in the laboratory and in the field.

The melon fly, *Bactrocera cucurbitae* (Coquillett), is one of the world's worst pests on cucurbit crops. A colony of melon fly was started in February 1996 using insects obtained from ripe fruits of a wild cucurbit vine (*Coccinea grandis*). Successful reproduction was obtained using whole fruits of papaya, or papaya domes transferred to a diet containing papaya, torula yeast and nipagin. From eggs placed directly on diet, larvae survived only in the absence of nipagin.

Rearing Methods for *Dacus solomonensis*

Dacus solomonensis Malloch is known only from Solomon Islands and Bougainville. It is a serious pest of snake gourd (Williams et al. 1990), and is an important quarantine risk to other countries in the Pacific area which do not already have melon fly, *Bactrocera cucurbitae* (Coquillett) (Waterhouse 1993). The authors established a laboratory colony of *D. solomonensis* to study its biology, behaviour, and pest status (via host status testing) under the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project. There have been no previously published studies regarding its life history.

D. solomonensis can be distinguished from other fruit fly species by its large size and a hump on abdominal tergum V (Drew 1989). *D. solomonensis* is the only fruit fly species other than melon fruit fly commonly reared from cucurbits in the Solomon Islands.

[1] Dodo Creek Research Station, PO Box G13, Ministry of Agriculture and Fisheries, Honiara

Laboratory Colony

A colony of *D. solomonensis* was started with pupae obtained in March 1996 from snake gourd fruit collected in northwestern Guadalcanal. The project began with 41 pupae from 7 kg of ripe and damaged green fruits. Eighty-three pupae were added in early April obtained from 3.7 kg of additional mature green fruit collected at the SICHE farm. The cage originally used measured 50 × 35 × 35 cm. Sugar was provided in petri dishes, and water was provided on sponges protruding from the tops of water-filled plastic containers. A mixture of sugar and protein hydrolysate was smeared on cards (3 parts sugar, 1 part protein) and hung from the tops of the cages. Fruit-fly type bacteria were supplied on an agar medium. Circles of agar removed from petri dishes were placed on the top of the cage. Flies fed through the mesh.

First matings of the fruit flies were observed on May 13 1996 at 3.45 pm. This was 3 days after a 40-watt fluorescent light was added directly above the cage, and about 6 weeks after the first flies had become adults. Mating occurred on the fruit dome or while insects were resting on the walls of the cage.

Mating was commonly observed late at night (10.00 pm). Several years ago, attempts to rear *D. solomonensis* were unsuccessful, as the authors were unable to obtain eggs from domes or whole fruits of snake gourd. Low levels of light at that time were perhaps responsible for the failure.

Several months after starting the colony, many of the flies were seen to have torn wings. Therefore flies were transferred to a larger cage (measuring 75 × 55 × 45 cm high) to give them more space and to prevent wings from being torn.

There was very little success using domes of cucumber and mature pumpkin, so egging began in late April using whole fruits of snake gourd. The fruits were left in the cage for a week at a time and by June, successes were noted. Larvae seemed to tolerate wet conditions in the rearing containers, and pupae were frequently found within the decomposing fruit. In May, about 30 eggs were obtained using a hollowed-out dome of pumpkin. The population went down to about 30 individuals on 21 June, but it rose again later. By October 1996, there were two cages with approximately 200 adult flies and several hundred pupae ready to emerge.

Observation

An observational experiment was set up to obtain basic information needed to develop an efficient rearing procedure for *D. solomonensis*.

For this experiment an immature pumpkin fruit (766 g) was used for egging. The idea was to determine the length of the developmental period from egging to pupation. Observations were carried out in an air-conditioned laboratory at an average temperature of 25 °C. The fruit was provided to flies within a large cage (75 × 55 × 45 cm high), because of previous observations that the wings of flies in a smaller cage became torn. This was apparently due to interspecific aggression associated with overcrowding.

The fruit was pierced 30 to 50 times with a pin before being put into the cage. A dome of immature pumpkin was placed into the cage at the same time. The whole fruit was removed and set up for observation after a 30 hour oviposition period. The dome was left in the cage for 24 hours.

Thirty-two eggs were obtained from the dome during the 24 hour period. Eggs started hatching 46 hours from the time the dome was first put into the cage. Egg hatch was between 80% and 90%. These eggs were transferred to a pumpkin diet (pumpkin mixed with torula yeast and nipagin). However, none of the larvae survived past the second instar.

Median larval period was about 12 days in pumpkin and snake gourd. The total number of pupae obtained from the pumpkin fruit was 193. Lengths of pupae ranged from 6–8 mm and individual weights varied between 0.03 and 0.05 g. From insects reared on snake gourd in a previous trial, the pupal period was generally 9 days (sometimes 10 days) at about 25 °C. Adults first started mating approximately 16 days after they emerged from pupae.

Artificial diets

Larval diets still need to be tested for mass rearing of this species. It would be desirable to use pumpkin or snake gourd for artificial diets because these fruits are available throughout the year. It is planned to use the same recipe used for *Bactrocera frauenfeldi* but replace papaya with pumpkin (i.e. for every 2000 g pumpkin, blend in 107 g torula yeast and 5.3 g nipagin).

Conclusion

The main reason for not being able to mass rear *D. solomonensis* in the past was because females would not lay eggs in snake gourd fruits or domes. Low light conditions might have been responsible for the previous failure. Domes of immature pumpkin fruits proved more successful for gathering eggs than mature pumpkin domes, sliced pumpkin or domes of mature and young snake gourd. However, larvae feeding on snake gourd fruit seemed to be much larger and healthier, perhaps because fruits of snake gourd deteriorated very slowly, giving time for the flies to develop.

Rearing Methods for Melon Fly *Bactrocera cucurbitae*

The melon fly, *Bactrocera cucurbitae* (Coquillett), is perhaps the world's most serious fruit fly pest of cucurbit crops. This pest is widely distributed, particularly in Asia, where it is endemic.

B. cucurbitae primarily infests cucurbit crops (e.g. cucumber *Cucumis sativus*, watermelons *Citrullus lanatus*, squash and pumpkin (varieties of *Cucurbita pepo*). However, in Hawaii, it is a serious pest not only of cucurbit crops, but also tomato, capsicum, beans and passion fruit (Harris and Lee 1989 as cited in Waterhouse 1993). Papaya (*Carica papaya*) is also a common host in Hawaii in papaya plantations where poor sanitation is practised (Liquido et al. 1989).

The authors began a colony of melon fly in February 1996 in a laboratory in Honiara to prepare for mass-rearing a parasitic wasp species, *Psyttalia fletcheri* (Silvestri). This melon fly parasitoid will be imported from Hawaii in early 1997. The colony was established with about 100 adults obtained from the fruit of a wild cucurbit vine, *Coccinea grandis*,

which commonly grows on fences in the Honiara area. Flies were released into a cage measuring approximately 40 × 65 × 50 cm high, and placed on an ant-proof table close to a window which provided bright indirect light. Flies were fed sugar, water, protein and bacteria as described for *D. solomonensis*.

The colony was increased to several hundred individuals via whole fruit egging with fruits of *Coccinea grandis*. Both ripe and green fruits (if punctured first) were acceptable for oviposition and reproduction. It was noted that adults from green fruits were obtained in as little as 13 days from the time of egging. At the time, the lab was not air-conditioned, and daytime temperatures probably averaged about 29°C. Given optimal conditions, development of melon fly is rapid in relation to many other fruit fly species. Time from egg to pupation is about 5 days in zucchini, and pupal period is about 7 days (Waterhouse 1993).

Colony size was further increased using whole fruit egging with papaya. According to Liquido et al. (1989), melon fly develops a 'dense population in papaya in laboratory cages', even though, under ordinary conditions, it is seldom reared from field-collected papaya. Papaya was a good laboratory host, and normally hundreds of individuals were reared from each papaya fruit left in the cage for periods of about 24 hours. However, pupal weights on papaya were not as high as those on cucumber (data presented below).

Female flies readily oviposited in papaya domes (hollowed out fruits with hundreds of small holes made with a dissecting needle). After 24 hours, eggs were washed out of domes and placed on a diet of papaya and torula yeast, with nipagin added as an antimicrobial agent. For every 1 kg of papaya 54 g torula yeast and 2.6 g nipagin was added. The first several times eggs were added to artificial diet, it was noted that larvae did not develop. At the time, it was assumed that the melon fly colony was not yet 'laboratory adapted', and therefore attempts should continue using larger numbers of eggs. In subsequent attempts using artificial diet, domes were left in for 48 hours before use. Eggs of melon fly typically hatch in a little over 24 hours (Waterhouse 1993). Therefore many of the eggs had already hatched and larvae were feeding in the thin flesh of the dome. To avoid losing these larvae, domes were set on top of artificial diet instead of trying to wash out eggs and larvae. Under these circumstances, larvae developed normally and pupated in sawdust provided beneath larval rearing trays. Later, an experiment was carried out that caused the suspicion that nipagin in the diet might be toxic to eggs or first instar larvae. The experiment involved comparing pupal weights when insects were reared on either cucumber, papaya or the papaya/torula yeast diet previously described. For this experiment, eggs were obtained from a papaya dome left in the cage for less than 24 hours. Eggs placed on fruits hatched and larvae developed normally. No larvae were seen in containers in which eggs had been placed on top of papaya diet. In a subsequent test, melon fly eggs were added to papaya diet with and without nipagin. Larvae successfully developed on the diet without nipagin. The yeast which grew over the surface of the diet had to be stirred into the diet several days after the start of the test, in order to prevent the yeast from suffocating larvae. Large larvae churned the diet sufficiently to prevent excessive yeast growth. On the diet with nipagin, eggs hatched but all larvae died as first instars.

As mentioned previously, the authors conducted an experiment using cucumber and papaya to compare pupal weights for melon flies reared from these fruits. Various numbers of melon fly eggs (not strictly counted) were added to whole fruits or sections of these fruits. The weights of each fruit sample was recorded. Each fruit sample was kept individually in a plastic 4-litre ice-cream container partially filled with sterilised sawdust which served as a pupation medium. Sawdust was replaced or dry sawdust was added as necessary to prevent samples from becoming too wet. Care was taken not to lose any pupae when sawdust was changed. Pupae obtained from samples were weighed and counted. For each fruit sample, the number of pupae which emerged per gram of fruit was calculated. It was expected that pupal weights would be less in samples where larvae were crowded, and the idea was to compare pupae from cucumber and papaya with regard to this effect. In total, pupae from six cucumber samples and six samples of papaya were collected. No dead larvae were seen in fruit samples. Maximal pupal weights were greater on cucumber, consistent with the status of melon fly as primarily a pest of cucurbit crops (Fig. 1). For a given number of pupae per gram of fruit, pupal weights were greater on cucumber. This is demonstrated by the separation between the two polynomial curves fitted to data for cucumber and papaya.

As at October 1996, eight months after beginning rearing operations, two cages of melon flies, each containing approximately 1000 adult flies, were being maintained. Melon fly are very easy to rear compared with other fruit fly species, primarily because adults are very long-lived — adult lifespans up to 150 days are normal, but lifespans up to 480 days have been recorded under cool conditions (Waterhouse 1993). No difficulty was expected in increasing the size of the melon fly colony before the arrival of the parasitoid species from Hawaii.

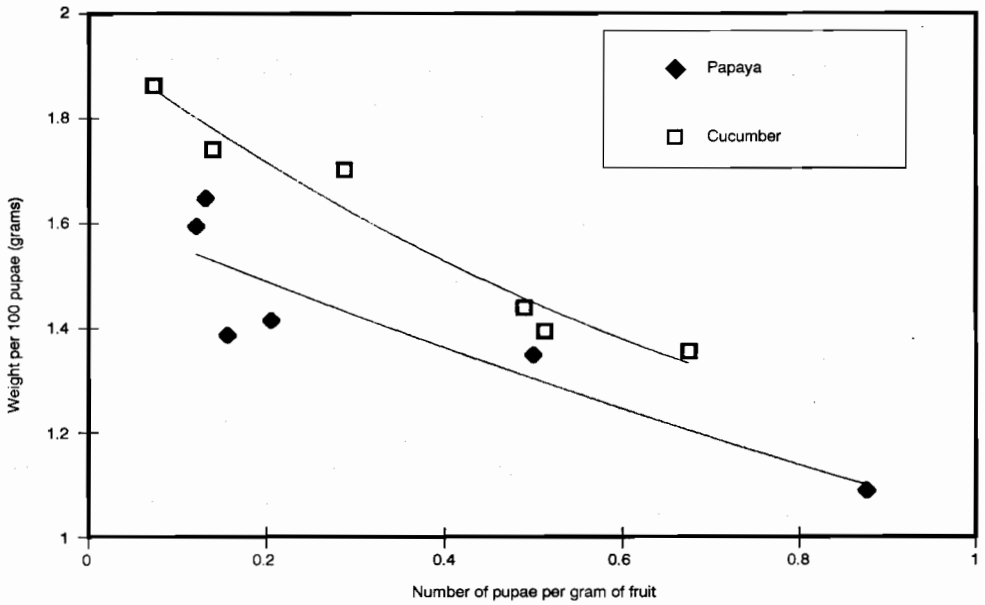


Figure 1. Weight of melon fly pupae as a function of the number of melon fly pupae produced per gram of fruit.

References

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceania regions. Memoirs of the Queensland Museum, Brisbane, Australia, 26: 1–151.

Harris, E.J. and Lee, C.Y. 1989. Influence of bitter melon, *Momordica charantia* L. (Cucurbitaceae) on distribution of melon fly, *Dacus cucurbitae* Coquillet (Diptera: Tephritidae) on the island of Molokai, Hawaii. Proceedings of the Hawaiian Entomological Society, 29: 49–56.

Liquido, N.J., Cunningham, R.T. and Couey, H.M. 1989. Infestation rates of papaya by fruit flies (Diptera: Tephritidae) in relation to the degree of fruit ripeness. Journal of Economic Entomology, 82: 213–219.

Waterhouse, D.F. 1993. Biological control: Pacific prospects. Supplement 2. Australian Centre for International Agricultural Research, Canberra, Monograph No. 20, 138 p.

Williams, C., Vagalo, M., Tsatsia, F. and Pauku, R. 1990. Entomology section report 1987–1990 (Dodo Creek Research Station). Internal report of the Research Division, Ministry of Agriculture and Lands, Solomon Islands.

Application of Bacteria to Laboratory Rearing of Fruit Flies

Annice Lloyd[1]

Abstract

Certain species of bacteria known as Fruit Fly Type Bacteria in the family Enterobacteriaceae are closely associated with different stages in the life cycle of many fruit fly species. These Fruit Fly Type (FFT) bacteria colonise the alimentary tract of adult flies and are distributed onto host fruit surfaces by mouthing and regurgitation of crop contents. During oviposition, some of these bacteria are introduced into the host fruit where they grow in association with developing larvae causing damage to host fruit tissue. FFT bacteria have also been shown to be an important natural source of protein for adult flies which are strongly attracted to the odours produced by these bacteria. The use of pure cultures of FFT bacteria as well as the normal rearing diet of autolysed yeast protein, sugar and water improves viability and egg production in newly established colonies. The methods of isolating and identifying FFT bacteria from fruit flies and the preparation of bacterial feeding plates are discussed.

Significance of Bacteria in the Life Cycle of Fruit Flies

BACTERIA associated with various species of tephritid fruit flies have been the subject of numerous investigations which were reviewed by Drew and Lloyd (1989). Studies undertaken with *Bactrocera* species in Queensland showed that certain species of bacteria in the family Enterobacteriaceae (termed Fruit Fly Type or FFT bacteria) were commonly associated with all stages of the life cycle (Lloyd et al. 1986). Three species, *Erwinia herbicola, Klebsiella oxytoca* and *Enterobacter cloacae*, were most frequently isolated from the alimentary tract of wild flies, from oviposition sites and rotting tissue associated with larvae in infested fruit. Other species of bacteria, *Citrobacter freundii, Proteus mirabilis, Proteus vulgaris, Providencia rettgeri, Escherichia coli, Serratia liquefaciens* and non-pigmented *Serratia marcescens* were less frequently isolated. As no one species of bacteria was consistently associated with any one species of fly, it was suggested that although there was a close association between fruit flies and FFT bacteria, the relationship was not truly symbiotic (Drew and Lloyd 1989).

[1] Plant Protection Unit, Queensland Department of Primary Industries, Brisbane

Other studies on the relationship of fruit flies to their host plants (Drew and Lloyd 1987, 1991) showed that adult flies can utilise these FFT bacteria as a protein source. This was further demonstrated by the fact that females developed eggs when fed on pure cultures of these bacteria as their sole source of protein. Furthermore, adult flies introduce these bacteria onto fruit and leaf surfaces in host trees by regurgitation of crop contents or by proboscis foraging. These fruit surface FFT bacteria are introduced into the host fruit during oviposition so that larvae develop in a 'soup' of bacteria and rotting host fruit tissue (Lloyd 1988). Field studies with wild *B. tryoni* populations (Drew and Lloyd 1987) showed that bacteria introduced into the host tree appear to provide an important natural protein source for developing females. The odours produced by FFT bacteria are highly attractive to adult flies (Lloyd 1991) and numerous studies in recent years have been aimed at developing fruit fly attractants based on bacterial odours.

A more recent study by Vijaysegaran (1995) demonstrated that the mouth parts of tephritid fruit flies are adapted to ingest only soluble food or particles no larger than the FFT bacteria which are commonly found in the crops and alimentary tracts of adult flies. Thus, there is considerable evidence to indicate that bacteria play a vital nutritional role in the natural diet of fruit flies.

Bacteria in Laboratory Reared Fruit Fly Colonies

The microbial flora of laboratory-reared fruit flies is generally more variable than that of wild flies and frequently reflects the microbial population of the rearing environment. In a study of laboratory-reared *B. tryoni*, the predominant bacterial species in the alimentary tract were found to be similar to those in wild flies but other species such as *P. vulgaris*, red-pigmented *S. marcescens* and *Pseudomonas* species predominated at certain times (Lloyd 1991).

High populations of red-pigmented *S. marcescens* were found to be consistently associated with the presence of *Drosophila melanogaster* in laboratory-rearing facilities. The fact that protease-producing strains of *S. marcescens* are known to have a detrimental effect on fruit fly larvae (Fitt and O'Brien 1985) means that precautions should be taken to limit *Drosophila* populations around laboratory colonies.

When oviposition occurs into whole fruit, either in the field or in the laboratory, FFT bacteria are introduced with the eggs and larval development occurs in a soup of bacteria which frequently comprises only 1 or 2 species of FFT bacteria (Lloyd 1991). In laboratory rearing procedures, eggs are usually collected in artificial egging devices or in hollowed-out fruit and are then seeded on to larval diet. This procedure effectively removes many of the natural FFT bacteria from the rearing environment. The pH of larval medium is so low that few FFT bacteria survive and the natural bacterial association with the larvae is lost. The nutritional significance of this in laboratory rearing is poorly understood. Studies with *B. dorsalis* (Tamashiro et al. 1990) have shown that under axenic (microbe-free) rearing conditions, fecundity was significantly reduced although other rearing parameters such as incubation period of eggs, percentage egg hatch, percentage pupation, adult emergence, appeared to be unaffected.

Bacteria as a Dietary Supplement for Adult Flies

In view of the abundance of evidence to indicate that FFT bacteria play an important role in fruit fly nutrition, supplementary feeding of adult flies with live cultures of FFT bacteria was commenced in Queensland some years ago. The technique was found to be beneficial in helping newly established colonies to adapt to laboratory rearing conditions and in improving mating vigour, fecundity and fertility of older colonies. In recent years, supplementary bacterial feeding has frequently been adopted in establishing new colonies of previously uncultured endemic pest species in several Pacific Island countries (Allwood, pers. comm.). Although the benefits of live bacterial supplements in the adult diet have been observed, they have not been quantified in specifically designed feeding tests. Further research is warranted in this area.

Methodology

The methods developed at QDPI to isolate and identify FFT bacteria and to prepare and use bacterial feeding plates are given below.

Isolation of FFT bacteria

To obtain pure cultures of FFT bacteria for use as a feeding supplement, these bacteria must first be isolated (and preferably identified) from fresh wild flies of the species to be reared. Wild flies should be caught by hand in fruiting host trees using sterile glass tubes. After anaesthetising by cold (3 minutes in freezer), flies are surface sterilised first in 70% alcohol (30 seconds) and then in 0.25% sodium hypochlorite (1 minute) as described by Lloyd et al. (1986). Flies are then aseptically mounted in a sterile wax block and dissected using fine dissecting forceps and sterile technique. The crop or part of the mid-gut is then removed and streaked on to sterile plates of a suitable bacteriological medium (e.g. Peptone Yeast Extract Agar — PYEA) as described by Lloyd et al. (1986). Inoculated plates should be incubated for 2–3 days at 30 °C before predominant colonies are subcultured to obtain pure cultures of FFT bacteria. Selected isolates should be identified using standard bacteriological techniques and commercially available identification test strips for Enterobacteriaceae.

If fresh wild flies are not available, FFT bacteria may be isolated from rotting tissue associated with larvae in an intact infested host fruit. Fruit with unbroken skin must be selected and surface sterilised in 70% alcohol (2 minutes) followed by 0.25% sodium hypochlorite (5 minutes) prior to aseptic dissection. A loopful of rotting tissue can be streaked onto an agar plate and incubated and subcultured as described above. Once a pure culture of an identified FFT bacterial species has been obtained, stock slope cultures should be maintained for inoculating feeding plates as required. The purity of stock cultures should be checked regularly by streak plating.

Preparation and use of bacterial feeding plates

When adult diets are supplemented with live bacterial cells, the normal dietary components of hydrolysed protein, sugar and water must also be provided. Bacterial feeding plates should be inoculated from a fresh 2–3 day old slope culture of the FFT species. A

sterile water suspension (5 mL) of the bacteria should be prepared using a sterile pasteur pipette to suspend the growth from the slope. Two or three drops of bacterial suspension should be placed on a sterile agar plate of medium. The drops are spread over the surface of the agar with a glass spreader rod sterilised by dipping in alcohol and flaming. Plates should be incubated for 48 hours at 30°C to provide a thick, even lawn of bacterial growth.

Freshly cultured plates of bacteria are preferred for supplementary feeding but, if necessary, cultured plates may be sealed in plastic and stored for up to 5 days in the refrigerator before use. To present the bacteria to caged flies, the agar in the plate should be loosened (by running a spatula around the edge) and then the plate inverted on to the top of a cage to allow the loosened agar to rest on the cage gauze, bacterial side down. The empty petri dish should be left inverted over the agar. Feeding plates should be replaced after approximately 3 days and used plates and agar should be autoclaved prior to disposal. FFT bacteria are not known to be pathogenic to humans, but all general microbiological precautions for dealing with live organisms should be observed.

Conclusion

Much has been written about the methodology employed in laboratory rearing of fruit flies (Leppla 1989, Fay 1989). Diet bases and nutritional supplements for both adults and larvae have been investigated for many different fruit fly species. However, the nutritional importance of microbial flora in artificial rearing conditions has frequently been overlooked.

Over the past decade in particular, there has been increasing awareness of the role that bacteria play in the natural life cycle of fruit flies as both attractants and food sources. Applying this knowledge to laboratory rearing procedures by supplementing adult diets with live FFT bacteria has proven to be beneficial, particularly in establishing new colonies. Further research to investigate and quantify the longer term effects of live bacterial additions to normal laboratory adult diets would seem warranted.

References

Drew, R.A.I. and Lloyd, A.C. 1987. Relationship of fruit flies (Diptera: Tephritidae) and their bacteria to host plants. Annals of the Entomological Society of America, 80, 629–636.

Drew, R.A.I. and Lloyd, A.C. 1989. Bacteria associated with fruit flies and their host plants. In: Robinson, A.S. and Hooper, G., eds, World Crop Pests, Volume 3A, Fruit Flies, Their Biology, Natural Enemies and Control. Amsterdam, Elsevier Science Publishers, 131–140.

Drew, R.A.I. and Lloyd, A.C. 1991. Bacteria in the life cycle of tephritid Fruit Flies. In: Barbosa, P., Krischik, V.A. and Jones, C.G., eds, Microbial Mediation of Plant-Herbivore Interactions, John Wiley and Sons, New York, 441–465.

Fay, H.A.C. 1989. Rearing: Multi-host species of fruit fly. In: Robinson, A.S. and Hooper, G., eds, World Crop Pests, Volume 3B, Fruit Flies, Their Biology, Natural Enemies and Control. Amsterdam, Elsevier Science Publishers, 129–140.

Fitt, G.P. and O'Brien, R.W. 1985. Bacteria associated with four species of *Dacus* (Diptera: Tephritidae) and their role in the nutrition of larvae. Oecologia 67: 447–454.

Leppla, N.C. 1989. Laboratory colonisation of fruit flies. In: Robinson, A.S. and Hooper, G., eds, World Crop Pests, Volume 3A, Fruit Flies, Their Biology, Natural Enemies and Control. Amsterdam, Elsevier Science Publishers, 91–103.

Lloyd, A.C., Drew R.A.I., Teakle, D.S. and Hayward, A.C. 1986. Bacteria associated with some *Dacus* species (Diptera: Tephritidae) and their host fruit in Queensland. Australian Journal of Biological Sciences, 39, 361–368.

Lloyd, A.C. 1988. The distribution of alimentary tract bacteria in the host tree by *Dacus tryoni.* First International Symposium on Fruit Flies in the Tropics. Kuala Lumpur. Malaysia, 289–295.

— 1991. Bacteria associated with *Bactrocera* species of fruit flies (Diptera: Tephritidae) and their host trees in Queensland. PhD Thesis, University of Queensland.

Tamashiro, M., Westcot, D.M., Mitchell, W.C. and Jones, W.E. 1990. Axenic rearing of the oriental fruit fly, *Dacus dorsalis* Hendel (Diptera: Tephritidae). Proceedings, Hawaiian Entomological Society 30: 113–120.

Vijaysegaran, S. 1995. Mouthpart structure, feeding mechanisms and natural food sources of adult fruit flies in the genus *Bactrocera* (Diptera: Tephritidae). PhD Thesis, University of Queensland.

Rate of Development of the Immature Stages of *Bactrocera frauenfeldi* in Papaya-based Diet

L. Leblanc[1] and R. Hollingsworth[1]

Abstract

The duration of each instar and the pupal stage for *Bactrocera frauenfeldi* (Schiner) was experimentally determined in the Federated States of Micronesia (FSM) and Solomon Islands. Eggs were placed on a diet of papaya flesh, blended with torula yeast and nipagin. One hundred larvae were extracted every 12 hours. At 25.9°C, almost all larvae were going through the first instar during the 48 to 72 hours after egg laying. Between 96 and 108 hours, more than 90% had reached the second instar in FSM (68 and 80 hours in Solomon Islands). Third instars appeared at 120 hours and after 192 hours, nearly 90% had reached this stage in FSM, but in Solomon Islands appeared at 92 hours and were dominant after 128 hours. By 204 hours, mature larvae started to exit the diet to pupate and the largest numbers of larvae exited at 252 hours. Pupal stage duration was 11 days. Mean total development time from egg to adult was 21.5 days in FSM.

MANGO fruit fly, *Bactrocera frauenfeldi* (Schiner), is a pest of breadfruits, guavas, mangoes, papayas, Tahitian chestnuts, *Syzygium* spp. and many other fruits present in northeastern Australia, Papua New Guinea, Solomon Islands and most of Micronesia, from Palau to Kiribati, with the exception of Guam and Northern Mariana Islands. It is the most abundant pest fruit fly in Solomon Islands and the only species present in the Federated States of Micronesia (FSM). Laboratory colonies of mango fruit fly have been maintained in Solomon Islands since May 1994 and in FSM since January 1995. These were established to carry out basic research on the life history of mango fruit fly, on the host status of various fruits and on quarantine treatments using heat. This paper reports on the duration of the three larval instars and the pupal stage.

Methods

In FSM, a standard procedure developed by the Regional Fruit Fly Project (RFFP) was followed. Five replicates were used. Papaya egging domes were made by cutting the ends off ripe papayas, hollowing out the flesh leaving a minimal amount of flesh on the skin, and puncturing the skin with an entomological pin. Eggs were collected by placing these domes inside of cages containing two and a half to three weeks old gravid mango fruit flies. The domes were left inside the cages for two hours (replicates 1 and 2) or six hours (replicates 3 to 5) to ensure that enough eggs were obtained. Eggs were washed from the domes with a gentle spray of water. They were deposited on artificial diet in five trays, each containing 700 grams of RFFP standard larval diet (500 g papaya flesh blended with 26.7 g of torula yeast and 1.3 g of nipagin). The number of eggs placed in each tray, estimated with the calibrated dropper, was 3600. The trays were kept over moist sawdust in separate plastic boxes with a fine mesh screen top. Percentage egg hatch was determined by placing at least 100 eggs on moistened black filter papers inside petri dishes and by counting the number of unhatched eggs after 72 hours. Percentage egg hatch was 81.6% in replicates 1 and 2 and 83.5% in replicates 3 to 5.

Starting 48 hours after the beginning of egg laying, at least 100 larvae were extracted from each diet tray by scooping out a small amount of diet containing larvae, at 8.30 am and 8.30 pm. Larvae were extracted by diluting the diet in water and sieving the solution through a fine net strainer that retained the larvae. Larvae were killed in boiling water which

[1] Regional Fruit Fly Project in the South Pacific. South Pacific Commission, Private Mail Bag, Suva, Fiji

was allowed to cool to room temperature before the larvae were transferred into vials containing 70% isopropyl alcohol. Larvae were extracted for 156 hours for replicate 4, up to 192 hours for replicate 3, and up to 240 hours for replicates 1, 2, 5. Numbers of larvae from each instar were counted and the proportions of first, second and third instars calculated for each sample extracted from the trays. Larval identification was based on White and Elson-Harris (1992). The total numbers of larvae extracted and counted were 1585 first instars, 2838 second instars and 3379 third instars. In replicates 3 to 5, mature larvae exiting the diet were also extracted from the sawdust every 12 hours, counted and placed in small containers with moist sawdust inside small ventilated containers. Larvae from each collecting time and replicate were placed in separate containers to allow accurate determination of the duration of the puparia. In total, 1462 mature larvae were collected, from which 1199 adult flies emerged.

Throughout the study, ambient and diet temperature was recorded four times daily (8.00 am, 12.00 noon, 4.00 pm, 8.00 pm) for the first 240 hours and twice a day (8.00 am, 6.00 pm) while puparia were incubating until adult emergence. Temperature remained within an acceptable range, with means ± standard deviations of 26.5 ± 0.5°C (ambient), 25.9 ± 0.3°C (diet) and 26.8 ± 0.4°C (ambient while puparia were present).

In Solomon Islands, the methods were similar to those used in FSM except for the following differences. Egging domes were left inside the cage for 22 hours. Percentage egg hatch was 33%. Time was expressed as number of hours after beginning of egging, as in FSM. Only two replicates were used. The first replicate, with 3000 eggs in 1000 g of diet, was used to extract larvae during the first 139 hours. The second replicate, with 2000 eggs in 500 g of diet, was used to extract larvae from the diet between 140 and 162.5 hours and to collect mature larvae every 12 hours to determine pupal stage duration. Larvae were extracted by diluting the scooped out diet in water saturated with sugar, which caused the larvae to float. It was not possible to obtain as many as 100 larvae every 12 hours. In total, 128 first instars, 241 second instars and 256 third instars and 166 mature larvae were collected. Diet temperature, recorded every 12 hours during larval development, was 24.1 ± 0.7°C.

Results and Discussion

Results for mango fruit fly in FSM have allowed confident determination of the duration of each stage at a constant temperature. Figure 1 illustrates the results as the proportions of each instar every 12 hours after egg laying. All larvae were at first instar in the first 48 to 72 hours. At 84 hours, at least 50% of the larvae

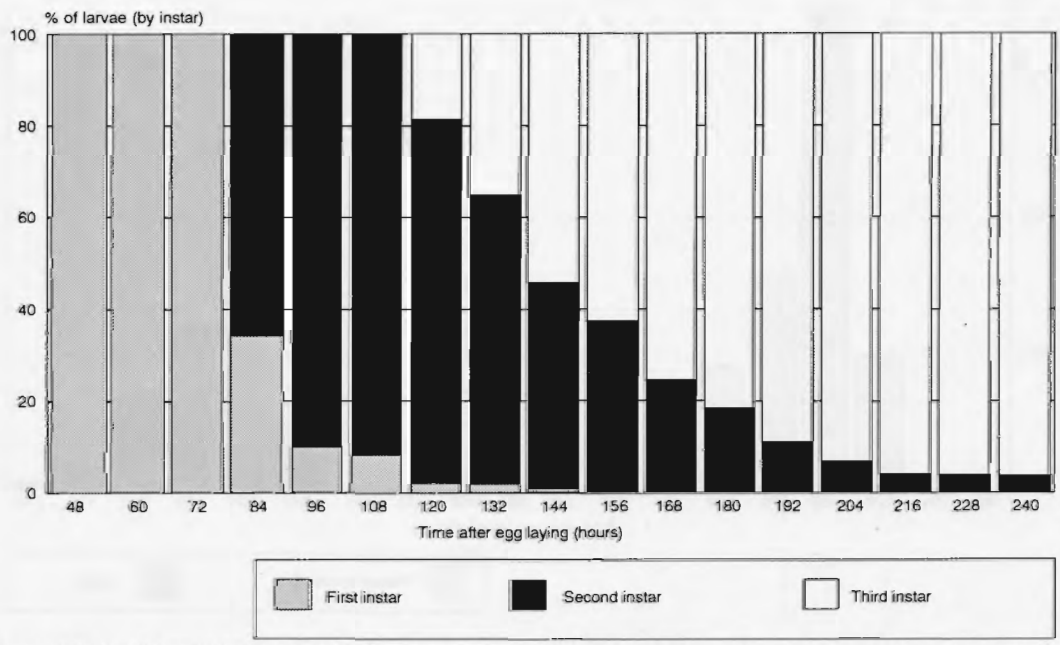


Figure 1. Rate of larval development for *Bactrocera frauenfeldi* as a percentage of larvae of each instar extracted from papaya-based diet every 12 hours in the Federated States of Micronesia (mean of replicates 1 to 5).

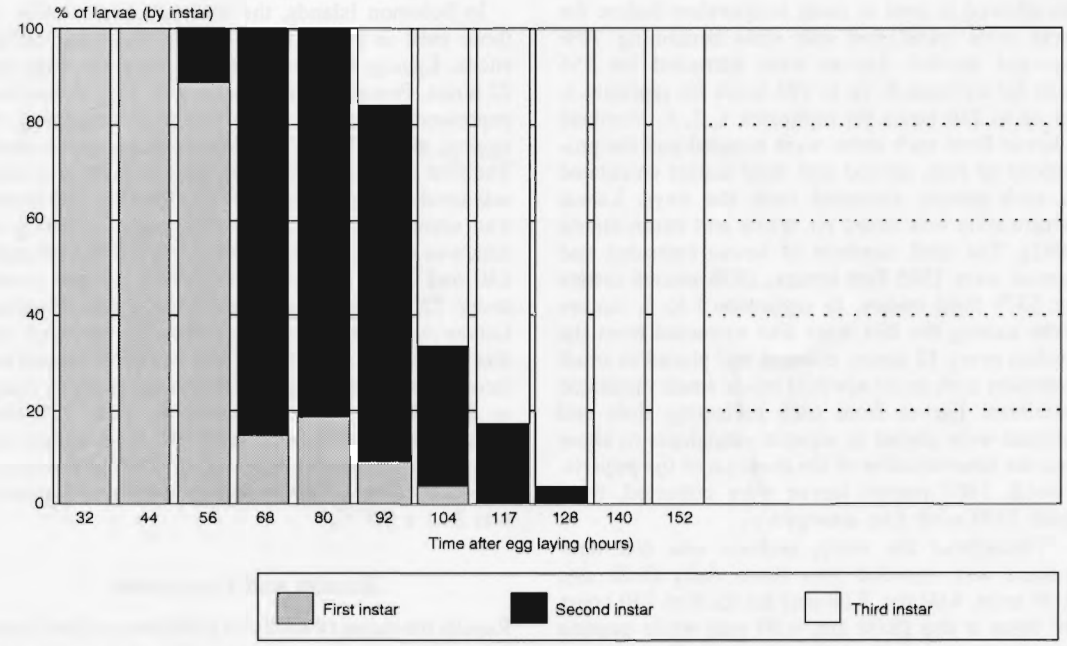


Figure 2. Rate of larval development for *Bactrocera frauenfeldi* as a percentage of larvae of each instar extracted from papaya-based diet every 12 hours in the Solomon Islands (one replicate).

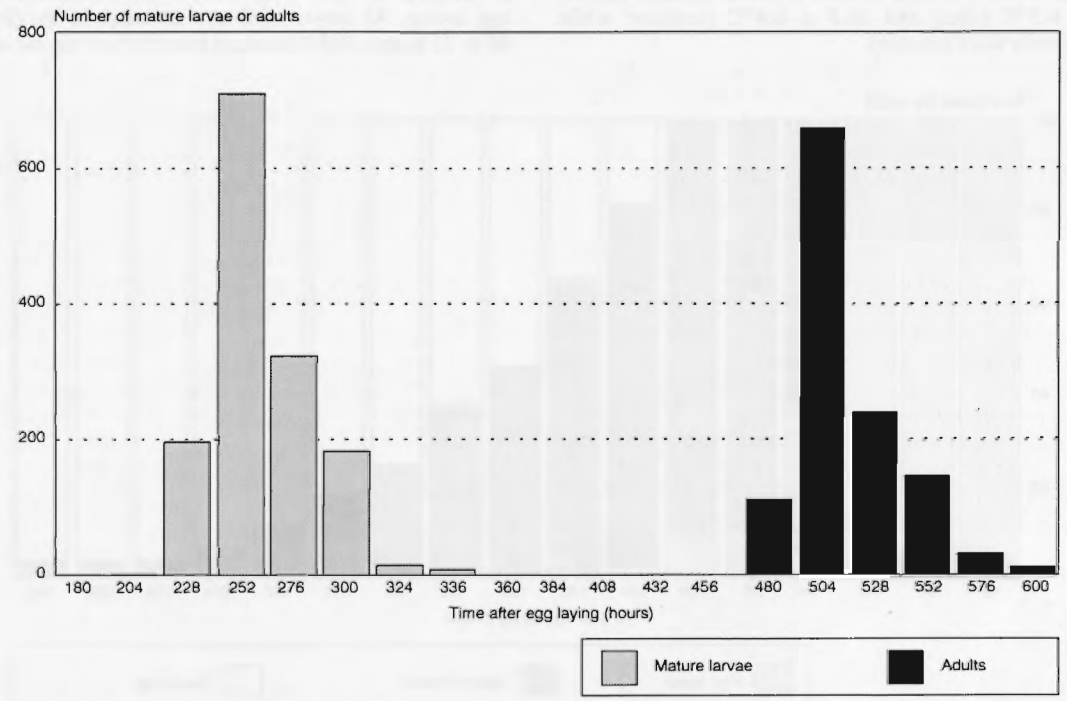


Figure 3. Rate of development for *Bactrocera frauenfeldi*: larval maturity and adult emergence (total of replicates 3 to 5 every 24 hours).

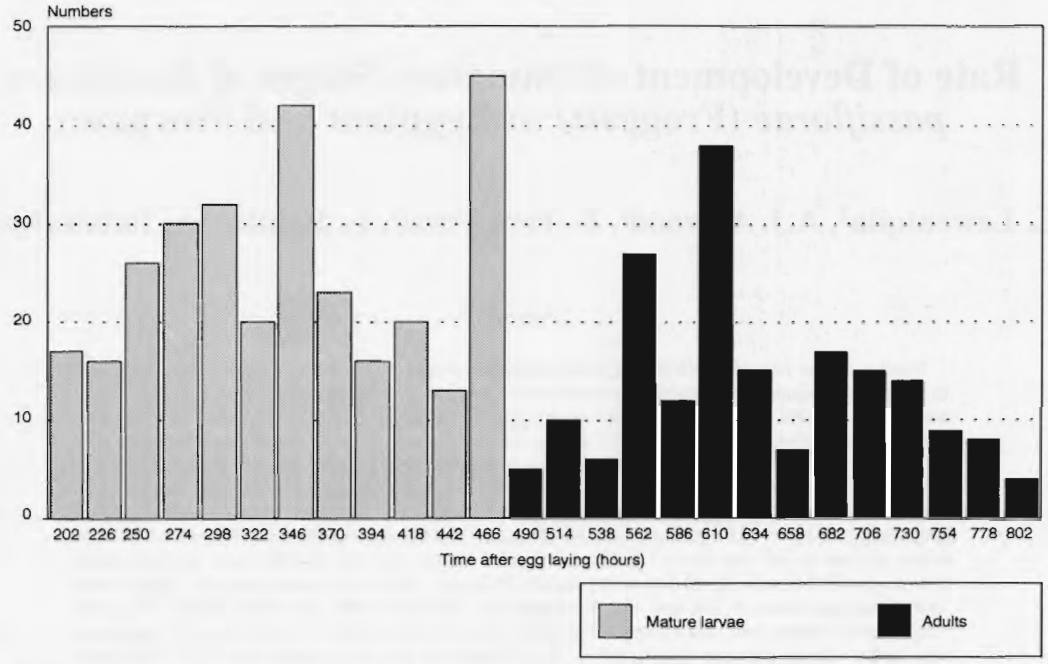


Figure 4. Larval maturity and adult emergence for *Bactrocera frauenfeldi* in the Solomon Islands (total numbers of mature larvae and adults emerged every 24 hours).

had reached the second instar in every replicate and over 90% were at that stage between 96 and 108 hours. Third instars appeared at 120 hours and nearly 90% of the larvae had reached the third instar at 192 hours. Diet temperature remained constant throughout larval development. This contradicts the usual increase in temperature during the third instar. Number of larvae in the tray used for temperature recording may have been too low to cause an increase in temperature. At 192 hours, 1190 larvae had already been extracted from that tray and only 329 larvae were subsequently obtained.

By 204 hours, a few larvae started exiting the diet to pupate in the sawdust. In the three replicates (3 to 5), the maximum number of larvae exited after 252 hours, which is therefore the mean duration of egg and larval development. Figure 3 illustrates numbers of mature larvae collected and numbers of adults eventually emerging every 24 hours. The proportion of adults emerging from the pupae was 82%. The duration of the pupal stage was consistently 11 days. The emerging adults were not sexed. Total development time, from egg to adult, was therefore 21.5 days at 25.9°C (larval stage) and 26.8°C (pupal stage).

In Solomon Islands, larval development time was similar to that in FSM, but slightly faster (Fig. 2). Second instars started appearing at 56 hours and over 80% were at that stage at 68 and 80 hours. Third instars were observed by 92 hours and were prevalent (90%) at 128 hours. The first mature larvae exited the diet at 202 hours and larvae gradually became mature until 466 hours (Fig. 4).

Percentage adult emergence was 77.7%. Pupal stage was shorter for males than females. For males, 60% emerged after 11 days, 33% after 12 days, 4% after 13 days, and 3% after 14 days. For females, 54% emerged after 11 days, 37% after 12 days, 7% after 13 days, and 2% after 14 days. Total development to adult varied from 20 to 34 days. Regular physical disturbance of the cultures, by vibration of the table and handling of the trays, stimulated larvae to massively pop exit the diet. It is the most likely cause for the flattened larval emergence peak observed in Figure 4. Detrimental effects of disturbance is also suggested by the high mortality of pupae from the larvae that pupated early.

Reference

White, I.M. and Elson-Harris, M.M. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. International Institute of Entomology. Australian Centre for International Agricultural Research. 601 p.

Rate of Development of Immature Stages of *Bactrocera passiflorae* (Froggatt) in Eggplant and Pawpaw

L. Leweniqila[1], A.J. Allwood[2], E. Tora Vueti[1], L. Ralulu[1], A. Balawakula[1]

Abstract

Studies on the rate of development of the immature stages of *Bactrocera passiflorae* (Froggatt) in eggplant (*Solanum melongena* Linnaeus) and pawpaw (*Carica papaya* Linnaeus) fruits were undertaken on the laboratory colonies at Koronivia Research Station, Nausori, Fiji. The temperature was maintained at 24.5 ± 0.5 °C. Eggs were collected using hollowed out, punctured ends of a pawpaw for 8 hours. Two wedges were made on the opposite sides of each fruit and approximately 200 eggs were placed in each wedge. Each artificially seeded fruit was destructively sampled by collecting approximately 100 eggs or larvae every 12 hours. In pawpaws, egg hatch began after 36 hours and was completed by 48 hours. The duration of the first instars was 48 to 96 hours, second instars was 84 to 156 hours and third instars was 120 to 180 hours. Second instars first appeared between 72 and 84 hours and by 96 hours, 80% were second instars. Third instars first developed between 108 and 120 hours and by 144 hours, 96% were third instars. Pupation started at 192 hours and was completed at 240 hours. Eclosion began at 480 hours. In eggplants, egg hatch was the same as for pawpaws. The duration of the first instars was 48 to 144 hours, second instars was 72 to 180 hours, and third instars was 120 to 180 hours. Second instars first appeared between 60 and 72 hours and by 120 hours, 73% were second instars. Third instars first appeared between 108 and 120 hours and by 180 hours, 90% were third instars. Pupation began at 192 hours and eclosion began at 420 hours.

FRUIT flies are regarded as the major pest of the horticulture industry and for many countries, their mere presence and or damaging effects have necessitated the adoption of post-harvest disinfestation treatments. Fiji is no exception and with the imminent withdrawal of fumigation using ethylene dibromide (EDB) as a post-harvest disinfestation treatment for the export of fresh fruits and vegetables, it has had to research alternative quarantine treatments.

As an exporting country to New Zealand, Fiji is required to determine rates of development of fruit fly species in fruits as outlined in the New Zealand Ministry of Agriculture and Fisheries Regulatory Authority Standard 155.02.03, Specification for the Determination of Fruit Fly Disinfestation Treatment Efficacy. These studies are a precursor to the development of a disinfestation treatment as they identify the duration of different life cycle stages and the stages to be targeted for heat tolerance studies. These studies on the rate of development of the immature stages of *Bactrocera passiflorae* (Froggatt) in fruits of pawpaw and eggplant were undertaken by the Regional Fruit Fly Project in conjuction with three Fiji College of Agriculture students as their final year projects.

[1] Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Reseach Station, PO Box 77, Nausori, Fiji
[2] Regional Fruit Fly Project, South Pacific Commission, Private Mail Bag, Suva, Fiji

Materials and Methods

Eggs of *B. passiflorae* were collected using hollowed out, punctured ends of pawpaws during an eight hour period. Eggs were washed out of the pawpaw dome with water using a handsprayer. A sample of 100 eggs was set up on moist filter paper held in a petri dish, which was covered and placed in an opaque container to determine percentage egg hatch. Fruit selected for artificial infestation were of export quality i.e. free of bruises, pawpaws were at colour break and free of insecticides. Fruits were harvested one day before infestation, washed in water and

placed in cool storage. Before infestation, fruit surfaces were wiped with 70% ethanol. A cork borer (No. 3) was used to make two to three wedges on either side of the fruit. Using a plastic dropper, approximately 100 eggs were placed onto each wedge, the wedge was replaced and secured with tape. For eggplants, a strip of black filter paper was placed into the hole of one fruit to help the observations on time of egg hatch. Fruits were placed in sealed, well-ventilated containers. Each artificially seeded fruit was destructively sampled by collecting approximately 100 eggs or larvae every 12 hours. For pawpaws, a saturated solution of sugar (200 g/L of water) was prepared for floatation of larvae from the flesh of the fruit. Larvae were extracted and placed in a beaker of hot water. After the water cooled, it was drained and larvae placed in vials of 70% ethanol solution. Observations were carried out using a light microscope. For eggplants, the fruits were placed under a microscope and a fine tipped paintbrush used to collect 100 larvae or eggs. These were placed in a beaker of hot water until the water cooled and then transferred to vials of 70% ethanol solution for later observations under a light microscope. The study on eggplants was replicated three times.

Results and Discussion

In pawpaws, as shown in Figure 1, egg hatch began after 36 hours and was complete by 48 hours. First instars were present until 96 hours; making the duration of first instars from 36 to 96 hours, after oviposition. At 84 hours, second instars first appeared, making up 25% of the sample collected. At 96 hours, 80% of larvae collected were second instars. The duration of this stage was from 84 to 156 hours. At 120 hours, third instars first appeared, making up 49% of the sample collected. At 144 hours, 96% of larvae collected were third instars. The duration of this stage was from 120 to 180 hours. The first pupation was recorded at 192 hours and the last by 240 hours. Eclosion began at 480 hours and observations ceased at 528 hours. In terms of days, eggs began to hatch by one and a half days, second instars developed by three and a half days, and third instars developed by the fifth day. Pupation began at the eighth day and eclosion began on the 20th day.

In eggplants, as shown in Figure 2, egg hatch began after 36 hours and was complete by 48 hours. The duration of first instar was from 36 to 144 hours. Second instars first appeared at 72 hours, although only 1% of the sample collected. At 120 hours, 73% of larvae collected were second instars. The duration of second instars was from 72 to 180 hours. Third instars first appeared at 120 hours and by 180 hours, 90% were third instars. The duration of third instars was from 120 to 180 hours. The first pupa appeared at 192 hours. Eclosion began at 420 hours. In terms of days, eggs began to hatch by one and a half days, second instars developed by the third day and third instars developed by the fifth day. Pupation began on the eighth day and eclosion at 17.5 days.

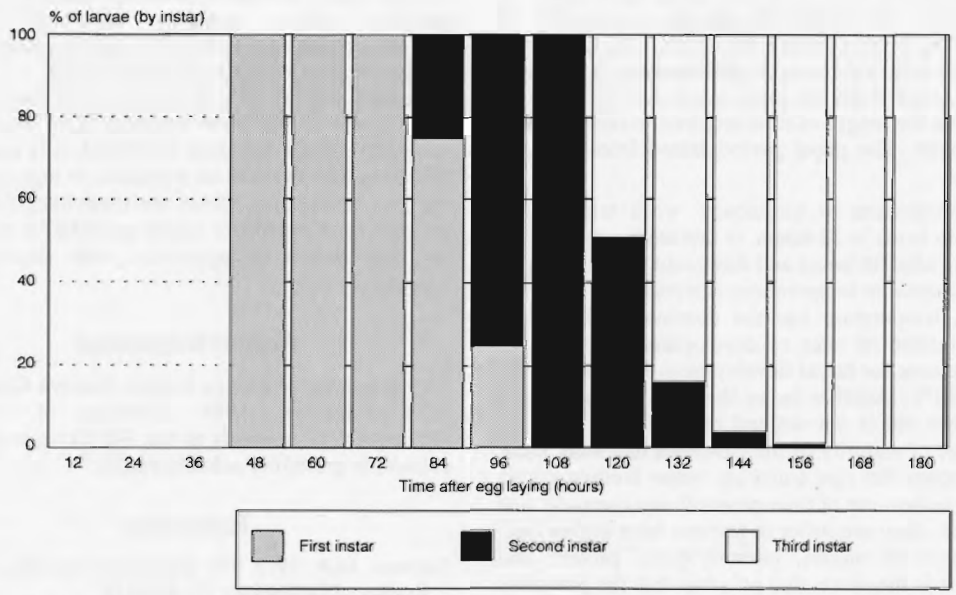


Figure 1. Rate of *Bactrocera passiflorae* larval development in papaya. Experiment carried out at Koronivia Research Station, Fiji.

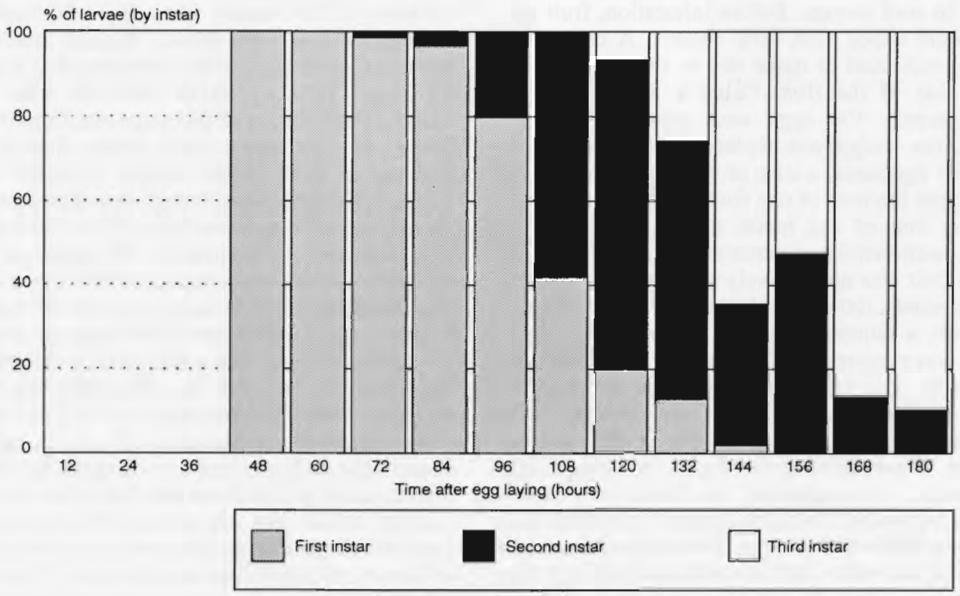


Figure 2. Rate of *Bactrocera passiflorae* larval development in eggplant. Experiment carried out at Koronivia Research Station, Fiji.

Simmonds (1935) found that when using pawpaws as food, minimum larval periods from 7 to 10 days were obtained in different batches. Under normal Fijian summer conditions, with temperatures in the range of 25–29 °C, he found the duration of the egg stage to be 32 hours. The first instar lasted from 20 to 24 hours and the second instar also lasted about 24 hours. The duration of the third instar was very variable, not only in different fruits, but even in the same fruit. Larvae from the same batch of eggs differed greatly in the length of time required to complete the third instar. The pupal period lasted from eight to ten days.

In comparison to Simmonds' work where eggs started to hatch in 32 hours, in this study eggs started hatching after 36 hours and this could be attributed to the difference in temperature. According to Bateman (1972), temperature has the dominant role in the determination of rates of development and optimal temperatures for larval development are in the range of 25–30 °C. Another factor that could have made a difference but is not defined in the former study is the stage of maturity of the pawpaws that were used. It is known that ripe fruits are better feeding media for larvae because of their physical and chemical features, i.e., they are softer in texture, have higher concentrations of sugars, carbohydrates, protein and water. It is therefore also possible that the pawpaws used in Simmonds' work were at a riper stage than colour break.

When comparing the results obtained in this study for the rates of development in eggplant and pawpaw, it is seen that the development of larvae in eggplant is more prolonged than that in pawpaws at each larval stage. This could have been due to many factors, with the main ones being the differences in nutritive value of pawpaws and eggplants and changes in the fruit caused by decomposition from the invasion of bacteria, yeasts and fungi.

As determining rates of development is a technical requirement of the New Zealand MAF Regulatory Authority NASS Standard 155.02.03, it is inevitable that future studies will be focussed on high potential export commodities. These are most likely to be on mangoes and breadfruit based on MAFFA priorities and the results of appraisals with farmers and exporters.

Acknowledgements

The assistance of Shalen Kumar, Sandya Chand and Vika Raiwalui, 1995 Diploma of Tropical Agriculture III students at the Fiji College of Agriculture, is gratefully acknowledged.

References

Bateman, M.A. 1972. The ecology of fruit flies. Annual Review of Entomology 17: 493–518.

Simmonds, H.W. 1935. Fruit Fly Investigation. Department of Agriculture, Fiji. Bulletin No. 19. 7–8.

Control Strategies for Fruit Flies (Family Tephritidae) in the South Pacific

A.J. Allwood[1]

Abstract

Fruit flies (family Tephritidae) are recognised world-wide as being one of the most serious pests of horticultural production in tropical and sub-tropical regions. As well as causing direct fruit and vegetable losses, their presence in a country results invariably in constraints to international and, in some instances, within-country trade. The strategies for controlling fruit flies in Pacific island countries comprise regulatory control, physical control, cultural control, biological control, behavioural control, genetic control, chemical control and combinations of some of these into an Integrated Pest Management approach. Each of these strategies is discussed in the context of the Pacific island countries and both subsistence and commercial production. For Pacific island countries, emphasis should be placed on the adoption of regional harmonisation of quarantine requirements with respect to the movement of fruit fly hosts to restrict the spread of unwanted fruit fly species. Field control of fruit flies should focus on growing crops that are not prone to fruit fly attack, bagging of high-value produce, sound crop sanitation, early harvesting, where appropriate, and the use of protein bait sprays in subsistence and commercial production.

FRUIT flies (family Tephritidae) are one of the most serious insect pests of horticultural produce throughout the tropical and sub-tropical world. They attack sound and damaged fruits and vegetables by laying eggs under the skin. The eggs hatch into larvae that feed in the decaying flesh of the fruits or vegetables. Infested fruits and vegetables quickly become rotten and inedible or drop to the ground prematurely, thus causing considerable losses in production. Feeding by fruit fly larvae cause complete destruction of fruits, rather than cosmetic damage as is caused by many other insect pests. As well as these direct losses, other major losses result from quarantine restrictions that are imposed by importing countries to prevent the entry and establishment of unwanted fruit fly species. Considerable financial burdens are imposed on Governments, farmers and exporters, who have no choice but to implement quarantine surveillance systems, quality assurance schemes and acceptable post-harvest quarantine treatments if they wish to export fruit fly host products.

Fruit flies have unique biological, economic and social attributes that determine the types of control systems in horticultural crops (Roessler 1989). Fruit flies are 'r-selected' and as such show a high reproductive capacity with relatively short and overlapping generations and sudden outbreaks (Bateman 1972). Most fruit fly species are very mobile and are effective at searching for food and oviposition sites. This combination of attributes makes them very successful at colonising new areas, at achieving large populations relatively quickly and causing enormous losses to horticultural production, especially in the tropical and sub-tropical regions of the world. Fortunately, male and female flies need protein to complete sexual maturity, thus providing a viable option for control by using protein-based baits.

This paper identifies and discusses options for fruit fly control that may be appropriate for South Pacific nations.

Strategies for the Control of Fruit Flies

Strategies for the control of fruit flies include physical control, cultural control, biological control, behavioural control, genetic control, chemical control and combinations of some of these into an Integrated Pest Management (IPM) approach. Some of these techniques are appropriate for South Pacific island nations; others such as genetic control are

[1] Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji

probably too expensive or too sophisticated technically to use in the South Pacific under normal conditions.

Physical control

The principle of physical control involves providing a barrier between the host fruits and the egg-laying female fruit fly. The most common method is to bag or wrap fruit before the fruits reach a stage of maturity at which they are susceptible to infestation. Bags made from double layers of newspaper or brown paper are used.

Bagging or wrapping is a common practice in Malaysia for the protection of crops of carambola or starfruit (*Averrhoa carambolae* L.), particularly those grown for export (Vijaysegaran 1989). In Malaysia, damage levels may be reduced from nearly 100% to 15–25% by bagging. Similarly, this technique is used in Thailand to protect mangoes from fruit fly attack and in Taiwan to protect melons from melon fly (Wen 1988). Unconfirmed reports show that some mango growers in the Mareeba and Townsville areas of Queensland are investigating the prospects of bagging to supplement other methods of control, such as protein bait spraying.

Generally, this technique is applicable where relatively small areas of production are involved (e.g., village or subsistence production); where the costs of labour is cheap; where high quality, high value, unblemished produce is necessary; and where no alternative practical methods of control are available. This technique is appropriate for South Pacific island production systems and should be encouraged especially for backyard and village production.

Cultural control

Cultural control includes practices such as those below, that may be regarded as part of the normal production system and do not include the application of insecticides.

Production during periods of relatively low fruit fly activity

Fruit fly activity and populations vary throughout the year. Trapping data in several Pacific Island countries (Tonga, Fiji, Cook Islands) show that the populations of fruit flies are low during May, June, July and August, i.e., during the cooler months. Damage caused by *Bactrocera facialis* (Coquillett) to capsicums in Tonga at this time of the year, for example, is relatively low — less than 10%. Therefore, the growing of capsicums in Tonga in May–August may be worthwhile, considering that New Zealand authorities are prepared to consider seasonal abundance data and data on seasonal damage levels in low risk crops as part of a move to recognise a 'winter window' for importation of some commodities. The combination of low fruit fly activity and effective field control in the exporting country during cooler months and the low risk of establishment of fruit flies in winter months in the importing country may open up new markets for low risk fruit fly host commodities. Also, growing crops during the cooler months reduces pressure on the effectiveness of field control systems, such as protein bait sprays.

Growing less susceptible varieties

With the advent of a standard for testing the susceptibility of various fruits and vegetables to fruit flies (Anon. 1994), there is an option now to be able to grow varieties that may be less susceptible or not susceptible to fruit flies. Under the Regional Fruit Fly Project in the South Pacific (RFFP) in Fiji, two varieties of chillies, 'Hot Rod' and 'Red Fire', have been cleared by New Zealand Ministry of Agriculture (Regulatory Authority) for export without additional post-harvest quarantine treatment. These varieties are classed as non-hosts for fruit flies in Fiji (Heimoana et al., these Proceedings).

Similarly, fruit crops such as lychee and rambuttan are not infested by fruit flies in northern Thailand, providing the skin is intact. Pineapples are not hosts for fruit flies at any stage of maturity in Fiji (Heimoana et al., these Proceedings). Other crops that may be non-hosts or at least low risk are squash (pumpkin), zucchini, cucumber, some varieties of watermelon, rockmelon, limes and pawpaw at colour break in some countries in the South Pacific.

Sound crop sanitation

The collection and destruction of fallen, damaged, over-ripe and excess ripe fruits is strongly recommended to reduce the resident population of fruit flies. Convincing farmers that this practice may remove a major source of infestation is often difficult as the practice is time-consuming and labour intensive.

Evidence from Hawaii shows that pawpaws left on the ground act as a major breeding site for Oriental fruit fly (*Bactrocera dorsalis* (Hendel)) and melon fly (*Bactrocera cucurbitae* (Coquillett)). Melon fly infestation was recorded in pawpaw fruits on the ground throughout a study period of 21 months, but for only part of the period in fruits on the trees. This shows that melon fly will infest pawpaws on the ground. Larval loads per fruit on the ground were significantly higher than larval loads of fruits on the trees. To eliminate or reduce this reservoir of the resident population, crop sanitation should be an essential component of melon fly and

Oriental fruit fly programs in pawpaw orchards in Hawaii (Liquido 1991).

Initial results from sampling cumquats (*Fortunella japonica* Thunb.) in Fiji indicate similar trends to those for pawpaw in Hawaii. Thirty-five percent of the fruits on the ground were infested with *Bactrocera passiflorae* (Froggatt), while about 7% of fruits on the tree at a similar stage of maturity were infested (RFFP, unpubl. data).

Crop residues such as fallen, over-ripe or damaged fruits may be destroyed by deep-burying or by burning or by feeding to pigs. Putting fruit or vegetable residues into compost heaps or rubbish dumps is not recommended. Not adopting sound crop sanitation places unnecessary pressure on other components of control systems, particularly protein bait sprays, whose effectiveness may be threatened under high population pressures. Under quality assurance schemes being adopted for production of commodities for export, sound crop sanitation is an essential component and a prerequisite for any farm that is registered for export production. This will inevitably increase the importance of sound crop sanitation as a component of an integrated approach to controlling fruit flies. Recognising the mobility of dacine fruit flies, crop sanitation needs to be encouraged over a wide area and, in some instances this may have to be supported by legislation.

Early harvesting

Avoidance of fruit fly infestation is possible by harvesting crops at a stage of maturity at which the fruit or vegetable is not susceptible to fruit fly attack. Bananas, for example, have been exported around the world because they are not susceptible to fruit flies at the mature green stage, except in countries where banana fruit fly (*Bactrocera musae* (Tryon)) and papaya fruit fly (*Bactrocera papayae* Drew and Hancock) occur. Banana fruit flies lay eggs in banana fruits when the fruits are very small. The eggs do not hatch until the fruit commences to ripen. Papaya fruit fly may also infest green bananas. Pawpaws, harvested at colour break, are less likely to be infested by fruit flies than if harvested at later stages of maturity. Harvesting at colour break has become one of the conditions for export of pawpaws to New Zealand from Cook Islands and Fiji. In Hawaii, Liquido et al. (1989) determined that the infestation rates of both Oriental fruit fly and melon fly in pawpaws increased with increasing fruit ripeness.

To facilitate using this option, the standard used to test the susceptibility of fruits to fruit flies (Anon. 1994) may also be used to assess the differences between the susceptibilities of fruits at various stages of maturity. For example, preliminary field cage tests on 'Waimanalo' and 'Sunrise' pawpaws at the colour break stage of ripeness in Fiji indicated that these varieties at colour break may not be infested by *Bactrocera xanthodes* (Broun) and *B. passiflorae* in Fiji (RFFP, unpubl. data).

Biological control

Despite a large amount of effort being devoted to the use of biological control agents (predators and parasitoids) to control fruit flies, there have been few instances that may be regarded as sustainable successes. Generally, predators have little effect on the populations of fruit flies in an orchard or vegetable production situation. Predators may include spiders, ants, carabid beetles, assassin bugs, staphylinid beetles, lygaeid bugs and probably others. In Crete, Bigler et al. (1986) found that the numbers of olive flies (*Bactrocera oleae* (Gmelin)) were reduced by birds that ate 81% of infested fruits. In consuming the fruits, predators, unfortunately, also consumed parasitoids so there is an indirect adverse effect. In the endemic forest habitat, however, predation by fruit-eating vertebrates such as birds and primates results in marked reductions in fruit fly numbers (Drew 1987).

The use of parasitoids to control fruit flies biologically has always had wide appeal, but tropical fruit flies have not, in general, proved to be good targets for biological control (Waterhouse 1993). Waterhouse also stated that this is unfortunate as there are more than a dozen damaging or potentially damaging native fruit fly species in the South Pacific region. The most documented research on using parasitoids to reduce fruit fly populations has been in Hawaii, where a large number of species of parasitoids have been introduced and released to control Oriental fruit fly, Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann)), and melon fly. The parasitoids belong to the families Braconidae, Chalcididae and Eulophidae. Releases of a suite of parasitoids resulted in reductions in populations of Mediterranean and Oriental fruit flies of up to 95% (Waterhouse 1993). Also, in normally heavily infested commercial fruits, the levels of damage caused by fruit flies were reduced to a point where the fruits were virtually free from infestation. These results were due mainly to the establishment of the wasp *Fopius arisanus* (Sonan) and, to a lesser extent, the establishment of *Fopius vandenboschii* (Fullaway) and *Diachasmimorpha longicaudata* Ashmead). Haramoto and Bess (1970) claimed that Oriental fruit fly, by 1968, was no longer a major pest of many kinds of fruits except guava, though they were heavily infested prior to the releases of the parasitoids. This level of control, however, has not been

sustained. Wong et al. (1984) contend that Oriental fruit fly and Mediterranean fruit fly are still very serious pests of a wide range of fruits and vegetables. They suggested that inundative releases of laboratory-reared parasitoids may be an appropriate option.

In Australia, there are several native parasitoids of Queensland fruit fly (*Bactrocera tryoni* (Froggatt)), but they exert very little control on populations of fruit flies (Snowball et al. 1962). CSIRO introduced several species of parasitoids into Australia in the 1950s. *F. arisanus* apparently bred in seven dacine and trypetine hosts, but by 1966, neither *F. arisanus* nor *D. longicaudata* affected the incidence of Queensland fruit fly (Snowball 1966). Now, only *F. arisanus* is established (Waterhouse 1993).

In the South Pacific, there are only a few native parasitoids of fruit flies. For example, *Diachasmimorpha hageni* (Fullaway) and *Psyttalia fijiensis* (Fullaway) were recorded in Fiji as early as 1916. Simmonds (1936) recorded parasitism levels of 5–10% in 1935. These promising results, together with results from Hawaii, saw a major effort to introduce parasitoids to Fiji and Cook Islands between 1927 and 1935 and in the 1950s. Parasitoids such as *F. arisanus, D. longicaudata, Aceratoneuromyia indica* (Silvestri), *Tetrastichus giffardianus* Silvestri and *Psyttalia concolor* (Szépligeti) were introduced into Fiji.

Recent surveys during the RFFP in 1991–1995 show that parasitism levels are still relatively low, generally at less than 10%. This level of parasitism is consistent with parasitism levels throughout northern Australia and South-east Asia. There are occasions when levels of parasitism exceed 60%, but this is usually towards the end of a major fruiting season, e.g. guava. Based on these results, no special effort is being made in the South Pacific to encourage augmentative releases of existing parasitoids. However, field control systems based on protein bait sprays take cognisance of the need to conserve the parasitism levels that occur naturally.

With respect to melon fly in Solomon Islands, there may be a case to introduce a suite of parasitoids to reduce the population of melon fly to a level that may reduce the pressure on the efficacy of protein bait sprays. The RFFP and the Solomon Island Government are planning to introduce and release the parasitoid *Psyttalia fletcheri* Silvestri, and possibly later *F. skinneri* (Fullaway), *Diachasmimorpha dacusii* (Cameron), and *D. albobalteatus* (Cameron).

As the populations of mango fruit fly (*Bactrocera frauenfeldi* (Schiner)) are extremely high throughout the year in the Federated States of Micronesia, the release of *F. arisanus* to reduce the population is also planned.

Behavioural control

Use of colours, shapes and odours

Behavioural control covers an array of techniques that involve manipulation of some aspects of behaviour of fruit flies such that populations are reduced. Prokopy (1968) pioneered work on the attractiveness of different colours and shapes to adults of the apple maggot (*Rhagoletis pomonella* (Walsh)). Red spheres coated with a non-drying adhesive combined with attractants with odours resembling ripening apples resulted in excellent control of this pest species. The use of insecticide cover sprays was virtually eliminated. Unfortunately, though tropical dacine fruit flies are attracted to various colours (eg. Queensland fruit fly to blue and *B. xanthodes* to grey), there does not seem to be any immediate prospects for using this technique for control in the South Pacific

Male annihilation

Male annihilation involves the use of a high density of trapping stations consisting of a male lure combined with an insecticide (usually technical malathion), to reduce the male population to such a low level that mating does not occur. This is achieved by distributing cordelitos (lengths of 6-ply cotton string about 30–45 cm) or caneite blocks, compressed fibre-board or coconut husk (2.5 cm × 2.5 cm × 1.0 cm) impregnated with the lure/insecticide mixture. These are distributed from the ground or air at the rate of 250 per km^2. This treatment is repeated every 6–8 weeks. There are several examples of the successful use of methyl eugenol in the technique. Oriental fruit fly was eradicated from the Island of Rota in the Marianas by Steiner and his colleagues (Steiner et al. 1965). The insecticide used during the eradication was naled. Outstanding successes have been recorded using this method for eradication of Oriental fruit fly from California (Chambers et al. 1974) and from the Amami Islands of Japan (Shiga 1988).

Recently, this method, using lengths of string or cord soaked in methyl eugenol and malathion, was successful in eradicating papaya fruit fly from several Torres Strait Islands, in an effort to keep this species out of Cape York in Queensland (Drew, pers. comm.). This method is currently being used in an attempt to eradicate papaya fruit fly from northern Queensland (Fay et al, these Proceedings) and may be used to eradicate Oriental fruit fly from Tahiti and Moorea (Allwood and Drew 1996).

The effectiveness of using Cue-lure as the lure for the male annihilation of species attracted to it is not as great as that using methyl eugenol. Therefore,

attempts to use Cue-lure to eradicate melon fly populations have been unsuccessful, though populations were reduced initially. Cue-lure baits reduced the male population in islands of Japan by 99% after 5 months' treatment, but the percentage of mated females did not decrease (Iwaizumi et al. 1989). Using Cue-lure in this way is effective if combined with protein bait sprays as was used in eradicating Queensland fruit fly from Easter Island (Bateman et al. 1973).

This technique is applicable to specific situations where the areas being treated are geographically or ecologically isolated so there is no migration of males into the treated area. If the male annihilation technique is to be used, it is essential that the host ranges of the target species are known, because host surveys and liquid traps are the only reliable methods of assessment of populations after the male annihilation is commenced.

Protein bait sprays

The use of bait sprays comprising an attractant and a toxicant date from 1889 in Australia (Hooper 1989). The bait or attractant was usually molasses or sugar solution and the toxicant was usually a stomach poison such as lead arsenate or Paris green. Experiments were carried out against melon fly in Hawaii and against the cucumber and vegetable marrow fly (*Dacus vertebratus* (Bezzi)) in South Africa. The Hawaiian experiments indicated a reduction in fly numbers but not practical control (Back and Pemberton 1918), whereas the South African experiments suggested that 95% of a treated cucumber crop was saved from destruction (Gunn 1916).

Maxwell-Lefroy (1916) claimed that a mixture of equal parts of casein, sugar and water which was allowed to stand for 24 hours before use was an ideal fruit fly bait. Casein is an excellent source of protein and casein hydrolysate is reasonably attractive to some species of fruit flies, notably Mediterranean fruit fly (Mazor et al. 1987).

Subsequent developments tended to focus on the insecticide component of bait sprays and the bait component was nearly always sugar and molasses. Even though more attractive mixtures had been found earlier, it seems that they were never considered for use in bait sprays. This approach changed with Steiner's work in Hawaii on the use of protein hydrolysate as an attractant for bait sprays (Steiner 1952). The effectiveness of his spray combinations began to receive widespread recognition after a protein hydrolysate/malathion and water formulation was applied by aircraft in 1956 and 1957 to eradicate an outbreak of Mediterranean fruit fly in Florida (Steiner et al. 1961).

At the same time as Steiner was developing the protein hydrolysate bait spray, Gow (1954), also in Hawaii, was examining proteinaceous baits for Oriental fruit fly. He concluded that the attraction of proteinaceous materials was due chiefly to products of microbial action and a specific strain of the bacterium *Proteus* consistently gave the best results when cultured on soybean protein. Despite Gow's discoveries, protein bait sprays, until recently, remained basically unchanged from Steiner's pioneering work. These bait sprays were based on acid hydrolysates of a plant protein (usually derived from maize). They were used in Queensland in this basic form for about 15 years, until the past 10 years, when the acid hydrolysate component of bait sprays was replaced with a yeast autolysate.

The protein bait acts as a food attractant and its effectiveness relies on the fact that immature females need a protein meal to be able to develop mature eggs. When they feed on the bait spray residue on the foliage, they ingest the insecticide and die. Because the bait spray relies on its attractant properties for its mode of action, overall coverage of the tree canopy is unnecessary and a 'spot spraying technique' is adequate. Experiments and experience indicate that bait spraying is most effective in 'area' treatment programs. It is ideal for medium to large orchards or where adjacent properties use the technique. The method has been used to control fruit fly in the major citrus growing areas in Queensland for about 20 years and has proved very successful. This technique is now being used as one component of quality assurance schemes for export produce. For example, it is being used as a field control method for mangoes grown in Fiji for the Japanese markets. Similarly, protein bait sprays have been included in quarantine protocols developed between Fiji, Tonga and Cook Islands and New Zealand for export of eggplant, some chillies, watermelons and pawpaws.

Most bait sprays used in other parts of the world still rely on acid hydrolysates for their protein source, but in the South Pacific, Australia and Southeast Asia, a different protein formulation has been produced in recent years. The most commonly used protein now is a yeast autolysate produced by enzymatic autolysis. The protein hydrolysate used previously was manufactured by hydrolysing a plant protein with hydrochloric acid. This resulted in a protein bait with a very low pH. Excess acid was neutralised with sodium hydroxide leaving a residue of about 17% salt in the bait. Application of this type of bait spray often caused burning of fruit and foliage. There is minimal salt in the yeast autolysate used now so problems of phytotoxicity do not arise. Also, the pH of yeast autolysates are higher than the pH of acid hydrolysates. This may be better for the

growth of bacteria on the leaf surface in the presence of yeast autolysate. The yeast autolysate is more attractive to fruit flies than the acid hydrolysate previously used. It is possible that the presence of salt in the acid hydrolysate inhibited the development of naturally occurring bacteria which grow on the protein and contribute to the bait's attractiveness (Drew, pers. comm.).

The yeast autolysate produced in Queensland is a light brown liquid, containing 420 g per litre protein. It is marketed under the name Mauri's Pinnacle Protein Insect Lure. It may be stored at ambient temperature provided it is kept in a cool dark place. Refrigeration or air-conditioning will extend storage life and is recommended if possible, but it is not essential. In Malaysia, the protein source used in bait sprays is a yeast autolysate produced as a by-product of the brewing process in the production of stout. It is marketed under the name of 'Promar'. It has proved to be an excellent attractant for the local species of fruit flies. The implementation of a bait spraying program for fruit fly control in carambola using the new protein formulation has been very successful (Vijaysegaran 1989). Fruit-wrapping is still used for export quality fruit, but use of regular bait spray applications has allowed the critical period for wrapping and thinning to be extended. Another major advantage is that the protein bait sprays are less destructive to pollinators than the insecticide cover sprays previously used. As a result, overall production of carambola has increased dramatically. Malaysian researchers have since extended the bait spraying technique successfully to soursops and chillies and have done preliminary testing of the technique for large area application in mango plantations (Vijaysegaran, pers. comm.).

In the South Pacific, under the RFFP and ACIAR Project, a prototype plant to convert waste yeast from the Royal Beer Company brewery in Tonga into yeast autolysate has been established. This plant converts waste yeast into protein autolysate through a process of heating and addition of the enzyme papain and the food preservative potassium sorbate. This technology appears successful and economically viable in Tonga, and it may be extended to other countries in the South Pacific. Results from the RFFP and ACIAR Project in Fiji and Tonga show clearly that protein bait spraying is a very effective control method for fruit flies under conditions in the South Pacific. In Tonga, damage levels for capsicum and some varieties of chillies may be reduced from 97–100% to less than 7%, with weekly protein bait sprays of 20–25 litres of bait per hectare applied as a band of coarse spray to the foliage of plants in every third row (Heimoana et al., these Proceedings). The protein bait spray consists of 50 mL of Mauri's Pinnacle Protein Insect Lure plus 4 mL of 50% emulsifiable concentrate malathion made up to one litre with water.

In Fiji, by applying the above protein bait spray mixture to every guava tree in an orchard at Nadi on a weekly schedule, it was possible to reduce levels of damage from 40–45% to less than 4%. Similarly, by applying the protein bait spray to each tree in every second row of some 4000 mango trees in Nadi, it was possible to reduce levels of damage caused by *B. passiflorae* from 25% to 1–2% (Leweniqila et al., these Proceedings).

The major disadvantage of protein bait sprays is that control may not be totally adequate at times of extreme pest pressure, especially if re-invasion of the treated area is continuous, particularly where the treated area is small in relation to untreated, surrounding areas. Control may also be less effective as the season progresses and populations develop with females at all stages of sexual maturity. Recent studies have shown that gravid females of the Queensland fruit fly are less interested in food than in finding suitable egg-laying sites. They may, therefore, be less attracted to spots of protein bait spray and may sting some fruit before feeding on the poisoned bait. Consequently, there is always a chance that, as the season progresses, there will be some fruit infested.

However, the advantages of protein bait sprays far outweigh the disadvantages. Protein bait sprays are less harmful to beneficial insects making them suitable for use in IPM programs. Because of the spot spraying technique, there is less insecticide applied to the crop or tree and non-target species have more refuges. Costs are considerably lower as less material is used per tree or per hectare. In addition, spot spraying is less time consuming than for cover spraying and therefore less demanding of labour. Farmers may also be able to use simpler, cheaper spraying equipment. Bait sprays are more environmentally sound because of reduced pesticide usage and less risk of spray drift. Spray applications can be directed on to foliage and away from fruit to minimise fruit residue problems. Reduced pesticide usage and use of coarse sprays at low pressure result in less hazard to the spray operator.

As most countries and organisations in the South Pacific are enthusiastic about promoting the concept of IPM, the protein bait spray technology fits perfectly into this approach. Protein bait sprays can make an important contribution to the adoption and success of IPM programs by controlling fruit flies with minimum impact on beneficial insects.

Genetic control

The Sterile Insect Release Method (SIRM) aims at eradicating a species by flooding the population with sterilised males so that the chance of sterile males mating with wild females is greatly increased. The females generally mate once only under field conditions. The best example of success of this method is in eradication of melon fly from various Japanese islands.

Prerequisites for this method are appropriate mass culture diets and facilities, capacity to produce hundreds of millions of flies per week and to monitor their fitness to compete with wild flies, appropriate techniques for sterilising flies using Cobalt-60 or Cesium-137, effective transport and release techniques, and methods to evaluate the progress of the eradication program. These requirements mean a very expensive, sophisticated technique and one that is appropriate for ecologically or geographically isolated areas into which wild flies are not likely to migrate and so dilute the effect of flooding the wild population with sterilised males. It is a technique that is not likely to be used in the South Pacific island nations, without significant financial justification.

Chemical control — insecticide cover sprays

The history of insecticide sprays to control fruit fly commenced with the use of inorganic insecticides such as lead arsenate and sodium fluorsilicate by Back and Pemberton (1918). These control measures could also be considered as pioneering bait sprays because the lead arsenate was mixed with molasses or sugar solution to attract the fruit flies. Poisoned baits, again with a molasses or sugar base, were used in the 1880s, but they were placed around the crop at bait stations rather than being sprayed on the plants.

With the development of synthetic chemical insecticides after World War II, DDT became the standard insecticide for fruit fly control. The great advantage of DDT was that it repelled female fruit flies, which enhanced its effectiveness. Complete coverage of the tree was needed and sprays had to be applied regularly, usually every 5–7 days from early in the season. DDT was eventually replaced by the organophosphatic insecticides, dimethoate and fenthion, which have been in use for more than 30 years (Bateman 1978). As well as killing adult flies on contact, both of these insecticides penetrate the fruits and kill eggs and young larvae. Consequently, they have an advantage in keeping fruit infestation to a minimum. However, to be most effective, they have to be sprayed on the fruit surface and thorough coverage of the crop or tree is essential.

There are several disadvantages of insecticide cover sprays. Dimethoate and fenthion have comparatively long withholding periods, so the crop is not protected for periods of seven days or more just before harvest. Application of cover sprays may be expensive in terms of labour and materials because the entire crop or tree has to be treated. Achieving adequate spray coverage of large, dense plantation trees may be difficult and may require sophisticated spray equipment. The insecticides used adversely affect beneficial organisms, including biological control agents and pollinating agents. Consequently, cover sprays do not fit into IPM programs. Blind stings or stings where eggs do not develop are common and these may result in fruit being rejected for export or rotting due to the introduction of bacteria during oviposition.

Advantages of insecticide cover sprays are that they normally provide a high level of protection against infestation and, provided the spray application is sound, the level of protection is usually consistent.

Integrated pest management (IPM) approach

The approach being fostered in the South Pacific and elsewhere in the world is to use as little insecticide as possible by adopting an IPM strategy. The use of cover sprays of dimethoate or fenthion is not encouraged in the South Pacific for this reason. Promoting a combination of bagging or wrapping of fruits, production during periods of low fruit fly activity, growing less susceptible varieties, adopting sound crop sanitation procedures, harvesting at times when the fruits or vegetables are least susceptible, and using protein bait sprays that will conserve existing parasitoids, fits into the concepts of IPM and reduced pesticide use in the South Pacific. All of these techniques are appropriate for the control of fruit flies in subsistence or commercial fruit and vegetable production.

References

Allwood, A.J. and Drew, R.A.I. 1996. Strategy for eradication of Oriental fruit fly in French Polynesia. Regional Fruit Fly Project Report (South Pacific Commission), Report No. 26, 27 p.

Anon. 1994. Specification for determination of fruit fly host status as a treatment. New Zealand MAF (Ministry of Agriculture and Fisheries) Regulatory Authority Standard 155.02.02, 17 p.

Back, E.A. and Pemberton, C.E. 1918. The Mediterranean fruit fly in Hawaii. USDA Bulletin, 538, 118 p.

Bateman, M.A. 1978. Chemical methods for suppression or eradication of fruit fly populations. In: Drew, R.A.I., Hooper, G.H.S. and Bateman, M.A., eds, Economic Fruit Flies of the South Pacific, Watson and Ferguson, Brisbane, 115–128.

Bateman, M.A., Insunza, V. and Arretz, P. 1973. The eradication of Queensland fruit fly from Easter Island. FAO Plant Protection Bulletin 21: 114.

Bateman, M.A. 1972. The ecology of fruit flies. Annual Review of Entomology, 17: 493–518.

Bigler, F., Neuenschwander, P., Delucchi, V. and Michelakis, S. 1986. Natural enemies of preimaginal stages of *Dacus oleae* Gmel. (Dipt.: Tephritidae) in western Crete. II. Impact on olive fly populations. Bolletino del Laboratorio di Entomologia Agraria 'Filippo Silvestri', 43: 79–96. (Abstracted in Review of Applied Entomology, 77: 4746.)

Chambers, D.L., Cunningham, R.T., Lichty, R.W. and Thrailkill, R.B. 1974. Pest control by attractants. A case study demonstrating economy, specificity and environmental acceptability. Bioscience, 24: 150–152.

Drew, R.A.I. 1987. Reduction in fruit fly (Diptera: Tephritidae) populations in their endemic rainforest habitat by frugivorous vertebrates. Australian Journal of Zoology, 35: 3: 283–288.

Gow, P.L. 1954. Proteinaceous bait for Oriental fruit fly. Journal of Economic Entomology, 47: 1: 153–160.

Gunn, D. 1916. The cucumber and vegetable marrow fly (*Dacus vertebratus*). Report of the Division of Entomology, Department of Agriculture, Union of South Africa, Pretoria.

Haramoto, F.H. and Bess, H.A. 1970. Recent studies on the abundance of Oriental and Mediterranean fruit flies and the status of their parasites. Proceedings of the Hawaiian Entomological Society, 20: 3: 551–556.

Hooper, G.H.S. 1989. Fruit fly control strategies and their implementation in the tropics. In: Vijaysegaran, S. and Ibrahim, A.G., eds, First International Symposium on Fruit Flies in the Tropics, Malaysian Agricultural Research and Development Institute (MARDI), Serdang, Selangor, 430 p.

Iwaizumi, R., Sakei, M. and Hashimoto, H. 1989. Evaluation of the effectiveness of the suppression control of the melon fly *Dacus cucurbitae* (Diptera: Tephritidae) using Cue-lure toxicant in the field. Shokubutsu Boekijo Chosa Kenkyu Hokake (= Research Bulletin of the Plant Protection Service) No. 25: 43–46 (Abstracted in Review of Agricultural Entomology, 1990. 78: 4: 4162).

Liquido, N.J. 1991. Fruit on the ground as a reservoir of resident melon fly (Diptera: Tephritidae) populations in papaya orchards. Environmental Entomology, 20: 2: 620–625.

Liquido, N.J., Cunningham, R.T. and Covey, M.H. 1989. Infestation rates of papaya by fruit flies (Diptera: Tephritidae) in relation to the degree of fruit ripeness. Journal of Economic Entomology, 83: 2: 476–484.

Maxwell-Lefroy, H. 1916. A fly destroyer. Queensland Agricultural Journal. 5: 220

Mazor, M., Gothilf, S. and Galun, R. 1987. The role of ammonia in the attraction of females of the Mediterranean fruit fly to protein hydrolysate baits. Entomologia Experimentalis et Applicata. 43: 1: 25–29. (Abstracted in Review of Applied Entomology, 75: 4324.)

Prokopy, R.J. 1968. Visual responses of apple maggot flies, *Rhagoletis pomonella* (Diptera: Tephritidae) orchard studies. Entomologia Experimentalis et Applicata, 11: 403–422.

Roessler, Y. 1989. Insecticidal bait and cover sprays. In: Robinson, A.S. and Hooper, G.H.S., eds, Fruit flies: their biology, natural enemies and control, World Crop Pests, 3A: 169–173.

Shiga, M. 1988. Progress of fruit fly eradication program in the subtropical area of Japan. Japanese Journal of Tropical Agriculture, 32: 1: 61–65. (Abstracted in Review of Applied Entomology, (1990) 78: 4: 3750.)

Simmonds, H.W. 1936. Fruit fly investigations, 1935. Fiji Department of Agriculture. Bulletin No. 19, 18 p.

Snowball, G.J. 1966. Status of introduced parasites of Queensland fruit fly (*Strumeta tryoni*), 1962–1965. Australian Journal of Agricultural Research, 17: 719–739.

Snowball, G.J., Wilson, F., Campbell, T.G. and Lukins, R.G. 1962. The utilisation of parasites of Oriental fruit fly (*Dacus dorsalis*) against Queensland fruit fly (*Strumeta tryoni*). Australian Journal of Agricultural Research, 13: 3: 443–460.

Steiner, L.F., Mitchell, W.C., Harris, E.J., Kozuma, T.T. and Fujimoto, M.S. 1965. Oriental fruit fly eradication by male annihilation. Journal of Economic Entomology, 58: 5: 961–964.

Steiner, L.F., Rohwer, G.G., Ayers, E.L. and Christenson, L.D. 1961. The role of attractants in the recent Mediterranean fruit fly eradication program in Florida. Journal of Economic Entomology, 54: 30–35.

Steiner, L.F. 1952. Fruit fly control in Hawaii with poison-bait sprays containing protein hydrolysates. Journal of Economic Entomology, 45: 5: 838–843.

Vijaysegaran, S. 1989. An improved technique for fruit fly control in carambola cultivation using spot sprays of protein baits. Seminar Belimbing Dayamaju dan Prospeks. 18–19 July, 1989. Kuala Lumpur, Malaysia.

Waterhouse, D.F. 1993. Biological control Pacific prospects — Supplement 2. (Publ. Australian Centre for International Agricultural Research, Canberra, 1993). 138 p.

Wen, H.C. 1988. Preliminary study on the control of melon fly in the field. Journal of Agricultural Research of China, 37: 2: 220–224. (Abstracted in Review of Agricultural Entomology (Series A) (1989) 77: 5: 3308.

Wong, T.T.Y., Mochizuki, N. and Nishimoto, J.I. 1984. Seasonal abundance of parasitoids of the Mediterranean and Oriental fruit flies (Diptera: Tephritidae) in the Kula area of Maui, Hawaii. Environmental Entomology, 13: 1: 140–145.

Assessment of Protein Bait Sprays for the Control of Fruit Flies in Chilli and Capsicum Crops in Tonga

V. Heimoana[1], P. Nemeye[2], T. Langi[1] and A.J. Allwood[2]

Abstract

Research into protein bait spraying has been carried out in Tonga since 1993 to investigate cheap and effective methods to control fruit flies. Initially Mauri's Pinnacle Protein Insect Lure (MPPIL) was used. The bait was prepared by mixing either 50 mL or 80 mL of MPPIL with 5 mL of 50% emulsifiable concentrate malathion and making up to one litre with water. The bait was applied to every third row of capsicum or chilli on a weekly schedule as a band to foliage. About 10–12 litres of bait were applied per hectare. Samples of 100 pieces of fruit were taken from treated and untreated plots each week and held for 5–7 days for damage assessment. *Bactrocera facialis* (Coquillett) was the only species reared from capsicum and chilli during field testing. The level of damage in treated capsicum plots was reduced to less than 7%, while damage in untreated plots was as high as 97%–100%. The field test on 'Hot Beauty' chilli, a very susceptible variety, using similar methods resulted in levels of damage in treated plots of 2% and less and, in untreated plots, of 93%.

During 1995, a new ACIAR project, which aimed at producing protein bait locally from Royal Tonga Brewery waste, was initiated. The new bait (RTB39) was first tested in the field on capsicums in August 1995. The bait was formulated for field application by mixing 200 mL of modified waste yeast and 4 mL of 50% emulsifiable concentrate malathion and making up to one litre with water. It was applied to the crop as a band to the foliage at a rate of 23–25 L/ha. Weekly damage evaluations of 100 fruit from treated and untreated plots found that the treatment reduced damages from 90% to less than 6% after 6 weeks. As bait is applied to foliage, defoliation due to disease and drought reduced bait effectiveness after 11 weeks of the trial. In comparison, damage levels in the untreated area increased from 27% to 100% over the same period.

THE quarantine risks posed by tephritid fruit flies in the Pacific region have led to quarantine protocols between the various island nations and New Zealand, their main trading partner. Protocols between New Zealand and Australia, for example, are based on tight schedules of specific chemical sprays in conjunction with post-harvest chemical dips to reduce infestation possibilities to satisfactory levels. The high cost and environmental and human hazards that the use of these chemicals incur, render agreements of such nature non-viable for Pacific island countries. Other options on which quarantine protocols could be based have been considered and include non-host status, area freedom, trapping surveys and field control using protein bait sprays.

In Australia, the most commonly used protein bait for fruit fly control is manufactured by Mauri Foods under the name Mauri's Pinnacle Protein Insect Lure (MPPIL). During 1993 and 1994, bait sprays using MPPIL were carried out in Tonga (P.S. Nemeye, pers. comm.). The bait consists of autolysed yeast and water mixed with the insecticide malathion. However, the cost of Mauri bait is a factor limiting its use in the islands. ACIAR, with assistance of the Regional Fruit Fly Project (RFFP) and USAID, funded a project in Tonga to convert local brewery yeast into a suitable and cheaper protein bait. Waste yeast from Tonga was sent to the Queensland Department of Primary Industries (QDPI) Agricultural Research Laboratories in Brisbane to develop a suitable formulation.

[1]Ministry of Agriculture and Forestry, Research Division, Nuku'alofa, Kingdom of Tonga
[2]Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji

Subsequently, reformulation equipment for commercial level production was installed at the Royal Tonga Brewery. In mid-1995, a batch of reformulated yeast protein bait, coded RTB39, was sent to Tonga for field trial. In June 1996, the first batches of locally manufactured bait, coded Tongalure 1 and Tongalure 2, were tested in laboratory and field trials by staff from the RFFP, ACIAR project and MAF, Tonga. The difference between the two protein sources was in cooking time and consistency. In some trials, MPPIL bait was used as a standard in attractant efficacy tests. This paper summarises the results of field tests using the Mauri formulation to control fruit flies in capsicum and chillies, and the bait coded RTB39 in capsicum. It also identifies further field testing being carried out in capsicum using the locally manufactured (Royal Tonga Brewery) version of RTB39.

Field Testing of MPPIL 1993–1994

Two different concentrations of MPPIL mixture were tried in capsicum during 1993 and 1994. Bait spray made up of 80 mL/L lure and 4 mL of 50% emulsifiable concentrate malathion per litre of water was tested in 1993, while a lower concentration of 50 mL/L lure was tested during 1994. The sprays were applied weekly to each plant in every third row for more than 12 weeks. Damage assessment was carried out by sampling 100 fruit per week and keeping the pieces of fruits in separate plastic containers for a period of 5–7 days to evaluate infestation. The assessment was first carried out 2–3 weeks prior to baiting to evaluate field infestation before treatment. Bait spraying with the 80 mL/L formulation of lure kept damage levels in the treated plot below 7% while levels rose to 97% in the untreated plot over a period of 15 weeks (Fig. 1).

Using the 50 mL/L formulation, bait spraying controlled fruit fly damage in the treated plot to levels below 5% for 6 weeks after commencing the trial, compared to damage levels between 3% and 29% in the untreated plot (Fig. 2). This was followed by a 3-week period of relative ineffectiveness where heavy rains washed off the bait and fungal diseases defoliated plants. During this time, damage levels rose to 100% in the untreated plot but only to 28% in the treated plot. Once biweekly sprays of fungicides (Manzate and copper) were applied after the ninth week of the trial, the bait became effective again as leaf growth improved, keeping damage levels in the treated plot between 0% and 4% while the control plot remained at 100 % damage.

Trials carried out on 'Hot Beauty' chilli during a 23-week period between 1994/95 with 50 mL/L formulation of lure using similar methods, resulted in a reduction of damage levels to 2% and less in mature green fruit. In comparison, untreated plots reached damage levels as high as 93% (Fig. 3).

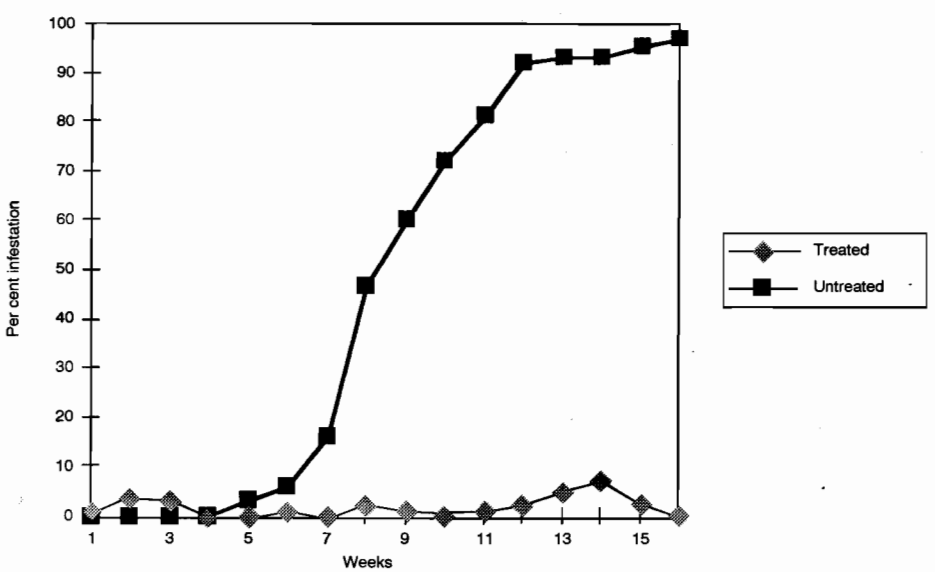


Figure 1. Effect of bait spray treatment (MPPIL) at 80 mL/L on fruit infestation by *Bactrocera facialis* in capsicum, 1993. Note: Bait spraying commenced in Week 4.

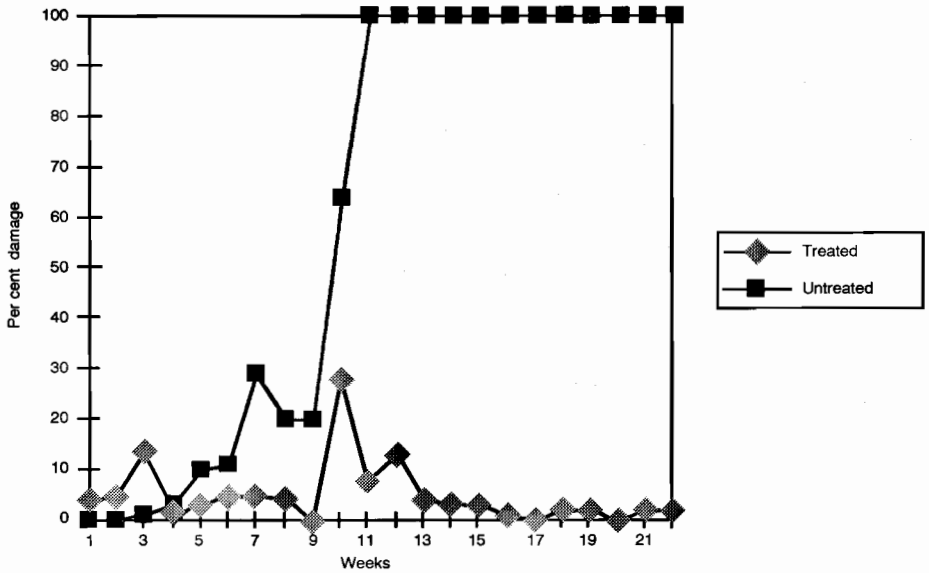


Figure 2. Effect of bait spray treatment (MPPIL) at 50 mL/L on fruit infestation by *Bactrocera facialis* in capsicum, 1994. NB: Bait spraying commenced in Week 4.

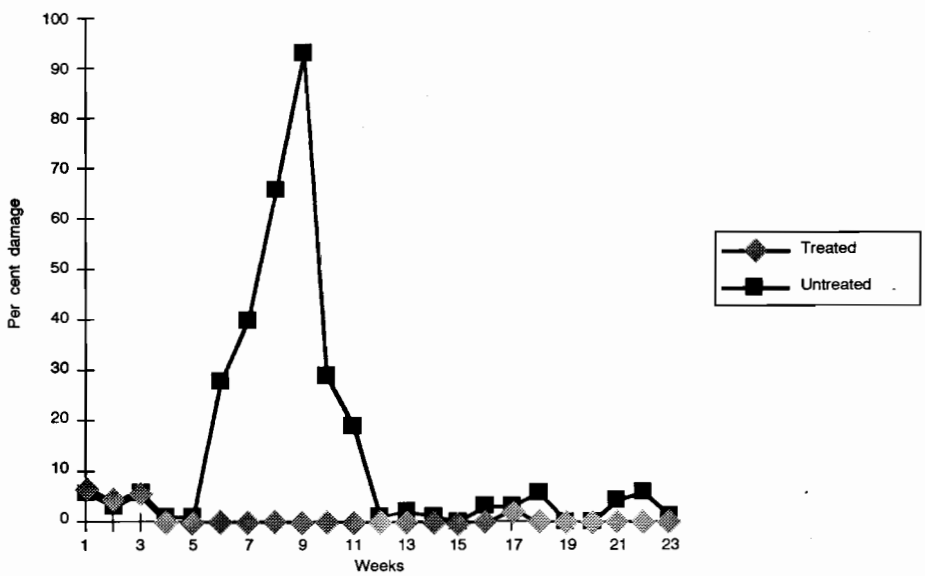


Figure 3. Effect of bait spray treatment (MPPIL) at 50 mL/L on fruit infestation by *Bactrocera facialis* in 'Hot Beauty' chilli, 1994. NB: Bait spraying commenced in Week 4.

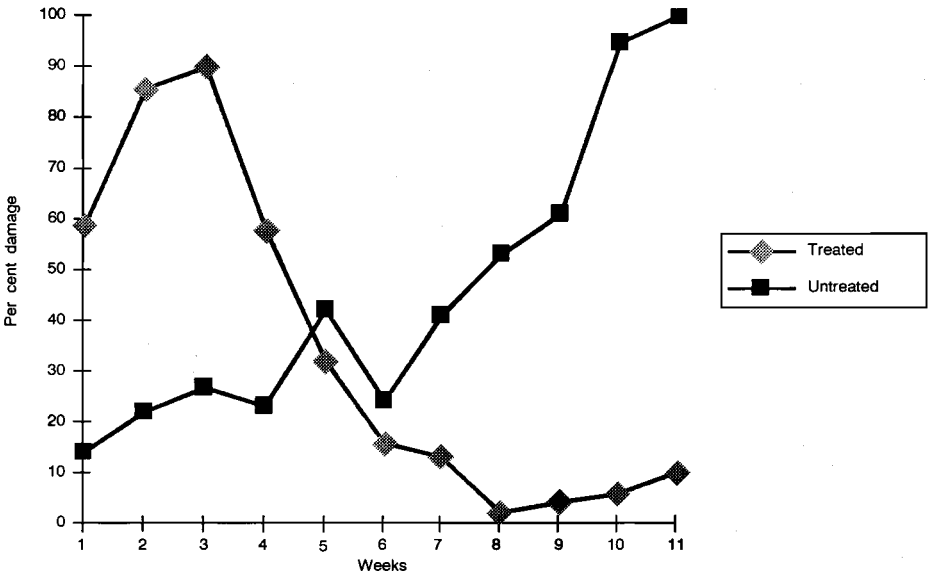


Figure 4. Effect of bait spray treatment (RTB39) on fruit infestation by *Bactrocera facialis* in capsicum, 1995. NB: Bait spraying commenced in Week 3.

Review of RTB39 Bait Spray Trial 1995

Royal Tonga Brewery Bait (RTB39) was tested in capsicum at a concentration of 200 mL of yeast autolysate and 4 mL of 50% emulsifiable concentrate malathion per litre of bait. Bait sprays were applied weekly to every third row at a volume of 23–25 L/ha. Damage levels were assessed by randomly collecting 100 fruits per plot each week and evaluating the number of infested fruit.

Checking for infestation started two weeks prior to the commencement of bait spraying. Initial damage levels were low in the untreated plot but high in the treated plot. At the beginning of the spray program, infestation in the treated plot was as high as 90% which gradually decreased to 2% over the following 5 weeks (Fig. 4). Levels of damage again began to rise and reached 10% during the 11th week of the trial. The increase in infestation resulted from poor coverage by the bait spray as the amount of foliage declined due to disease in the crop. By comparison, the infestation level in the control plot was 14% before the beginning of the trial and rose to 27% at commencement. The levels of damage in the untreated plot rose steadily from 41% to 100% by Week 11. To effectively employ bait sprays in fruit fly control, adequate foliage cover and regular application are essential.

Conclusion

Both bait formulations, MPPIL and RTB39, are effective in fruit fly control. Damage levels were brought to less than 7%, using either formulation, for the period of the trials. The only time the bait became ineffective was when plants were defoliated either due to drought or diseases or when excessive rain washes the bait off the foliage. This was illustrated in 1994 in capsicum when damage levels in the untreated plot rose rapidly to 100% during weeks 10 and 13 and when levels in the treated plot rose to 28%.

In 1996, bait spray testing with a locally manufactured version of RTB39 continued. Attractancy trials have shown its effectiveness as a lure for fruit flies. The Regional Fruit Fly Project staff have planted a total of six plots of capsicum (Var. Yolo Wonder) at three different sites: Ha'ateiho Village, Vaini Research Station and at Malapo Village. Each site consists of a treatment plot and a control plot. As soon as fruits reach maturity, damage assessment will commence followed by bait spraying and continued damage evaluation. It is hoped that the positive results achieved with bait sprays in previous years can be replicated using the new bait formulation.

Results of Protein Bait Spraying in Fiji and Cook Islands

L. Leweniqila[1], A.J. Allwood[2], A. Kassim[2], E. Tora Vueti[1], L. Ralulu[1] and G. Walker[2]

Abstract

Protein bait spraying, as a field measure for fruit fly control, was first introduced into Fiji and Cook Islands by the Regional Fruit Fly Project in 1991. The bait, consisting of 50 mL of Mauri's Pinnacle Protein Insect Lure plus 4 mL of 50% emulsifiable concentrate malathion, made up to one litre with water, was applied at the rate of 50 mL as a spot per tree on a weekly schedule. Fruits were sampled from treated and untreated areas weekly and determinations of levels of damage done. In Fiji, field trials were carried out on guava (*Psidium guava* Linnaeus) at Koronivia and Nadi and on mangoes (*Mangifera indica* Linnaeus var. Kensington) at Nadi. Levels of damage on guava at Koronivia were reduced from 35.5% to 0% in the treated area and in the untreated area, damage ranged from 8.6% to 27.1%. Levels of damage to guava in the treated area at Nadi were maintained at 1.7–6.4%. In the untreated area, the level of damage ranged from 18.2% to 41.6%. After three weeks after the last spray, sampling showed an increase in damage level in the previously treated area to 30%. In the mango trial at Nadi, the application of bait spray to every second tree maintained the levels of damage in the treated area at 0% to 1.0%. In the untreated area, damage levels ranged from 2% to 26.9%. In Cook Islands, two field trials were carried out on pawpaws, one during the cooler months and the second during the warmer months. In both trials, the levels of damage at four stages of maturity (colour break, quarter ripe, half ripe and ripe) were very low (0% to 0.7%). Though the level of damage was expected to be low during the cooler months, higher levels were expected during the warmer months, around 10% to 12% at the ripe stage. Naturally, no positive effect of bait spraying could be demonstrated. Despite these results, it is believed that application of protein bait sprays, together with sound crop sanitation and harvesting at colour break, form the basis for an integrated approach to fruit fly control.

PROTEIN bait spraying was first introduced into Fiji and Cook Islands in 1991 by the Regional Fruit Fly Project. The work carried out in the two countries was similar in that field trials were conducted on tree crops. In Fiji, trials were conducted on guava and mangoes and in Cook Islands on pawpaws. Protein bait sprays consist of a protein source, an insecticide and water. The principle behind protein bait spraying is that all immature female fruit flies need to feed on protein in order to become sexually mature. Fruit flies that feed on this poisoned protein die and as a result young female fruit flies are prevented from ovipositing in fruits.

[1]Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2]Regional Fruit Fly Project, South Pacific Commission, Private Mail Bag, Nabua, Fiji

Materials and Method

In Fiji, two small-scale trials were conducted on the local pink variety guava, and one large scale trial on Kensington mangoes. The trial sites for guava were at Bal Kumar's farm at Koronivia with its control site at the Koronivia Research Station guava field and at the Garden of the Sleeping Giant, Nadi guava orchard, with its control site another guava field about 500 metres away. The test at Koronivia ran for eight weeks and at Nadi for five weeks. At both sites, fruits were sampled for two weeks before bait spraying began. All fruit trees were baited weekly. A mixture of 50 mL Mauri's Pinnacle Protein Insect Lure, 4 mL of 50% emulsifiable concentrate malathion made up to one litre with water was applied at the rate of 50 mL as a spot per tree. A 10 litre manual pressurised sprayer was used. One hundred fruits were sampled weekly from treated and

untreated plots before the bait was applied. Fruits were first placed in paper bags and transported to the fruit fly laboratory in Koronivia where they were set up in well-ventilated containers. After seven days, fruits were dissected and numbers of larvae per fruit recorded. All infested fruit were set up in containers with sawdust.

The large scale trial was conducted on Kensington mangoes at the Tailevu Development Company mango farm. Protein bait spray was applied to every second tree and the test was carried out for seven weeks. One hundred fruits were sampled one week before spraying began and 50 fruits every week thereafter. Fifty fruits were also collected weekly from the nearby control site at Legalega Research Station. Sampled fruits were placed in paper bags and then plastic bags and transported to the fruit fly laboratory in Koronivia. Fruits were set up in well-ventilated containers and dissected seven days after harvest. Infested fruits were then set up on sawdust for pupation and eclosion.

Cue-lure and methyl eugenol traps were set up at the three sites and cleared on a weekly basis.

Results and Discussion

In Fiji, the small-scale trials on guava at Nausori demonstrated the effectiveness of protein bait spraying (Fig. 1). In the treated area, damage levels were reduced from 35.5% to 0.0%. In the untreated area, damage levels ranged from 8.6% to 27.1%. At the Nadi site as shown in Figure 2, damage levels at

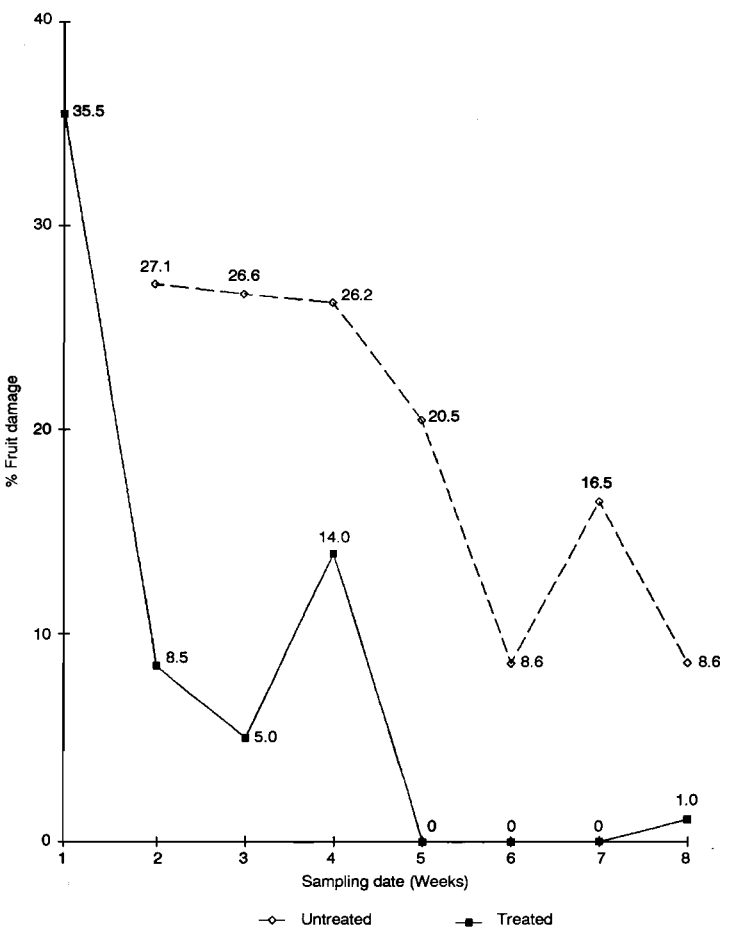


Figure 1. Effect of weekly application of bait spray on the levels of damage in guava caused by *Bactrocera passiflorae* (Koronivia, 1992).

the treated site were maintained at 1.7% to 6.4% and at the untreated area, damage levels ranged from 18.2% to 41.6%. Application of bait spray was terminated after five weeks. The treated and untreated plots were sampled after four weeks and damage levels in both plots were 39%.

The application of bait to every second tree on mangoes at Nadi (Fig. 3) maintained damage levels at 0% to 1% in the treated area and in the untreated area, the damage levels ranged from 2.0% to 26.9%.

Data obtained from field trials in Cook Islands did not demonstrate effective fruit fly control as damage levels were very low, except in summer when levels of damage may reach 12%. However, results indicate that when protein bait spraying is combined with high standards of crop sanitation and field hygiene, there is protection of the crop and greater flexibility in harvest times. Harvest may be delayed from mature green-colour break to a colour break-quarter ripe stage of maturity. Quality of the fruit may be enhanced by harvesting later.

Protein bait spraying has been adopted by Fiji as part of its quarantine pathway in the export of mangoes to Japan and in Cook Islands, it is also part of recommended practice for pawpaw growers. The bait spray technology is now adopted by farmers who export but has not been adopted by subsistence farmers mainly because of the high cost of Mauri's Protein Insect Lure. The major constraint faced in conducting these trials was the insufficient fruits for sampling for long periods.

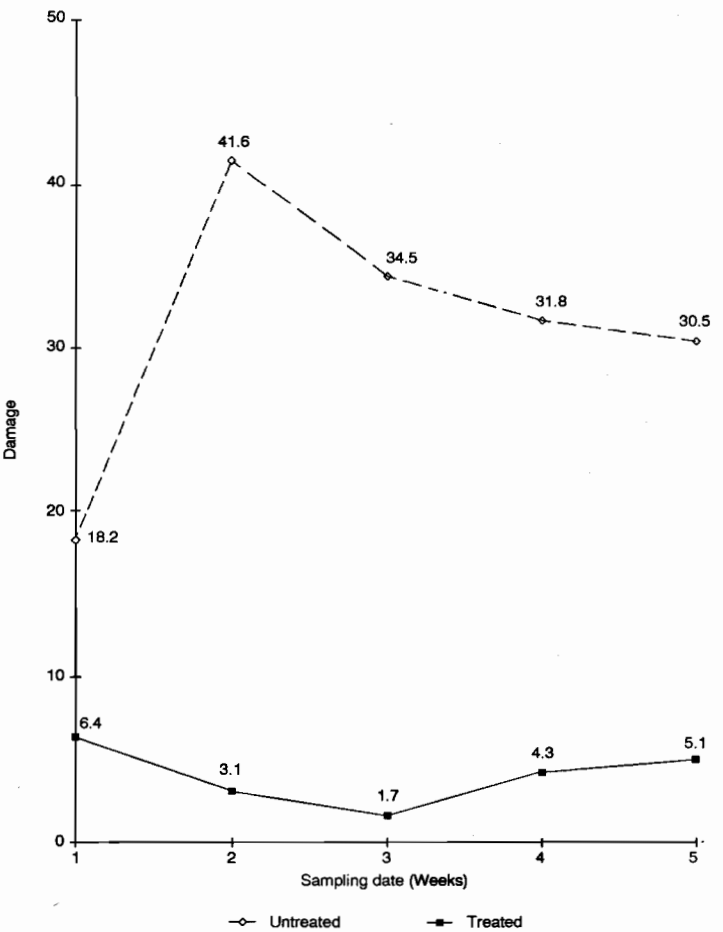


Figure 2. Effect of weekly application of bait spray on the levels of damage in guava caused by *Bactrocera passiflorae* (Nadi, 1993).

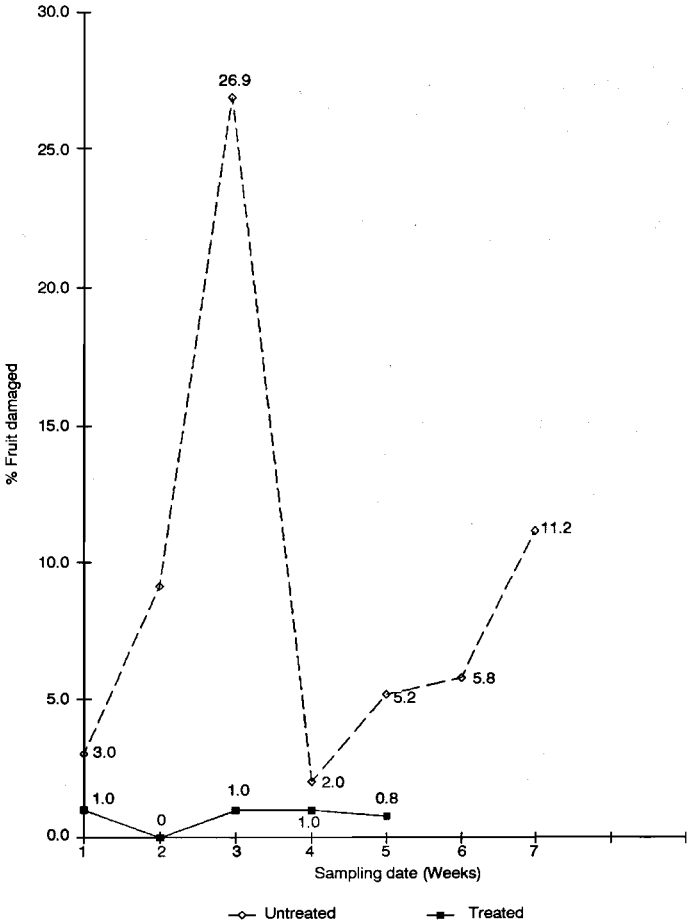


Figure 3. Effect of weekly application of bait spray on the levels of damage in mango caused by *Bactrocera passiflorae* (Nadi, 1992).

Can Fruit Flies Be Controlled in a Village with a Mixed Orchard? Pacific Island Experiences

L. Leblanc[1], L. Leweniqila[1], D. Tau[1], T. Tumukon[1], A. Kassim[1] and R. Hollingsworth[1]

Abstract

Preliminary experiments for area control of fruit fly populations by weekly protein bait spraying in mixed orchards have been carried out in Vanuatu, Fiji, Solomon Islands and on Pohnpei Island, in Federated States of Micronesia (FSM). Control of *Bactrocera trilineola* on guava in Vanuatu, *B. passiflorae* on kumquat in Fiji and *B. frauenfeldi* on guava in Solomon Islands was successful. In FSM, damage by *B. frauenfeldi* on Surinam cherry was under control for four months but bait spraying eventually failed to maintain control. The reasons for the failure are thought to be the very high fruit fly population pressure on Pohnpei, the small size of the area treated, the very high annual rainfall on Pohnpei washing the bait off the leaves and the high susceptibility of the indicator host to fruit fly attack.

BAIT spraying for fruit fly control involves spraying plants with a protein that attracts mainly immature female fruit flies in need of a protein meal for egg maturation, in combination with an insecticide to kill them. For the past four decades, acid hydrolysates of plant proteins were used, but were generally phytotoxic. Australians have used, since 1986, a non-phytotoxic protein autolysate derived from yeast manufactured by Mauri Foods. It was successfully tested against Queensland fruit fly (*Bactrocera tryoni*) on passion fruit (Smith and Nannan 1988) and is now widely used in Australia and some Pacific Island countries. Bait spraying is applied as a spot treatment, where a small amount of bait solution is sprayed over one square metre of foliage on each tree, rather than as a cover spray.

Area control is bait spray treatment over large areas in an attempt to suppress entire fruit fly populations (Bateman 1982). It involves not only spraying host trees in an orchard, but all the trees inside and surrounding the orchard. According to Bateman (1982), 50 spots of 100 mL of bait solution per hectare, in grids of spots 15 m apart, will successfully control Queensland fruit fly. Area control with Mauri's yeast autolysate has been very effective on citrus, avocado and passion fruit orchards in Queensland and autolysate from brewery waste yeast is widely used to control fruit flies on carambola and soursop orchards in Peninsular Malaysia (Sabine 1992).

Area control is a relatively new concept to Pacific Island countries. So far, only small scale preliminary area control experiments have been carried out by the Regional Fruit Fly Project. Results from these experiments are presented and discussed in this paper.

[1]Regional Fruit Fly Project in the South Pacific. South Pacific Commission, Private Mail Bag, Suva, Fiji

Methods

Four separate area control trials were conducted in orchards in the Federated States of Micronesia (FSM), Fiji, Vanuatu and Solomon Islands. In all cases, 50 mL of Mauri's Pinnacle Protein Insect Lure concentrate (yeast autolysate) were diluted in water, with 4 mL of malathion 50% EC, to one litre of bait solution. Every week, 50–100 mL of solution were sprayed on each tree in a mixed orchard. The main tree species in the spray areas were hosts for fruit flies, such as guavas, carambolas, papayas, *Syzygium* apples, mangoes, *Citrus* spp., soursops and avocadoes. In Vanuatu, the area sprayed and the control orchard were composed exclusively of guava trees with grass undergrowth. Samples of ripe fruits were

Table 1. Differences in area control experiments by bait spraying in Vanuatu, Fiji, Solomon Islands and Federated States of Micronesia.

	VANUATU	FIJI	SOLOMON IS.	FSM
	Spray location			
	Efate, Port-Vila, Tenmo	Viti Levu, Naduruloulou Res. Sta.	NE Guadalcanal, Ngalibiu, CDCI	Pohnpei State Agriculture Station
Area sprayed	1000 m^2	5000 m^2	10 000 m^2	1000 m^2
No. trees sprayed	60	50	122	19
Untreated control	Yes	No	Yes	No
First spray	April 10, 1995	May 6, 1994	May 23, 1996	April 3, 1995
No. sprays	9	15	6	42
Last spray	June 5, 1995	August 12, 1994	June 27, 1996	January 22, 1996
Indicator host	*Psidium guajava*	*Fortunella japonica*	*Psidium guajava*	*Eugenia uniflora*
Pest fly species	*B. trilineola*	*B. passiflorae*	*B. frauenfeldi*	*B. frauenfeldi*
No. indicator trees	93 (incl. controls)	9	7	1
No. fruits sampled	100	100	9 to 74	25 to 50
Total no. of fruits sampled	1000 in spray area 1000 in control all from trees	900 from trees 400 fallen	193 from trees, 30 fallen in spray area 89 on trees in control	1280 from trees
First sampling	April 7, 1995	May 17, 1994	May 23, 1996	March 30, 1995
No. samplings	10	13	7	48
Last sampling	June 9, 1995	August 12, 1994	August 1, 1996	February 26, 1996
Results	Figure 1	Figure 2	Figure 3	Figure 4

collected from an indicator tree species and the fruits were incubated in containers in the laboratory to determine the proportion of fruits infested by fruit flies, as an indication of the effects of bait spraying. Fruits were mostly picked from the trees except in Fiji, where the first 9 out of the 13 collections were of fallen fruits, and a few fallen fruits collected in Solomon Islands. Samples from untreated control orchards were also collected in Vanuatu and Solomon Islands. The fruit fly species controlled and the indicator hosts were *B. frauenfeldi* and Surinam cherry (*Eugenia uniflora*) in FSM, *B. frauenfeldi* and guava (*Psidium guajava*) in Solomon Islands, *B. trilineola* and guava in Vanuatu and *B. passiflorae* and kumquat (*Fortunella japonica*) in Fiji. Details and differences in the methodology used by each country are summarised in Table 1.

Results

Results from the experiments, as weekly levels of infestation on indicator trees, are presented in Figures 1 to 4. The experiment was very conclusive in Vanuatu (Fig. 1). At the first spray week, 90% of the indicator fruits were infested. Four to six weeks after the first spray, damage ranged from 66% to 79%, followed by a sharp decrease in infestation, down to 15% after 10 weeks of spraying. During the whole experiment, levels of infestation in the untreated control orchard were never below 83%.

In Fiji, damage assessments on fallen fruits were initiated 11 days after the first spray and were 24% (Fig. 2). They varied from 19% to 38% during the first 10 weeks and were down to 10% at week 11. Damage on fruits picked from trees, on weeks 12 to 15, were very low.

Initial infestation levels in Solomon Islands were low, 15% in the treated orchard and 0% in control, because the guava season was just starting (Fig. 3). Infestations remained low up to two weeks after the last spray. In the third to sixth weeks following the last spray, infestations sharply increased to 68%.

Almost one year of weekly spraying on Pohnpei, FSM showed interesting results (Fig. 4). At the first spray in early April 1995, 68% of the Surinam cherries were infested. Four weeks later, infestation level was 36%. During the subsequent four months, fruit flies were maintained under control, with a mean infestation of 10.5%, and only three times above 20%. From early October onwards, bait spraying failed to control fruit flies. Levels of infestation were rarely below 20% despite weekly sprays. Weekly evaluations up to five weeks after the last spray showed an increase in losses to 74%.

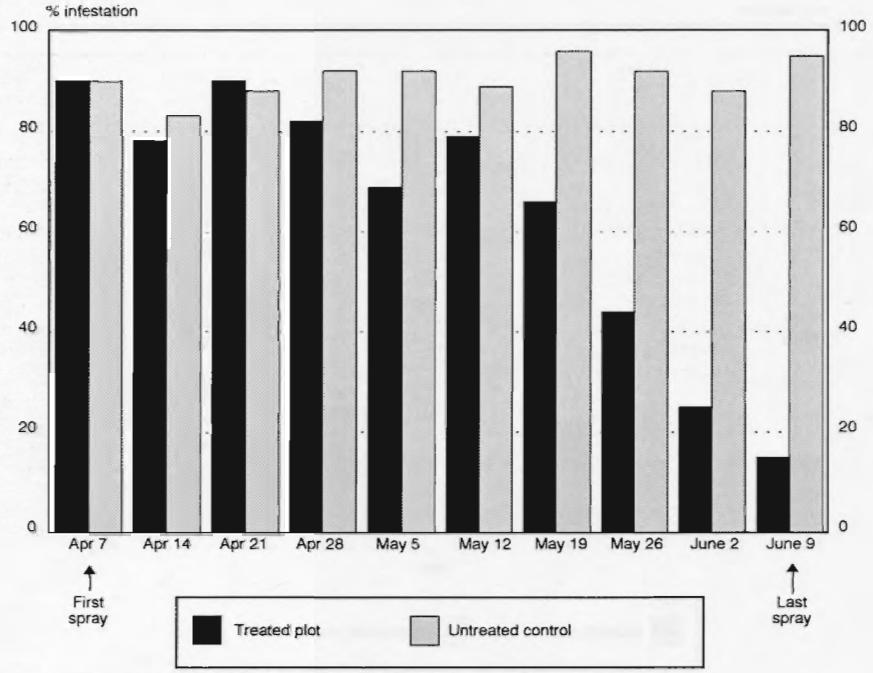


Figure 1. Weekly levels of infestation in bait spraying experiments in Vanuatu.

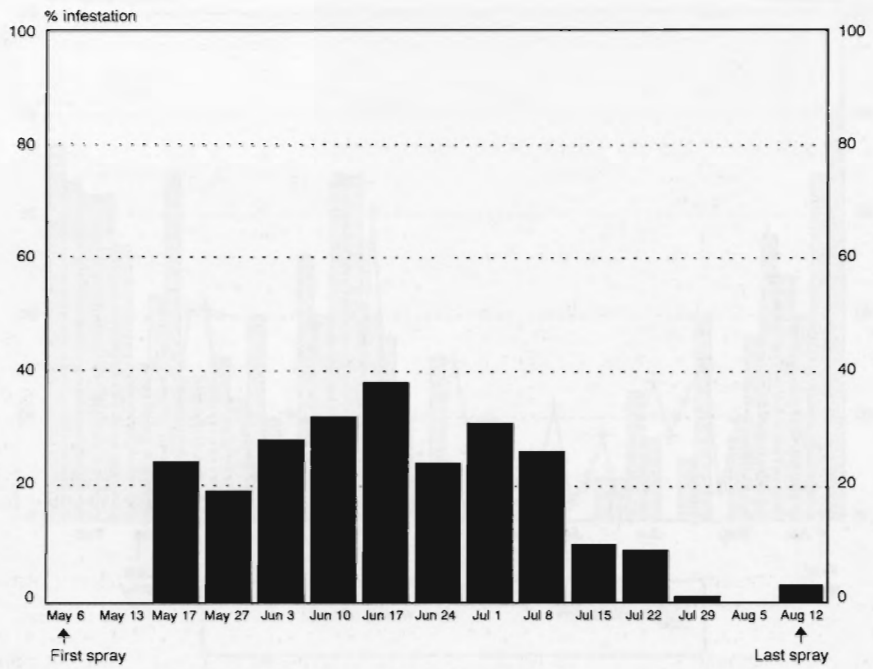


Figure 2. Weekly levels of infestation in bait spraying experiments in Fiji.

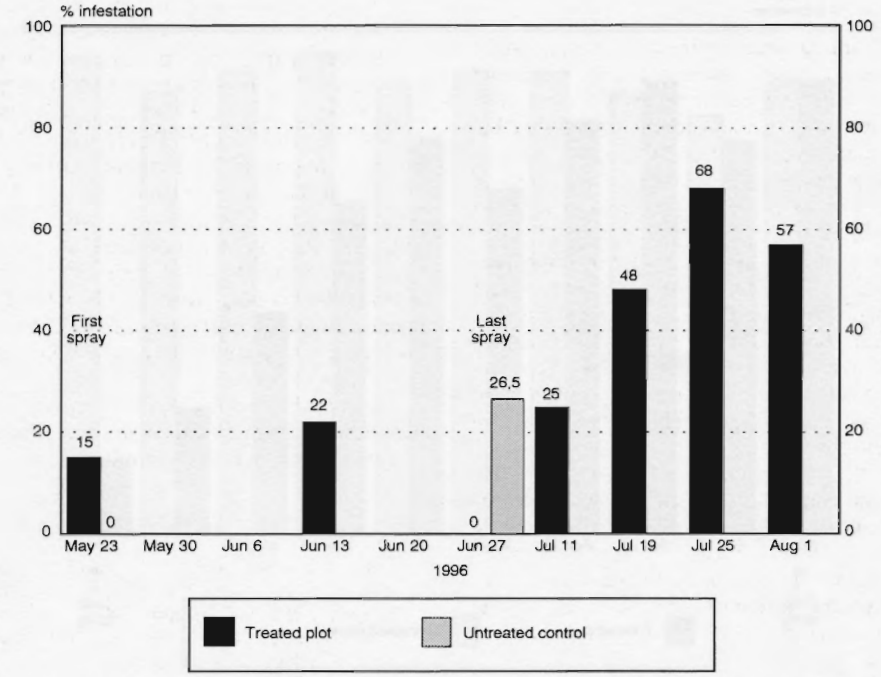


Figure 3. Levels of infestation in bait spraying experiments in Solomon Islands.

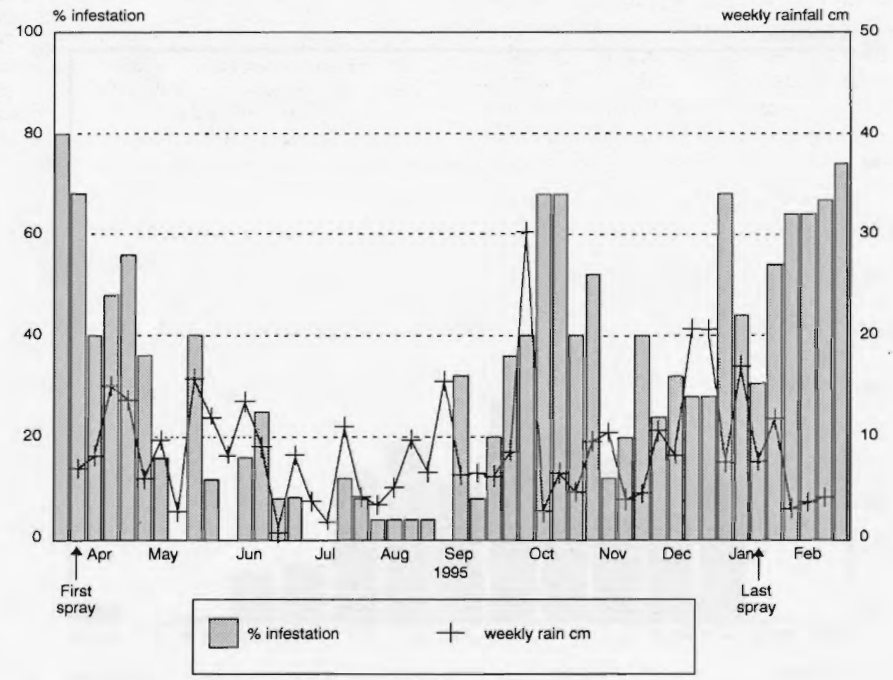


Figure 4. Levels of infestation in bait spraying experiments in the Federated States of Micronesia.

Discussion

The results from the preliminary area control experiments were convincingly successful in Vanuatu and significant in Fiji and Solomon Islands. In FSM, effective control was maintained for four months but eventually failed.

The FSM experience demonstrates limitations of bait spraying and important factors to consider when opting for area control.

Firstly, area control by bait spraying often fails under high fly population pressure (Horticulture Policy Council 1991). On Pohnpei, the mean number of mango fruit flies collected per day in Cue-lure traps is very high throughout the year (443 flies/trap/day as a mean from eight traps) (Leblanc and Allwood, these Proceedings). This makes effective control a very difficult task.

Secondly, the area sprayed in FSM (1000 m^2) was too small to be comparable to real area control. The orchard was surrounded by large numbers of fruiting host trees as fruit fly breeding grounds. A much larger area should be sprayed to achieve control. This requires a synchronised common effort by all the farmers in the area and a centralised coordination of the treatment.

Thirdly, heavy rainfalls on Pohnpei may have washed a large amount of bait off the tree leaves. During the 48 weeks of the whole experiment, total rainfall was 4060 mm. Detailed examination of data on Figure 4, comparing weekly rainfall and percentage infestation, reveals several instances, notably in early September, mid-October and late December, where high levels of infestation followed one or two weeks of particularly heavy rainfalls. The addition of a sticking agent to the bait concentrate may improve its adherence to leaf surfaces to resist pouring rains.

Fourthly, experience in Australia has shown that area control often fails under high fruit fly pressure and when used on crops that are highly susceptible to fly attacks (Horticulture Policy Council 1991). The indicator tree in FSM, *Eugenia uniflora*, is a major and preferred host for mango fruit fly (Leblanc and Allwood, these Proceedings). Area control under high fruit fly population pressure should perhaps be most recommended for less susceptible crops. Satsuma tangerines, grown in plantations on Kosrae Island, are ideal candidates in FSM, because only 20% of the ripe fruits are attacked in spite of large fruit fly populations.

Finally, the weekly spray frequency should be increased to every five days in case of intense population pressure or heavy rainfall.

References

Bateman, M.A. 1982. Chemical methods for suppression or eradication of fruit fly populations. In: Drew, R.A.I., Hooper, G.H.S. and Bateman, M.A. Economic fruit flies of the South Pacific region. Queensland Department of Primary Industries. Brisbane, 115–128.

Horticultural Policy Council. 1991. The impact of fruit flies on Australian horticulture. Horticultural Policy Council. Industry Report No 3. 124 p.

Sabine, B.N.E. 1992. Pre-harvest control methods. International Training Course on Understanding and Managing Fruit Flies (Fiji). Lecture No. 13. 20 p.

Smith, D. and Nannan, L. 1988. Yeast autolysate bait sprays for control of Queensland fruit fly on passion fruit in Queensland. Queensland Journal of Agricultural and Animal Sciences, 45(2): 169–177.

Modification and Testing of Brewery Waste Yeast as a Protein Source for Fruit Fly Bait

A. Lloyd[1] and R.A.I. Drew[2]

Abstract

In Australia, some brewery waste yeast is utilised for preparation of yeast extract which is used as a flavouring ingredient in the food industry. Excess waste yeast is discarded into the environment as is most waste yeast produced at breweries in Pacific countries. Using pasteurised waste yeast from a Brisbane brewery and from the Royal Brewery in Tonga, a method was developed at the Queensland Department of Primary Industries (QDPI) in Brisbane to convert this material to a protein bait for fruit fly control under ACIAR Project No. 7500. The process involved concentrating yeast slurry by heating in an open stirred container to drive off alcohol and excess water. The concentrated material was then treated with proteolytic enzyme (papain) and held at 65°–70°C for approximately 24 hours. Finally, potassium sorbate was added as a preservative. Laboratory produced bait formulations were tested extensively in the cage bioassays and in ground sheet field trials in guava and nectarine orchards near Brisbane. The most promising formulation was prepared in larger quantities and used in a capsicum field trial at Vaini Research Station in Tonga. Based on the laboratory procedures, food processing equipment was purchased and modified in Australia and subsequently installed in a pilot scale plant attached to the Royal Brewery in Nukualofa. Laboratory attractancy tests and field ground sheet trials have been undertaken at Vaini Research Station using bait produced in the pilot plant. A full scale field trial with capsicums is now in progress to test the efficacy of the new bait in commercial production.

CARBOHYDRATES and sugars were the most common baits used in fruit fly control (Roessler 1989), until Steiner (1952) reported the use of protein hydrolysates in the control of Oriental fruit fly in Hawaii. Since that time, bait sprays incorporating protein hydrolysates or autolysates have been extensively used in many fruit fly control and eradication programs. Protein bait sprays have several advantages over insecticide cover sprays: they limit the amount of insecticide used, they leave lower residues in crops and in the environment, they do not harm beneficial insects (pollinators and parasites) and are therefore frequently essential components in Integrated Pest Management programs.

Protein hydrolysates are produced by acid hydrolysis, usually with concentrated hydrochloric acid, of either yeast cells or plant material. When hydrolysis is complete, neutralisation with sodium hydroxide results in a product which contains degraded protein and a relatively high salt level. Several commercially produced fruit fly baits have been based on this process. In Australia, an autolysed protein bait (Mauri's Pinnacle Protein Lure), a by-product of yeast manufacture for the food industry, is also widely used for fruit fly control (Smith and Nannan 1988, Hargraves et al. 1986).

In the food industry, autolysed yeast extracts are defined as water soluble components of yeast cells and they are composed primarily of amino acids, peptides and polypeptides resulting from the enzymatic breakdown of proteins due to naturally occurring enzymes present in yeast cells (Peppler 1982). Such processes are well documented (Peppler 1982) and usually involve the removal of much of the yeast cell wall debris from the soluble yeast extract which is then concentrated to produce the final product.

With protein baits, yeast autolysate generally refers to products in which yeast cells have been disrupted by some process other than acid hydrolysis and released cell proteins have been degraded

[1] Plant Protection Unit, Queensland Department of Primary Industries, Brisbane

[2] Faculty of Environmental Sciences, Griffith University, Nathan Campus, Qld, 4111.

enzymatically. As no strong acidification and subsequent neutralisation is involved, yeast protein autolysates do not have a high salt content and are less likely to cause phytotoxic effects when applied to foliage as a fruit fly bait. Furthermore, for yeast autolysates to be used as protein baits, it is not necessary to remove all of the cell wall debris and the process may be much simpler than those employed in the preparation of yeast extract for the food industry.

The use of waste brewery yeast as a starting material for producing an autolysed protein bait for fruit flies is a relatively new concept. In most Pacific island countries, brewery yeast waste is discarded into the environment, while in Australia, some is used in the food industry but considerable quantities are also discarded. In Malaysia, a protein bait formulated from brewery waste yeast provided excellent control of fruit flies in carambola (Vijaysegaran 1989). In several Pacific island countries, protein bait spraying is playing an increasingly important role in field control of fruit flies and in quarantine requirements for horticultural export trade. A locally produced, inexpensive protein bait would have many advantages in the Pacific region.

ACIAR Project No. 7500

ACIAR Project No. 7500 was designed to develop an economical protein bait from waste brewery yeast. The aim was to research the process from experimental laboratory stages, through laboratory and field testing to small scale commercial production. The project involved close collaboration between staff at the Plant Protection Unit, Queensland Department of Primary Industries, Indooroopilly, staff at Vaini Research Station, Ministry of Agriculture, Nuku'alofa, Tonga and staff at the Royal Brewery, Nuku'alofa, Tonga where the commercial bait processing plant was established. USAid and the South Pacific Regional Fruit Fly Project (RFFP) contributed financially and staff from the Regional Fruit Fly Project were involved in laboratory and field tests in Tonga.

Phase I

The steps involved in this project were:

1. Preliminary laboratory experimentation with waste yeast from a Brisbane brewery.
2. Laboratory experimentation with waste yeast from Royal Brewery, Tonga.
3. Laboratory cage attractancy tests of bait formulations with *Bactrocera tryoni*.
4. Most promising baits tested in field ground sheet trials in nectarines and guavas.
5. Larger scale laboratory preparation of most promising bait.

Steps 1–5 were undertaken at the Plant Protection Unit, QDPI, Brisbane.

6. Bait prepared in (5) was tested in the field in Tonga by a damage assessment trial in capsicums grown under a weekly bait spray regime.

Phase II

The technology development phase of the project involved the following steps:

1. Based on the laboratory process developed in Phase I, equipment was purchased and modified in Australia.
2. Installation of processing equipment at the Royal Brewery in Nuku'alofa.
3. Trial production of commercial baits.
4. Laboratory and field ground sheet tests with commercial baits in Tonga.
5. Damage assessment trial with capsicums in Tonga using weekly applications of commercial bait.

Steps 1–4 involved QDPI staff from Brisbane collaborating with staff in Tonga and the RFFP.

Experimental Procedures

Laboratory preparation of baits

The starting material for bait production was waste yeast slurry with solids content of 15%–18%, pH 4.6–6.4 and approximate alcohol content of 6.5%. Live RTB (Royal Tongan Brewery) yeast slurry was pasteurised by heating to 65 °C and allowed to cool naturally to ambient temperature. The pasteurised slurry was chilled and sent as quickly as possible in an insulated cooler with frozen blocks to Brisbane. With a view to developing a procedure which would be simple and relatively inexpensive to adapt to small scale commercial production, concentration by heat, proteolysis by the addition of the enzyme, papain, and pH adjustment with sodium hydroxide were the major procedures studied.

Preliminary investigation showed that pasteurised yeast slurry (15%–18% solids) with or without further treatment, was relatively unattractive to Queensland fruit flies but concentration by boiling in an open vessel to reduce the volume by approximately 50% (i.e. to increase the solids content to 30%–35%) and to remove alcohol produced a much more attractive bait. Concentration in the laboratory was carried out by boiling yeast slurry which was constantly stirred on a magnetic stirrer hot plate. Under these conditions, 35% solids was the limit of concentration which could be achieved without significant burn-on occurring on the sides and bottom of the heating vessel. Concentrated yeast was then used to prepare various bait formulations with different

papain concentrations (0%, 0.2% and 0.4%) and different proteolysis times (up to 24 hours at 70 °C). Proteolysis in the laboratory was carried out by holding bait formulations in 500 mL glass bottles in a water bath at 70 °C for specified times. Following this, 0.2% potassium sorbate was added to all bait formulations as a preservative. Approximately 45 different bait formulations were prepared in this manner. Laboratory prepared baits were stored for 12 months at least to assess shelf life.

Bait testing methods

Since protein baits were first used in fruit fly control, many different methods have been used to test their effectiveness. Many years of research on such methods by QDPI have led to the development of a 3-stage testing process:

(1) Laboratory cage tests with lab-reared flies;
(2) Field ground sheet trials with wild or released flies;
(3) Crop damage assessment trials with a known fruit fly host, using regular bait spray applications during a complete growing season.

A combination of these methods allows assessment of both short and long range attractancy and phago-stimulatory characteristics of a protein bait. In developing a new protein bait, all three testing procedures should play a role. A brief outline of each of these methods is given below.

Laboratory attractancy tests

Laboratory cage tests carried out in Brisbane with *B. tryoni* used a two choice bioassay which tested the attractancy of each bait compared to water in a non-competitive situation, i.e., no other bait was present. Flies used in these tests were 10–16 days old, protein-deprived females, fed sugar and water only from eclosion. For each test, 20 flies were released into a small gauze cage (30 × 30 × 30 cm). Four cages of flies and one bait only were tested at any one time in a controlled temperature room (26 °C, 60%–70% relative humidity, with constant artificial lighting). Ten minutes prior to commencement of each test run, sugar and water were removed from the test cages and two dry wettex sponge squares (4 cm^2) were placed on the gauze top of each cage in diagonally opposite corners. This allowed flies to investigate the dry sponges prior to introduction of the test bait. At the commencement of each test, 1 mL of water was applied to one sponge square (the control) and 1 mL of diluted bait was applied to the other sponge square in each cage (the test). The sponges were inverted on to the top of the cage so that flies had direct access to both water and the test bait. Baits were usually diluted 1 in 6 or 1 in 14 but in some tests 1 in 100 dilutions were used to increase the sensitivity of the method.

The number of flies on each sponge was counted every two minutes for 10 minutes with the cages being rotated 180° after five minutes. The maximum number of flies feeding on each sponge during the test time was taken as a measure of attractancy of the bait relative to the water control. Preliminary studies undertaken in developing this test procedure indicated that with protein-deprived flies and a food bait, this method provided the most accurate measure of a land-on and feed response as elicited by protein baits applied to foliage in field situations (Lloyd, unpublished data). Flies were only ever tested once and then discarded. A clean gauze cage and new sponges were used for every test and the metal rod cage frames were wiped with a damp cloth between cage changes. This was done to avoid any interference during the test from regurgitated fluid which might have been deposited on the gauze by flies after feeding. In most laboratory tests, three or four baits, one of which was a standard Mauri's Pinnacle Protein Lure (1 in 20 dilution), were tested repeatedly over a three or four day period with flies from the same cohort.

On any one test day, four runs of tests were conducted between 9 am and 1 pm. Each run consisted of four replicate cages of the same bait as described above. This series of tests was repeated on four consecutive days using flies from the same cohort, but varying the times at which each bait was tested on each day. This meant that each bait was tested 16 times in a 4 × 4 Latin Square Design. The relative attractancy of each to the standard was expressed as the ratio of the mean maximum number of flies attracted to the standard Mauri's bait under the same conditions. A limited number of laboratory cage tests with RTB baits and *B. facialis* were undertaken in Tonga based on the above procedures.

All RTB baits prepared in Brisbane were first tested in the laboratory by the above method to determine the most attractive baits which were further tested in field situations with wild flies by the following method.

Field ground sheet attractancy tests

Natural populations of *B. tryoni* and *B. neohumeralis* in a fruiting guava orchard and a fruiting nectarine orchard at the QDPI Redlands Research Station near Brisbane were used to assess the attractancy of new RTB baits in a competitive situation under field conditions. The test procedures involved spot sprays (50 mLs) of diluted bait mixed with insecticide (Dipterex or 50% malathion e.c. at rate of 8 mLs/L) and applied to foliage above 1.5 m^2 calico sheets

pegged to the ground. For ground sheet trials in Brisbane, a thickener (carboxy methyl cellulose) at the rate of 22.5 g/L was added to the water in which the bait was prepared. No thickener was used for tests in Tonga. Ground sheet trials were conducted in a randomised block design using four treatments (baits) and nine replicates i.e. a total of 36 tests. Three blocks, each of six trees, were selected for applying bait spots. Two × 50 mL spots of different baits were applied to opposite sides of each of the six trees in such a way that all possible paired combinations of baits were tested in each block.

In all field ground sheet trials the standard Mauri's bait diluted 1 in 20 as recommended for field use was included as one of the four baits tested. Baits were freshly prepared on the day of the test and spot sprays applied to foliage over pegged ground sheets between 9 am and 10 am. Dead flies on each sheet were counted and retained for identification every hour for at least five hours. Weather permitting, counts were repeated on the second and third days after bait application.

In some trials, phytotoxicity was assessed by selecting and tagging undamaged leaves in each application spot which were then examined for burn or damage up to one week after bait application. Relative attractancy of each bait was expressed as the ratio of the total number of flies caught to the total number caught by the standard bait in the same time. Results were analyzed using a randomised block design with square root transformation. Trials carried out in Brisbane involved 36 spot applications. Trials undertaken in a pawpaw orchard in Tonga were based on the same method but involved 24 spot applications and laboratory reared *B. facialis* were released.

Damage assessment field trials

Two damage assessment trials with capsicum were undertaken in Tonga as part of this project. These are reported elsewhere (V. Heimoana et al., these Proceedings).

Shelf life of bait formulations

Potassium sorbate (0.2%) was added to new bait formulations as a preservative. Baits were stored at ambient temperatures for up to 12 months and inspected regularly for spoilage in the form of fermentation or mould growth.

Results

Laboratory and field tests

In laboratory cage tests, all bait formulations were highly attractive compared to the water control. Relative attractancy compared to Mauri's bait as a standard, ranged from approx. 0.6 to 0.9. In Brisbane, the number of field ground sheet trials which can be undertaken in a fruiting season with wild flies is limited to two or three per season for guavas and nectarines. For this reason, laboratory tests were used to screen the large number of new bait formulations (approx. 45) and only the most promising baits were used in ground sheet trials. A summary of results of these trials is shown in Table 1. RTB39 at a dilution of 1 in 5 was the most promising formulation. Analysis showed fly knockdown with RTB39 over a three day test in which a total of 3393 flies were caught was not significantly different to that with Mauri's bait. The high relative attractancy shown by baits RTB29, RTB30, RTB31 in laboratory tests (0.89, 0.89, 0.87 respectively) was not reflected in the low attractancy (0.05, 0.15, 0.17 respectively) shown in the field tests (Trial 1). These baits had 18% solids and were formulated from yeast slurry without prior concentration. Subsequent baits formulated using concentrated yeast slurry proved to be much more attractive. Results of Trial 3 (Table 1) showed that there was no difference in attractancy between different dilutions of RTB39 in laboratory tests (a non-competitive situation), but in field tests (a competitive situation) the 1 in 5 dilution was considerably more attractive than 1 in 10 or 1 in 14 dilutions. These differences between laboratory and field trials demonstrate the need for careful interpretation of bait attractancy test results and the need to assess attractancy under different conditions.

Table 1. Laboratory and field attractancy tests with RTB bait formulations.

Bait	Dilution	Relative attractancy		Details of field test
		Lab test	Field test	
Trial 1				
RTB29	1 in 6	0.89	0.05	Nectarines
RTB30	1 in 6	0.89	0.15	Total no. flies = 1364
RTB31	1 in 6	0.87	0.17	Duration: 2 days
Trial 2				
RTB33	1 in 14	0.80	0.37	Guavas
RTB39	1 in 14	0.74	0.44	Total no. flies = 1695
RTB40	1 in 14	0.64	0.36	Duration: 1 day
Trial 3				
RTB39	1 in 5	0.77	0.84*	Guavas
RTB39	1 in 10	0.72	0.62	Total no. flies = 3393
RTB39	1 in 14	0.72	0.55	Duration: 3 days

* NSD to Mauri's 1 in 20.

Crop damage assessment trial

On the basis of the above results, larger quantities of RTB39 were prepared in the laboratory in Brisbane and sent to Tonga to be used in the first damage assessment trial with capsicum. This trial showed a weekly bait spray application of RTB39 reduced infestation levels to 2% after 5 weeks compared to 53% damage in an untreated plot. After 11 weeks of bait spray treatment, infestation was 100% in the untreated plot and 10% in the treated plot. The increase in infestation in this plot from 2% to 10% was most likely due to reduced bait effectiveness because the crop foliage at this time of the trial was poor (V. Heimoana et al., these Proceedings).

Design and installation of commercial processing plant

Results from Phase 1 of the project demonstrated that an effective bait could be produced from brewery waste yeast using concentration by heating followed by proteolysis with papain and preservation with potassium sorbate. The attractancy of the bait was not improved by pH adjustment during formulation. With advice from Tetra Pak Marketing Sydney, suitable second hand food processing equipment was purchased in Australia and modified to process 50–100 litres of yeast waste in a simple batch process with manual transfer of material between steps. The design of the equipment as installed at the brewery site in Tonga is shown in Figure 1. A large domestic hot water system provided hot water which was circulated through the jackets of the holding kettles to maintain the temperature of the yeast concentrate at approximately 65 °C during proteolysis. This was lower than the temperature used in laboratory formulation but gave satisfactory results.

Production and testing of commercial baits in Tonga

The first commercial batches of fruit fly bait (code named Tongalure) were produced in May 1996 and were tested in laboratory bioassays and in ground sheet trials at Vaini Research Station with released *B. facialis* in June 1996. These commercially-

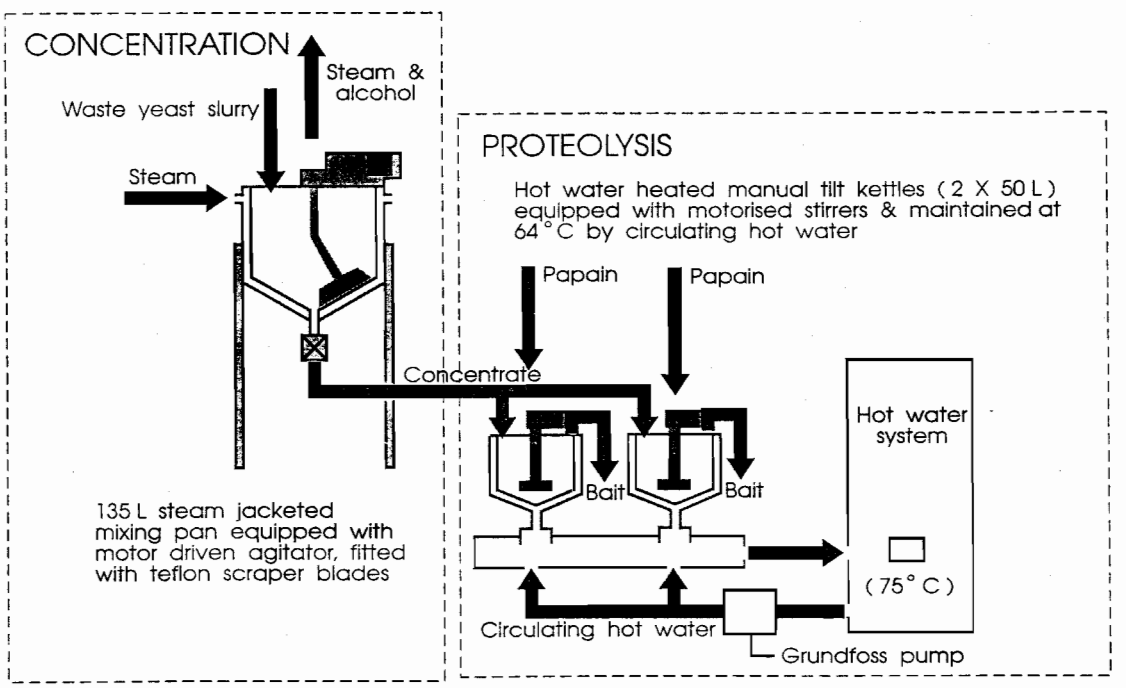


Figure 1. Production of protein bait from waste brewery yeast.

produced baits had pH 4.9–5.3 and 47% solids. The design of the commercial equipment allowed concentration to a higher level of solids than was achievable in laboratory preparation (approx. 35%).

The results of laboratory and field attractancy tests with the first two batches of bait produced in the commercial plant are shown in Table 2. The number of laboratory tests and the scale of the field tests undertaken in Tonga were smaller than those conducted in Brisbane, but results verified that both batches of bait were attractive to *B. facialis* although less attractive than the standard Mauri's bait (1 in 20). A second damage assessment trial using weekly applications of commercially produced Tongalure bait will be undertaken to test its efficacy in field control over a growing season.

Table 2. Laboratory and field attractancy test with commercially produced baits in Tonga.

Laboratory tests	Relative attractancy at different dilutions				
	1 in 5	1 in 10	1 in 20	1 in 50	1 in 100
Tongalure 1	0.66	1.97	0.83	0.94	0.40
Tongalure 2	1.0	1.36	1.16	0.72	0.36

NSD between baits $p < .05$ over all dilutions.
1 in 10 dilution significantly more attractive than 1 in 50, 1 in 100 $p < .05$

Field ground sheet tests	Relative attractancy at 1 in 10 dilution
Tongalure 1	0.36
Tongalure 2	0.35

Highly significant differences ($p < .01$) between Tongalure 1 and Mauri's and Tongalure 2 and Mauri's. NSD between Tongalure 1 and Tongalure 2.
* Standard bait used in both laboratory and field tests was Mauri's Pinnacle Protein Lure at 1 in 20 dilution.

Assessment of shelf life and phytotoxicity

No phytotoxic effects have been observed on foliage treated with any of the new bait formulations. Tests in Brisbane involved bait application to guavas and nectarines and in Tonga baits were applied to pawpaws and capsicums with no ill effects recorded. Potassium sorbate (0.2%) proved to be effective as a preservative with baits being stored for up to 2 years with no evidence of spoilage.

Discussion

Because the aim of this project was to develop an 'economical' protein bait from brewery waste yeast, the processing steps investigated were intentionally kept simple to allow transfer of technology from the laboratory situation to small scale commercial production with a minimum of difficulty and expense. The development of suitable methods to test the new bait formulations was an equally important part of the project.

Testing attractancy of food baits for fruit flies is a notoriously difficult exercise because of the complexity of factors involved in both fly behaviour (e.g. age, sex, nutritional state, prior experience) and test conditions (temperature, humidity, light, time of day). Until the specific chemical attractants in protein baits are able to be defined and quantified, the evaluation of new baits must depend on a combination of methods as described here. For each test method, the significance of the results in terms of fruit fly response as well as the practicability and limitations of the test must be considered.

The laboratory cage bio-assays using laboratory-reared flies determine relative attractancy of a bait to water (in a 2-choice test) and to a standard bait in a non-competitive situation. Such tests can be carried out all year round under standard conditions and are a useful screening mechanism for testing large numbers of new bait formulations. The 'land on and feed' response is a measure of both short range attractancy as well as of phago-stimulatory characteristics of the bait, both of which are essential for a bait to be effective in the field.

Field ground sheet tests rely on the availability of natural or released fly populations in non-sprayed fruiting orchard situations. The success of such tests is very much dependent on suitable weather conditions but these tests have the advantage of allowing short term assessment of longevity and phytotoxicity of baits. A large number of replicates for each treatment is required because of the known clumping effect of fruit flies in orchard situations (Lloyd and Drew, unpublished data.) Furthermore, in the experimental design employed, baits are tested in a competitive situation against a known highly attractive standard bait. As shown by the results in Table 1, some food baits may appear highly attractive over short ranges in non-competitive laboratory cage tests but may be relatively weak attractants over greater distances in competitive field situations.

The ultimate test of a new bait is its effectiveness in controlling fruit fly infestation in a known preferred host subject to regular bait spray applications over a complete growing season. Because of the time and labour involved in carrying out such damage assessment trials, prior testing of baits by the other two methods to select the most promising ones is essential.

ACIAR Project No. 7500 has demonstrated that an effective protein bait for fruit fly control can be produced by a relatively simple batch process using inexpensive and readily available waste yeast slurry which is discarded in many commercial brewing operations. The process used has been adapted from well established methods for producing yeast extracts for the food industry. The equipment required was manufactured by modifying standard food processing equipment. Additional requirements were a large domestic hot water system, a circulating pump, an available source of steam and power and fittings to install the equipment. The proteolytic enzyme, papain, and the preservative, potassium sorbate, were the only additional materials required.

When the final field trial on capsicums is completed, an economic assessment for commercial useage must be undertaken before larger scale production, packaging, distributing and marketing of the new bait can begin. The on-going success of this venture and the application of similar technology in other Pacific island countries will subsequently depend on economics of production and educating growers to appreciate the value of protein baits in fruit fly control.

References

Hargraves, J.R., Murray, D.A.H. and Cooper, L.P. 1986. Studies on the stinging of passionfruit by Queensland fruit fly, *Dacus tryoni,* and its control by bait and cover sprays. Queensland Journal of Agricultural and Animal Sciences 43, 33–40.

Peppler, H.J. 1982. Yeast Extracts. Economic Microbiology 7, 293–310.

Roessler, Y. 1989. Insecticidal bait and cover sprays In: Robinson, A.B. and Hooper, J., eds, Fruit flies: their biology, natural enemies and control. Vol. 3B, Elsevier 329–336.

Smith, D. and Nannan, L. 1988. Yeast autolysate bait sprays for control of Queensland fruit fly on passionfruit in Queensland. Queensland Journal of Agriculture and Animal Sciences. Vol. 45(2): 169–177.

Steiner, L.F. 1952. Fruit fly control in Hawaii with poison bait sprays containing protein hydrolysates. Journal of Economic Entomology, 45: 838–843.

Vijaysegaran, S. 1989. An improved technique for fruit fly control in carambola cultivation using spot sprays of protein baits. National Seminar on Carambola: Developments and Prospects, 18–19 July 1989, Kuala Lumpur, Malaysia.

Prospects for the Use of Biological Control Agents to Control Fruit Flies

A. Peters[1]

Abstract

Although tropical fruit flies in general have proved not to be good targets for classical biocontrol, the establishment of fruit fly parasitoids in some countries of the Pacific will almost certainly result in reduction of fruit fly populations. With limited knowledge of the life history and diverse behaviour of fruit flies targeted for biological control, it is difficult to predict whether the degree of reduction will be really valuable. There is no evidence to suggest that parasitoid establishment in an area would result in any adverse effect or other organisms. Establishment of parasitoids is likely to be of greatest value to the traditional farmer, of some value in reducing infestation in produce intended for the local market, but of very limited value for produce intended for export.

THIS paper is a summary of various biological control programs for fruit flies carried out in the Pacific region during the past century. Numerous papers have been written on this topic by many researchers and much of this information has been compiled by Waterhouse (1993).

Fruit flies are not attractive targets for classical biological control. This is partly because of several features in their life histories which make conditions very difficult for parasitoids. Adults of many species disperse widely on emergence, leaving parasitoids behind. Also, fly numbers increase rapidly when suitable fruits are found, but adults again disperse widely to other areas when fruits disappear once more leaving parasitoids behind.

Some examples of failures and successes in efforts to establish parasitoids in countries have been demonstrated by many years of extensive biological control programs conducted in the Pacific region and other countries outside it.

In the Pacific region, much information was gathered from the experiences of researchers in Hawaii, Australia and Fiji where quite a few biological control agents were introduced to control major economically important species of fruit flies. Four of the most important species included the melon fly *Bactrocera cucurbitae,* Oriental fruit fly *Bactrocera dorsalis,* Mediterranean fruit fly *Ceratitis capitata,* and the Queensland fruit fly *Bactrocera tryoni.*

[1] Biological Control Adviser, South Pacific Commission, Private Mail Bag, Suva, Fiji

Natural Enemies for the Control of Fruit Flies in the Pacific Region

Table 1 gives a list of natural enemies which were used in one way or another to control fruit flies in Pacific region countries including Australia and Hawaii during the past century. Some were native to some countries while others were introduced from outside the region.

Most of the parasitoids that attack fruit flies belong to the family Braconidae. Within this family, a few species of parasitoids have been recorded to be very active against several major species and gave good control on some of these species.

Biological Control of Fruit Flies in Hawaii

Biological control investigations aimed at *Ceratitis capitata* in particular commenced in 1912 in Hawaii. These led to the introduction and establishment of the parasitic wasps *Psyttalia concolor* from South Africa, *Dirhinus anthracina* from West Africa, and *Diachasmimorpha tryoni* from Australia (Clausen et al. 1965).

Table 1. Parasitoids for the control of fruit flies in the Pacific region.

Family	Species	Host stage attacked
Braconidae	*Fopius arisanus*	Egg
	F. vandenboschi	
	F. skinneri	
	F. deeralensis	
	F. carinatus	
	Diachasmimorpha longicaudata	Larva
	var. *longicaudatus*	
	var. *formosanus*	
	var. *malaiaensis*	
	var. *compensans*	
	var. *novocaledonicus*	
	D. tryoni	
	D. hageni	
	D. dacusii	
	D. albobalteatus	
	Psyttalia fletcheri	Larva
	P. concolor	
	P. incisi	
	P. fifiensis	
	Opius frogatti	
	O. perkinsi	
	Biosteres fullawayi	Larva
	B. giffardi	
	Phaenocarpa leveri	
Eulophidae	*Tetrastichus giffardianus*	Larva
	T. dacicida	
	Aceratoneromyia indica	
Chalcididae	*Spalangia endius*	Pupa
	S. cameroni	
	S. hirta	
	Dirhinus anthracina	
Pteromalidae	*Pachycrepodius vindemiae*	Mature larva/pupa
Cynipidae	*Aganaspis daci*	

By 1915, *Psyttalia concolor* had attained a high percentage parasitisation, but this species was replaced by *Diachasmimorpha tryoni.* The percentage parasitisation of *C. capitata* larvae in coffee berries ranged from 45.9% to 94.4% but was lower in fruits such as guava, mango and orange with a range from 3% to 24%.

The discovery of the Oriental fruit fly in Hawaii in 1946 immediately led to a massive program of importation of parasitoids. Seven species of parasitoids became established on the Oriental fruit fly, namely *Fopius arisanus,* F. *vandenboschi, Diachasmimorpha longicaudata, Psyttalia incisi* and *Aceratoneuromyia indica. F. arisanus* dominated all other species of parasitoids producing about 70% parasitisation of *Bactrocera dorsalis* in guava, the main reservoir of this species (Bess et al. 1961). In addition to hosts killed by the developing parasitoid larvae of *F. arisanus,* many host eggs (perhaps 50%) were killed as a result of transmission of micro-organisms by *F. arisanus* at the time of oviposition usually increasing fruit fly mortality to more than 95%.

Sampling of guava showed substantially lower numbers of *Bactrocera dorsalis* larvae from 1950 onwards and several cultivated fruits (e.g. avocado, banana, papaya and persimmon), previously heavily infested, became practically free from attack. Indeed, an overall 95% reduction in fly populations and pest damage was claimed for the decade after 1948 (Bess and Haramoto 1961; Clausen et al. 1965, Haramoto and Bess 1970).

Attempts at biological control of melon fly in Hawaii started by testing many of the parasitoids already mentioned in relation to the campaigns against Oriental fruit fly. It was found that none of the most effective parasites for the other pest species were able to complete their development in *Bactrocera cucurbitae.* A braconid wasp *Psyttalia fletcheri,* a widespread parasitoid of melon fly in India, was introduced to Hawaii in 1916. Within a few years of establishment in Hawaii, *P. fletcheri* was causing 50% parasitisation of melon fly in commercial crops and up to a 100% in the wild *Momordica* melons. Fullaway (1920) reported that it was again possible to grow melons successfully, the infestation per fruit having been reduced from 4 to 6.5 larvae to .3 or fewer larvae per fruit. Under the most favourable circumstances, the population of melon fly was reduced to such low levels that it virtually ceased to be a pest.

Biological Control of Fruit Flies in Australia

During the campaign to control the Queensland fruit fly in Australia in 1958, parasitoids were introduced from Hawaii and liberated in the field in New South Wales, Queensland and Lord Howe Island. These parasitoids included *Fopius arisanus, Diachasmimorpha longicaudata, Fopius vandenboschi, Psyttalia incisi, Dirhinus anthracina, Aceratoneuromyia indica,* and *Tetrastichus giffardianus.* Extensive samplings of fruits in eastern Australia between 1960 and 1962 revealed only *F. arisanus* was established on the mainland. It was bred from *Bactrocera barringtoniae, B. cacuminata, B. neohumeralis, and B. tryoni.* Level of parasitisation was 78% for most of the favoured fruits in Australia. The data obtained by Snowball (1966) and Snowball and Lukins (1964) indicated that the introduction of *F. arisanus* had

reduced the number of flies produced per fruit but had not much effect on the percentage of fruit infested.

Biological Control of Fruit Flies in Fiji

Following reports in the early 1950s of considerable success in the biological control of *Bactrocera dorsalis* in Hawaii, introductions to Fiji were resumed. Between 1951 and 1954, four species of braconid were released. Of these, only two, *F. arisanus* and *Diachasmimorpha longicaudata* were later recovered in the field (O'Connor 1954). By 1959, rearings from orange and grapefruit, yielding 21.4% *F. arisanus* and .3% *D. longicaudata,* were reported by O'Connor (1960) who added that in the opinion of H.W. Simmonds who had made a study of local fruit flies over the years, infestations of fruits were very much less than ten years previous. It seems likely that *F. arisanus* had been responsible for a considerable measure of control of fruit flies. Rao et al. (1971) stated that *F. arisanus* appeared to have played a significant part in controlling fruit flies. Hinckley (1965) also found that an increase in percent parasitisation in fruit flies was largely due to the more effective attack of *F. arisanus* on the eggs of *Bactrocera passiflorae* in guava and citrus.

Predators Known to Attack Fruit Flies

Table 2 shows different kinds of predators which have been known to attack fruit flies at different stages. Although predators are not known to control fruit flies effectively, they can somehow reduce fruit fly populations to some extent.

Table 2. Predators of fruit flies.

Common name	Species	Family	Stage attacked
Bugs	*Germalus pacificus* *Zelus renardi*	Reduviidae	Egg Adult
Ants	*Pheidole megacephala*	Formicidae	Egg, larva, pupa
Beetle	*Philontus turbidus*	Staphilinidae	Egg, larva, pupa
Earwig	*Chelisoches morio*	Chelisochedae	Larva
Spider	*Argiope* spp.	Araneidae	Adult
Bats	Various	Various	Egg, larva
Birds	Various	Various	Egg, larva

Table 3 shows various species of parasitoids which have become established in some countries of the Pacific. Some species of these parasitoids are native to some countries while others have been introduced from elsewhere.

Table 4 shows a great number of parasitoids which were introduced into Australia to try to control the Queensland fruit fly *Bactrocera tryoni* with very little success. It is interesting to note that *F. arisanus* was the only one which became established and gave good control.

Possible Reasons for Failure to Establish Parasitoids in the Past

Many of the early failures to establish parasitoids in Pacific region countries in the past have been attributed to several factors, including the lack of information on the biology and ecology of the target fruit fly pest and natural enemies associated with it. Limited studies had been conducted on the behavior of different species of fruit flies in the late 1800s and early 1900s and thus very little information was known about the pests and their natural enemies.

Another factor was the difficulty faced during rearing of both fruit flies and the parasitoids that attack them. This can also be attributed to the unavailability of background information on the biology and behavior of parasitoids and their hosts.

The third factor was transport difficulties when shipping parasitoids between countries. Transportation in the past took hours or days, causing mortality of most parasitoids. Those that survived the long journeys would not have performed as well as expected.

Table 5 gives a list of potential parasitoids which have given reasonable control on some of the most important species of fruit flies, and should be considered in future biological control programs in the Pacific region.

Discussion

Of at least 82 species of parasitoids that have been reared from the tephritids during exploration programs, it appears that only 44 were released and only 20 were known to have become established (Wharton 1989). It is important to examine what practical advantages might be expected to result from the establishment of additional parasitoids that attack Pacific region fruit flies.

Parasitoids that oviposit into the puparium have been largely neglected because of sampling difficulties but they also deserve further attention.

Table 3. Parasitoids established in Pacific region countries.

Country	Species	When liberated	Origin
Cook Islands	*Fopius arisanus*	Unknown	Unknown
Fiji	*Diachasmimorpha longicaudata*	1951, 1954	Hawaii
	D. hageni		Native
	Fopius arisanus	1951, 1954	Hawaii
	Aceratoneuromyia indica	1938, 1941	India
	Psyttalia concolor	1938	Unknown
	P. fijiensis		Native
	Tetrastichus giffardianus	1935	Hawaii
	Spalangia cameroni	1929	Hawaii
	S. endius		Native
	Pachycrepoideus vindemiae		Native
French Polynesia	One species introduced but did not establish		
Guam	*Psyttalia fletcheri*	1950, 1953, 1955, 1959, 1960, 1967	Hawaii
	Aceratoneuromyia indica		Native
Kiribati	None recorded		
Nauru	None recorded		
New Caledonia	*Diachasmimorpha longicaudata*		Unknown
	Psyttalia fijiensis		Unknown
	Opius frogatti		Unknown
	Spalangia endulis		Unknown
Northern Marianas	None established from 10 species introduced		
Papua New Guinea	*Diachasmimorpha longicaudata*		Native
	Opius sp.		Native
	Fopius deeralensis		
	Psyttalia fijiensis		
Western Samoa	*Aceratoneuromyia indica*	1935	Fiji
	Fopius arisanus		Unknown
Solomon Islands	*Diachasmimorpha kraussii*		Native
Tonga	*Fopius arisanus*		Unknown
	Psyttalia fijiensis		
	Spalangia sp.		
Vanuatu	*Biosteres* sp.		
	Tetrastichus giffardianus	1936	Fiji

Table 4. Liberation of parasitoids for the biological control of *Bactrocera tryoni* in Australia (Waterhouse 1993).

Parasitoid	Liberated	From	Result
BRACONIDAE			
Biosteres fullawayi	1933	Hawaii	—
Diachasmimorpha	1956, 1957	Hawaii	—
longicaudata	1958, 1959	Hawaii	*+
Fopius arisanus	1956, 1957	Hawaii	—
	1958, 1959	Hawaii	+
F. vandenboschi	1958, 1959	Hawaii	—
Psyttalia concolor	1932, 1933	Hawaii	—
P. incisi	1958, 1959	Hawaii	—
CHALCIDIDAE			
Dirhinus anthracina	1958	Hawaii	—
EULOPHIDAE			
Aceratoneuromyia indica	1937, 1938	India	—
	1958, 1959	Hawaii	—
Tetrastichus giffardianus	1932, 1933	Hawaii	—
	1958, 1959	Hawaii	—

*Established briefly but died out.
+Still present on Lord Howe Is.

Table 5. Potential parasitoids for the control of major fruit fly species in the Pacific.

Fruit fly species	Potential parasitoids
Bactrocera cucurbitae	*Psyttalia fletcheri*
	Fopius arisanus
	Diachasmimorpha albobalteatus
	D. daussii
B. dorsalis	*F. arisanus*
	F. vandenboschi
	D. longicaudata
B. tryoni	*F. arisanus*
	F. vandenboschi
	D. tryoni
Ceratitis capitata	*F. arisanus*
	Psyttalia concolor
	D. longicaudata

Waterhouse (1993) commented that, under favourable conditions and with a suitable host such as the Oriental fruit fly, *F. arisanus* can achieve parasitisation levels up to 70%. When the larval parasitoids *Fopius vandenboschi, Diachasmimorpha longicaudata* and *Psyttalia incisi* are also present, they are capable of causing a little additional mortality, with other species such as *Tetrastichus giffardianus* and *Aceratoneuromyia indica,* together causing useful but even lower mortality. This guild of parasitoids assembled in Hawaii was reported to have caused such a significant reduction in the population of the Oriental fruit fly that some less preferred hosts which were formerly attacked when fly densities were high became entirely free from damage and even a proportion of usually favoured hosts escaped attack (Clausen et al. 1965). Nevertheless, poisoned protein bait sprays and male lures, together with systemic surface sprays are used both by commercial growers and backyard gardners to achieve a high level of freedom from fruit fly attack. Such measures are too expensive for routine use by most traditional farmers in Pacific region countries.

Waterhouse (1993) said that, during the decade following the establishment of *F. arisanus* and *Diachasmimorpha longicaudata* in Fiji, fruit damage (mainly caused by *Bactrocera passiflorae* and *B. xanthodes)* was reported to have diminished although not to the same extent as with *B. dorsalis* in Hawaii. One possibility is that *B. passiflorae and B. xanthodes* are less suitable hosts for the parasitoids than *B. dorsalis.* Another is that Fijian fruit flies may be less effectively attacked in some host fruits than in others. For example, it is well known that *F. arisanus* pays little attention to fallen fruits. Thus any fruit fly species that oviposits in fallen fruit, as does *B. passiflorae,* is likely to escape attack by this species. A less likely third possibility that remains to be explored is that the mortality produced by the introduced parasitoids has little more than replaced that caused earlier by native parasitoids. An even lower impact than in Fiji has been reported on the Queesland fruit fly following the establishment of *F. arisanus* in Australia. Any or all of the three possible explanations discussed above may also apply in this case.

Conclusion

Further studies are required in order to predict the effects of introducing parasitoids to the Pacific region. Some of the questions that need to be thoroughly investigated before parasitoids are imported were posed by Waterhouse (1993):

- what are the major hosts of the target fruit flies;
- whether the target fruit flies are suitable hosts for the candidate parasitoids;
- what level of parasitisation, if any, is already being achieved by native or already introduced parasitoids;
- whether the target fruit flies commonly oviposit in fallen fruit.

Further, Waterhouse (1993) stated that the establishment of fruit fly parasitoids in the Pacific region will almost certainly result in the reduction in numbers of target pests but with existing knowledge, it is not possible to predict whether the degree of reduction would be really valuable as shown in Hawaii, useful but not really adequate as shown in Fiji, or of little significance as shown in Australia.

There is no evidence to suggest that parasitoid establishment would result in any adverse effects.

Establishment of parasitoids is likely to be of greatest value to the traditional farmer, of some value in reducing infestation in produce destined for the local market, but of far more limited value for export produce.

References

Bess, H.A. and Haramoto, F.H. 1961. Contributions to the biology and ecology of the Oriental fruit fly, *Dacus dorsalis* Hendel (Diptera: Tephritidae) in Hawaii. Hawaii Agricultural Experiment Station, Technical Bulletin 44: 1–30.

Bess, H.A., van den Bosch, R. and Haramoto, F.H. 1961. Fruit fly parasites and their activities in Hawaii. Proceedings of the Hawaiian Entomological Society, 17: 367–378.

Clausen, C.P., Clancy, C.W. and Chock, Q.C. 1965. Biological control of the Oriental fruit fly (*Dacus dorsalis* Hendel) and other fruit flies in Hawaii. United States Department of Agriculture, Agricultural Research Service, Technical Bulletin 1322: 1–102.

Fullaway, D.T. 1920. The melon fly: its control in Hawaii by a parasite introduced from India. Hawaii Forester and Agriculturist, 17: 101–105. (Review of Applied Entomology A, 8: 347).

Haramoto, F.H. and Bess, H.A. 1970. Recent studies on the abundance of the Oriental and Mediterranean fruit flies and the status of their parasites. Proceedings of the Hawaiian Entomological Society, 20: 551–556.

Hinckley, A.D. 1965. Fruit fly infestation and parasitisation in Fiji. Proceedings of the Hawaiian Entomological Society, 19: 91–95.

O'Connor, B.A. 1954. Annual report of the Senior Entomologst for 1954. Bulletin No. 29 Department of Agriculture, Fiji. 37–40.

O'Connor, B.A. 1960. A decade of biological control in Fiji. Fiji Department of Agriculture, Agricultural Journal, 30: 34–54.

Rao, V.P., Ghani, M.A., Sankaran, T. and Mathur, K.C. 1971. A review of the biological control of insects and other pests in South East Asia and the Pacific region. Technical Communication 6, Commonwealth Institute of Biological Control, Commonwealth Agricultural Bureax, 43–45.

Snowball, G.J. 1966. Status of introduced parasites of Queensland fruit fly *(Strumeta tryoni)* 1962–1965. Australian Journal of Agricultural research, 17: 719–739.

Snowball, G.J., and Lukins, R.G. 1964. Status of introduced parasites of Queensland fruit fly *(Strumeta tryoni)* 1960–1962. Australian Journal of Agricultural Research, 15: 586–608.

Waterhouse, D.F. 1993. Pest fruit flies in the oceanic Pacific. Biological Control Pacific Prospects Supplement 2, 9–47.

Wharton, R.A. 1989. Classical biological control of fruit-infesting Tephritidae. In: Robinson, A.S. and Hooper, G., eds, Fruit flies: their biology, natural enemies and control. Volume 3B. Chapter 9.1: 303–313. Elsevier. Amsterdam.

The Economic and Social Impact of the *Bactrocera papayae* Drew and Hancock (Asian Papaya fruit fly) Outbreak in Australia

R.A.I. Drew[1]

Abstract

If an order of priority were to be established for the major plant and animal pests and diseases worldwide, fruit flies would be at the top of the list. The major fruit fly pest species in particular rank with the most damaging of all pests and cause enormous economic losses. This is why the outbreak of *Bactrocera papayae* Drew and Hancock in north Queensland, one of the worst fruit fly pest species known, has caused enormous economic and social impacts and engendered fear into government and industry across Australia. In this paper these impacts are discussed together with recommendations for future actions needed to prevent a re-occurrence both in Australia and other South Pacific countries. The story of the *B. papayae* outbreak has been documented by Bellas (1996).

History

FRUIT flies reared from green pawpaw at East Trinity, near Cairns, north Queensland were identified as *B. papayae* by R.A.I. Drew and D.L. Hancock on 17 October 1995. The infested fruit were collected approximately 2 weeks earlier and represented the first ever outbreak of an Oriental fruit fly complex pest species in Australia. By the time of detection, the fly had become well established. There were large breeding populations in the urban areas of Cairns, Mareeba and Mossman and a continuous population spread over an area of approximately 2500 km^2. If all localities are considered where outlying flies have been trapped (or reared from fruit) up to mid-September 1996, an area of approximately 11 000 km^2 is involved. Considering the size and distribution of the fly population and the area of land infested at the time of discovery, the fly must have been introduced 2 to 2½ years earlier (approximately mid-1993) into Cairns.

B. papayae is endemic to southern Thailand, Peninsular and East Malaysia, Singapore, the entire chain of Indonesian islands and Kalimantan. It was introduced into Irian Jaya in the late 1980s and first detected in Papua New Guinea (PNG) in the Western Province in late 1992. By March–April 1993 it was found on Stephen and Darnley Islands towards the centre of Torres Strait and on Saibai, Boigu and Dauan Islands adjacent to the PNG coast. By late 1993 it was eradicated from Stephen and Darnley Islands and under suppression on the other three islands. From PNG or Torres Strait, it was introduced to Cairns.

[1] Department of Environmental Sciences, Griffith University, Nathan Campus, Qld, 4111

Economic and Social Impact

The impact of the *B. papayae* outbreak can be assessed under four main categories: industry, government, the nation and the environment.

Impact on industry

While no study has been made of the industry losses, sections of industry believe that export trade bans have cost some $100 million to date. These bans have restricted the export of most horticultural produce from within the declared Quarantine Zone to international and interstate markets. In order to overcome trade bans by the use of emergency post-harvest treatments, many producers had to construct expensive on-farm post-harvest treatment and fruit

handling facilities. In addition, the post-harvest treatments have added considerably to production costs, both in materials and labour. Before the discovery of the outbreak, some mango growers spent large sums of money on on-farm heat treatment and packing facilities to meet international export standards. Their main exports were mangoes to Japan. Not only was this export lost but the facilities are now lying idle and will continue to do so until the fly is eradicated or suitable market access technologies are developed. Another industry loss is the suspension of planning for expansion in production and trade developments in new and existing horticultural crops.

Industry has also suffered sociologically through a range of personal losses to people. There has been loss of jobs, income to industry workers, health problems to people through the chemical post-harvest treatments (fumigation and insecticide dipping), and severe emotional stress. Such losses are often overlooked and can involve major financial costs also.

Impact on governments

The *B. papayae* outbreak has had a major impact on state governments throughout Australia. To date, eradication costs have reached approximately $20 million and will probably exceed $55 million over 5 years. These costs are being met by the Federal and all State governments under a national cost sharing arrangement. While this expenditure is essential to cover monitoring, application of eradication strategies, installation and administration of road-blocks, regulatory and quarantine activities, it is a serious drain on national funds. Large and intense workloads have been placed upon Queensland government officers, particularly in the areas of policy development, policing trade and regulatory activities, establishing the monitoring and eradication campaigns and meeting a wide range of industry pressures. The political and industry pressures have been enormous and together with the above-named workloads, have caused serious stress on government workers.

Above all, the *B. papayae* outbreak has shown up weaknesses in business management systems. Such a national disaster requires the application of management principles that are not practised in normal day-to-day running of government departments. Consequently, incorrect decision-making, leading to inefficiencies in technical programs, have occurred and are continually having to be addressed. There is a real need for countries in the Pacific Region to become educated in disaster management principles. This can be done by studying the literature on this subject, particularly as it relates to fruit fly eradication programs. The experiences in such programs in Japan, USA and Australia can certainly be explored to the benefit of all.

Impact on Australia as a nation

Australia has suffered direct losses in trade to international markets which, in turn, must affect the national balance of trade. While in some situations a strengthening of relationships has been observed between governments and industries in the battle against a common enemy, in other instances there has been a weakening in relationships as a result of argument over cost-sharing for the eradication program. Such impacts are difficult to assess economically, but all add to the large socio-economic suffering that is occurring.

Impact on the environment

With a fruit fly outbreak as large as that presently being experienced with *B. papayae* in Queensland, major environmental issues always arise. The emergency post-harvest treatments have been based on fumigation, dimethoate and fenthion dipping. The temporary fumigation facilities had, in some cases, gas leakage problems. Also, the disposal of waste dimethoate and fenthion after packing shed dipping has been difficult environmentally, while some produce received at markets has had excess chemical residues. Although the male annihilation and protein bait eradication treatments have had minimal environmental impact, this would not be the case if they were not strictly controlled. All treatments are being applied by hand and so placed with accuracy in localities away from environmentally sensitive areas. Costly environmental impact studies will have to be conducted before any eradication treatments can be used in environmentally sensitive zones such as rainforests and water catchments.

If *B. papayae* is not eradicated, other major environmental problems will occur. Because the fly would eventually spread over large areas of Australia, large increases in insecticide useage would be required in order to achieve on-farm pre-harvest control. These applications of insecticides would be in addition to those already used against existing fruit fly species.

Further, *B. papayae* is an extremely virulent species and a broad generalist in terms of the fruit species that it is capable of using for breeding. If it is allowed to become established in rainforest areas, then its breeding activity in rainforest fruits would almost certainly exclude some of the endemic monophagous fruit fly species even to the point of extinction. Consequently, rainforest ecosystems are

under threat and must be protected from invasion by *B. papayae*. Again, it is difficult to cost the environmental impacts that are being encountered by the outbreak of *B. papayae*. However, they are serious and add to the overall economic losses.

Conclusion

The outbreak of *B. papayae* in Queensland has been a national disaster socially and economically. The fact that the initial invasion occurred some 2 years prior to its discovery highlights the need for all countries in the Asian and Pacific regions to have early warning systems for introduced exotic fruit flies. It is essential to detect introductions of exotic fruit flies early if eradication is to be achieved quickly and economically. Early warning systems, based on male lure trapping, are tried and tested and if well planned and carefully executed, will provide high levels of security as demonstrated in New Zealand. This was clearly proven during the recent detection of a breeding population of Mediterranean fruit fly in Auckland. Because of that country's excellent trapping network set up as an early warning system, eradication was achieved rapidly and relatively inexpensively. In contrast, Australia, without an early warning system, is paying dearly for this and will continue to do so for several more years until *B. papayae* is eradicated.

In conclusion, this writer would urge all quarantine and agriculture officers in all countries to influence their departments and governments to establish early warning systems for exotic fruit flies. Researchers have all the technical knowledge needed but they also need the political desire. If all work towards this target then all will certainly be making major contributions to their countries and regions, for the economic benefit of all.

Reference

Bellas, T. 1996. The Papaya Fruit Fly — A Failure of Quarantine. Department of the Parliamentary Library, Canberra, Research Paper No. 29, 1995–96, 1–36.

Losses Caused by Fruit Flies (Diptera: Tephritidae) in Seven Pacific Island Countries

A.J. Allwood[1] and L. Leblanc[2]

Abstract

Losses to fruits and vegetables caused by fruit flies (family Tephritidae) are substantial and may be broken into two categories. Firstly, direct losses are caused by the oviposition of eggs under the skin of fruits, subsequent larval feeding and, in some instances, premature fruit drop. Generally, fruit flies cause complete destruction of fruit, not cosmetic damage. Secondly, quarantine restrictions imposed by importing countries result in losses in overseas or, in some cases, within country markets. Invariably, these restrictions result in a cost to governments and horticultural industries for quarantine surveillance and regulatory inspections as part of guaranteeing quarantine security. Host surveys conducted in seven Pacific Island countries during 1991–96 provided data on the percentages of fruits and vegetables that were damaged by fruit flies. Surveys were conducted by regularly sampling fruits and vegetables and either holding the pieces of fruits in separate containers or holding the fruits for 5–7 days and then assessing if larvae were present or not. A summary of the expected losses to a range of fruits in each of the seven countries is presented.

FRUIT flies (Diptera: Tephritidae) are recognised by plant protection and quarantine personnel and farmers and exporters as one of the most serious pests of horticultural production and trade. The Tephritidae consists of approximately 4500 species distributed throughout the tropical, sub-tropical and temperate regions of the world (Hardy 1991). About one-third of the known species are frugivorous. Many of the remaining two-thirds of the known species infest and feed on other parts of plants, such as stems, roots, flowers, buds, seeds, ovaries and leaves. A few species diverge from these habits and scavenge and feed in rotting bark, wood and in termite mounds. There is a large number of species in Malaysia and Thailand that feed exclusively on bamboo shoots, resulting in complete destruction.

Fruit fly larvae cause complete destruction of host fruits and vegetables, not just cosmetic damage. As mentioned above, the larvae of bamboo shoot feeders cause complete loss of the shoot. Fruits infested by fruit flies often drop prematurely, e.g. carambola (*Averrhoa carambola* L.) in Malaysia, mandarin (*Citrus reticulata* Blanco) infested by *Bactrocera* (*Tetradacus*) *minax* (Enderlein) in Bhutan, and capsicum and chilli infested by *Bactrocera* (*Bactrocera*) *facialis* (Coquillett) in Tonga. Losses of fruits to fruit fly infestation are greater as the fruits approach the ripe stage of maturity. Mangoes and pawpaws are harvested at the green mature stage and colour break stages, respectively, to avoid the stages of maturity most susceptible to fruit flies. Many people in Pacific Island countries eat fruits, such as guavas, mangoes and kavika (*Syzygium malaccense* L.) at the green mature stage of maturity to avoid fruit fly attack.

Though the biology of many of the economically important species have been studied exhaustively and there are adequate methods of control available, obtaining reliable, up-to-date quantitative data on the losses caused by fruit flies in most countries is difficult. This paper identifies levels of losses caused by fruit flies in seven Pacific Island nations and identifies areas where additional economic and entomological research is necessary.

[1] Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji
[2] Regional Fruit Fly Project (FSM), Department of Resources and Development, Pohnpei, FSM

Losses Caused by Fruit Flies Worldwide

Many countries are not able to estimate crop losses caused by insect pests and diseases. Most are unlikely to be able to estimate losses to fruits and vegetables specifically caused by economically important fruit fly species. In this age of food shortage and starvation in some developing countries, it is imperative to be able to identify areas from which significant increases in food production can be achieved. Controlling fruit flies, together with improved cultural practices, are two ways of improving food production, alleviating poverty and improving security of nutritious food. Encouragement of greater consumption of fresh fruits and vegetables will also assist in overcoming nutritional diseases, such as coronary disease and diabetes.

The economic importance of fruit flies is derived from direct losses in production and lost market opportunities due to the presence of fruit flies and the consequent restrictions imposed on the trade of fresh commodities by importing countries. Added to this are the costs of field control of existing species, the eradication of outbreaks of exotic species, and the costs of quarantine surveillance. Despite knowing the cost components, very little effort has been made to quantify these costs. Isnadi (1991) stated that, in Indonesia, although a number of fruit crops are affected by infestation of fruit flies, little accurate information is available on the actual monetary loss. Vijaysegaran (1991) estimated that the cost of existing control methods amounted to 5% of the value of production of fresh fruits in Malaysia, but no effort was made to estimate the percentage or monetary crop losses due to fruit flies. In India, Agrawal and Mathur (1991) reported that the level of damage caused by the trypetine ber fruit fly (*Carpomya vesuviana* Costa) ranged from 10.4% to 47.0%, depending on the species of *Ziziphus*.

It seems that substantially more research into levels of damage by fruit flies has been done in temperate areas, particularly in European and Middle Eastern countries. The species of fruit flies on which most research has been done are *Rhagoletis cerasi* (L.) (European cherry fruit fly), *Ceratitis capitata* (Wiedemann) (Mediterranean fruit fly), and *Bactrocera* (*Daculus*) *oleae* (Gmelin) (olive fruit fly). Fischer-Colbrie and Busch-Petersen (1989) reviewed the topic of losses caused by these species. European cherry fruit fly may cause up to 90% losses of late cherries in the Upper Rhine, as compared to 80% to 90% of late maturing cherries in Bulgaria and Romania and 51% loss in Germany. Mediterranean fruit fly may cause 20% to 25% loss of citrus, 91% of peaches, 55% of apricots and 15% of plums in Jordan. Up to 100% of peaches were destroyed by Mediterranean fruit fly in Frankfurt. In his review of the pest status of species of fruit flies in the Mediterranean Region, Fimiani (1991) reported that losses caused by olive fruit fly include 25% in Italy, 30% to 35% in Greece, 20% to 40% in Yugoslavia, 20% to 60% in Israel and 15% to 20% in Cyprus.

More reliable figures are available for the costs of outbreaks of exotic fruit fly species and the associated loss in export markets. For example, if melon fly (*Bactrocera cucurbitae* (Coquillett)) became established in Tonga, the export market of squash/pumpkin to Japan would immediately cease until the outbreak was eradicated or a satisfactory quarantine treatment was developed. The monetary loss would be in excess of US$8–10 million. The outbreak of Mediterranean fruit fly in Auckland has already cost the New Zealand Government about NZ$6.0 million. Dowell and Wange (1986) listed eight fruit flies of greatest threat to California and estimated that the statewide establishment of these would cost US$910 million to eradicate and US$290 million to control.

The outbreak of papaya fruit fly (*Bactrocera papayae* Drew and Hancock) in northern Queensland has provided a clear picture of the massive costs that an outbreak of an exotic fruit fly may incur. Already, the outbreak has cost the National and State Governments and farmers and exporters over AUD$100 million since October, 1995. Internal regulatory control has cost, and will continue to cost, AUD$10–12 million per year. The eradication effort is likely to cost AUD$55–65 million over the next five years (Drew, these Proceedings).

Losses Caused by Fruit Flies in Seven Pacific Countries

With the commencement of the Regional Fruit Fly Project in the South Pacific (RFFP) in 1990 and associated projects, emphasis was placed on gathering data on the levels of damage caused by the various fruit fly species in Cook Islands, Federated States of Micronesia (FSM), Fiji, Solomon Islands, Tonga, Vanuatu and Western Samoa. This was done by systematically collecting samples of edible/commercial fruits and vegetables and wild/forest fruits. Samples of fruits were collected from areas where insecticide use was kept to a minimum. Wherever possible, at least 1 kg of fruit or 100 fruits were collected. The fruits were weighed, counted and set up in fruit holding laboratories either directly on moistened, sterilised, sieved sawdust or so that pupation could occur in sawdust in plastic containers with screened lids for ventilation. Fruits were set up either individually or in bulk, depending on the type of sampling being done. The stage of maturity of the fruits (green, mature green and ripe) and whether the

fruits were collected from the tree or ground was recorded. Whether a fruit was damaged or not was recorded. If samples were collected as part of bait spray testing experiments or specifically for damage assessments, the fruits were held individually in separate plastic containers. Fruits were examined after 10–12 days for larvae. If larvae were still present, the fruits were placed on new sawdust. Any puparia from the fruits were separated from the sawdust, counted and placed in moistened, sterilised sawdust in a petri dish in an emergence cage. When the flies emerged, they were fed on sugar and water for 5–7 days, killed by freezing and identified and counted.

This form of host survey provided data on the species of fruit flies present, the species not attracted to male lures, geographic distributions, edible or commercial host ranges, wild or forest host ranges, stages of maturity at which fruits were susceptible, percentage of fruits infested, numbers of puparia per fruit, numbers of puparia per gram of fruit and parasitoid fauna. During 1990–1996, a total of 22 100 samples of fruits were collected in the seven RFFP countries. This amounted to 13–14 tonnes of fruits. This quantity does not take into account very intensive sampling of guava, cumquat, capsicum, chilli, papaya, mangoes and Surinam cherry (*Eugenia uniflora* L.) during intensive damage assessment or during field testing of protein bait sprays. A summary of the percentage infested fruits for various commercial or edible fruits is shown in Table 1.

Discussion

As indicated by the limited data from other regions of the world and from the Pacific region, fruit flies are a very serious problem to horticultural production. The prospects for improving food security in the area of fruit and vegetable production alone is enormous, providing fruit flies can be controlled. In most production systems, especially in the subsistence area, unsophisticated control methods, based on destruction of damaged, over-ripe, fallen fruits, bagging of fruits, harvesting at a time when fruits are least susceptible and using protein bait sprays to kill adult flies, are available. These techniques need to be promoted at the village or subsistence level and the commercial level of production.

Table 1. Losses caused by fruit flies (Diptera: Tephritidae), expressed as a percentage of fruits infested in Cook Islands, Federated States of Micronesia (FSM), Fiji, Solomon Islands, Tonga, Vanuatu and Western Samoa.

Country	Commodity	Percentage Fruit Loss	Fruit Fly Species
Cook Islands	Papaya — Summer	12	*B. melanotus*
	Papaya — Winter	1	*B. xanthodes*
FSM	Breadfruit	35–38	*B. frauenfeldi*
	Guava	45–91	*B. frauenfeldi*
	Orange	4	*B. frauenfeldi*
	Rose apple (*Syzygium jambos*)	62	*B. frauenfeldi*
	Tangerine	17	*B. frauenfeldi*
	Surinam cherry	80	*B. frauenfeldi*
Fiji	Cumquat	60	*B. passiflorae*
	Guava	40–90	*B. passiflorae*
	Kavika	62	*B. passiflorae*
	Mango	20–25	*B. passiflorae*
Solomon Islands	Guava	30	*B. frauenfeldi*
	Snake gourd	>90	*B. cucurbitae*
	Squash/pumpkin	60–87	*D. solomonensis*
Tonga	Capsicum	97–100	*B. facialis*
	Chilli	89–97	*B. facialis*
	Guava	90	*B. facialis, B. kirki*
Vanuatu	Guava	95	*B. trilineola*
Western Samoa	Papaya — local var.	19–37	*B. xanthodes*
	Papaya — Sunset var.	4–31	*B. xanthodes*
	Guava	45–99	*B. kirki*

One of the deficient areas in estimating economic losses caused by fruit flies in the Pacific region and elsewhere is that there are very limited data on the monetary value of subsistence, small scale horticultural production. Surveys need to be done to determine the value of domestic production and the amount of produce used at home as well as sold in the urban and peri-urban markets and road-side stalls. When these data are available, then the real impact of improved fruit fly control will be obvious. The prospects for increased food production from the horticulture sector will be readily seen. These data will also provide ammunition to justify the support and maintenance of strong, effective quarantine surveillance.

Outbreaks of exotic species of fruit flies may have deleterious, long-lasting social and economic impacts on horticultural production, as shown in Queensland, Australia. The effects may be equated to the effects of natural disasters such as cyclones, earthquakes and floods, except that the results are often permanent unless eradication is feasible. Contingency plans or emergency response plans for coping with exotic fruit fly outbreaks (and other pests and diseases for that matter) needs to be formulated urgently. This should include a central depot for a stockpile of supplies and materials necessary to carry out an eradication program at a moment's notice in any Pacific Island country.

References

Agrawal, N. and Mathur, V.K. 1991. The fruit fly problem associated with cultivated crops in India and its control. In: Vijaysegaran, S. and Ibrahim, A.G., eds, First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, March, 1988, 140–151.

Anon. 1986. Report of the expert consultation on progress and problems in controlling fruit fly infestation. Food and Agriculture Organisation, Regional Office for Asia and the Pacific, Bangkok. RAPA Publication, 28: 1–18.

Dowell, R.V. and Wange, L.K. 1986. Process analysis and failure avoidance in fruit fly programs. In: Mangel, M., Carey, J.R. and Plant, R.E., eds, Pest Control: operations and systems analysis in fruit fly management. NATO Advanced Science Institute Series G: Ecological Sciences, 11: 43–65, Springer Verlag, Berlin.

Fimiani, P. 1989. Pest status: Mediterranean Region. In A.S. Robinson and G. Hooper (Eds). World Crop Pests: Fruit Flies, Their Biology, Natural Enemies and Control. Elsevier, Amsterdam. pp 372.

Fischer-Colbrie, P. and Busch-Petersen, E. 1989. Pest Status: Temperate Europe and West Asia. In: Robinson, A.S. and Hooper, G., eds, Fruit Flies: their biology, natural enemies and control, World Crop Pests, 3A: 91–99.

Hardy, D.E. 1991. Contribution of taxonomic studies to the integrated pest management of fruit flies, with special emphasis on the Asia-Pacific Region. In S. Vijaysegaran and A.G. Ibrahim (Eds) Proceedings First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia. pp 430.

Isnadi, S. 1991. The distribution of *Dacus* spp. in the Indonesian Archipelago. In: Vijaysegaran, S. and Ibrahim, A.G., eds, First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, March, 1988, 99–107.

Vijaysegaran, S. 1991. The current situation on fruit flies in Peninsular Malaysia. In: Vijaysegaran, S. and Ibrahim, A.G., eds, First International Symposium on Fruit Flies in the Tropics, Kuala Lumpur, Malaysia, March, 1988, 125–139.

An Economic Evaluation of Fruit Fly Research in the South Pacific

A. McGregor[1]

Abstract

The outputs from fruit fly research in the South Pacific region relate to the achievement of milestones that translate into increased production and exports. Some of these have already been achieved, while others are either likely or possible in the future. Underlying these outputs is the overall enhancement of fruit fly knowledge and technical skills and capacity building that have resulted from the Regional Fruit Fly Project's (RFFP) regional presence. Currently, the benefits are estimated at some US$1 million compared with costs of approximately US$640000. Outputs will accelerate over the next five years to reach an estimated US$5 million per annum compared with an annual expenditure of US$375000. The estimated internal rate of return (IRR) from these projections is 37%. To this would have to be added the benefits arising from increased local consumption of fruit and vegetables, resulting in improved nutrition. If the minimum funding to sustain the core RFFP activities is not forthcoming, then the estimated IRR would fall to 15%.

Economic Context of Research

ALL seven Pacific island countries (Fiji, Tonga, Western Samoa, Cook Islands, Vanuatu, Solomon Islands, and FSM) participating in the RFFP have over the past decade experienced low and erratic growth rates, structural trade deficits, and high levels of public debt. This situation can be expected to deteriorate further unless these countries can adjust to the new world trade environment resulting from the closure of the Uruguay round of the General Agreement on Trade and Tariffs (GATT). The terms of trade can be expected to continue to move against tropical bulk commodities as the demand for these commodities grows relatively slowly compared to world income. In contrast, the demand for goods such as horticultural products, specialty foods and sophisticated services (e.g. tourism) can expect to grow rapidly compared with world income.

The essential adjustment process for the Pacific island countries to the realities of the new trade environment will not be an easy task. These small island economies face obstacles in the development process that are not present in larger countries. They are inherently less diversified which makes them more vulnerable to both internal and external shocks. With small populations, economies of scale are difficult to achieve in domestic markets and investment in infrastructure more costly and often uneconomic. Superimposed on the problems of smallness, the Pacific island countries are relatively geographically isolated, prone to natural disasters, and operate under land tenure systems that constrain the availability of land and its productivity. However, there are offsetting advantages that stem from climate, location, a relatively pest free and unpolluted environment, natural beauty, and an ability to grow a wide range of nutritional, traditional foods. The Pacific island countries need to focus on products that minimise the disadvantages of size and isolation and maximise the advantages of location and environment. In varying degrees, a range of fruits and vegetables for export and domestic consumption are products for which the Pacific island countries have a competitive advantage. With suitable conditions in the right location, and with access to available markets, these are the crops that can give the highest returns to farmers' land and labour resources, and generate high levels of net foreign exchange and employment generation.

At first glance, the Pacific islands would seem to be an unlikely source of horticultural products for

[1] Trade and Development Office, Suva, Fiji

international markets given the size and isolation of these suppliers. However, international markets are interested in the products of a small producer when there is something special on offer — be it absence of a particular pest or disease, a seasonal window, premium quality, or a perceived contribution to good health and environmental sustainability. Certain high value horticultural products, from particular Pacific island countries, are in demand because they offer one or more of these special characteristics to international markets. The factors that can give a Pacific island country a competitive advantage in the production of particular horticultural products are discussed below.

In varying degrees, the Pacific island countries have a competitive advantage for a range of fruits and vegetables for export and domestic consumption. With suitable conditions in the right location, and with access to available markets, these are the crops that can give the highest returns to farmers' land and labour resources, and generate high levels of net foreign exchange and employment generation.

The factors that can give a Pacific island country a competitive advantage in the production of particular horticultural products are:

- excellent growing conditions for quality fruit production;
- isolation has meant relative freedom from major pest and diseases;
- strategic location in the southern hemisphere;
- direct transportation linkages to major Pacific Rim markets;
- linkages with tourism;
- an accepted non-chemical quarantine treatment in place; and,
- environmental and health concerns of the market place.

Despite the inherent competitive advantages in fruit and vegetable exports, the overall contribution of fruit and vegetable exports from Pacific island countries has not been great. The exception is squash exports from Tonga, and more recently Vanuatu, and papaya from Cook Islands. Fiji, in the recent past, exported relatively small quantities of a range of fruit and vegetable products to Pacific rim markets. However, quarantine constraints relating to fruit flies closed off these markets. The RFFP has been directed at removing, or at least ameliorating, these constraints by focusing on three broad areas:

i) the establishment of a database and quarantine surveillance system for fruit flies;
ii) bait spray development; and,
iii) facilitating the development of quarantine treatments.

RFFP Outputs and Benefits

The outputs from the RFFP relate to the achievement of milestones that translate into increased production and exports. Some of these have already been achieved, while others are either likely or possible in the future. Underlying these outputs is the overall enhancement of fruit fly knowledge and technical skills and capacity building that have resulted from the RFFP's regional presence.

Fiji

Fiji is by far the best served of the Pacific island countries in terms of air and sea linkages. The potential for developing major fresh fruit export industries has long been identified. However, this potential is far from realised.

There are four fruit fly species in Fiji, of which two are of economic significance. Under the RFFP, valid data have been established on geographic distribution, seasonal abundance, the level of damage caused, host ranges, and the stages of maturity at which fruits of commercial value become susceptible. Fiji has been able to establish and successfully maintain fruit fly colonies which have been used to support an active quarantine treatment research program.

Fiji's achieved 'likely' and 'possible' outputs for the RFFP are listed as follows:

Achieved outputs

- a non-host protocol for the export of two varieties of chillies to New Zealand;
- approval to export heat treated forced air (HTFA) papaya to New Zealand;
- an interim protocol for the continued used of ethylene dibromide (EDB) for export of egg plant to New Zealand;
- New Zealand certification of the left side of the HTFA chamber at Nadi airport for papaya;
- inclusion of the pineapple varieties other than smooth cayenne in the export protocol to NZ;
- a protocol for trans-shipment of low risk products through Hawaii to Canada;
- improved quality of commercial mango production.

'Likely' outputs over next two years

- approval to export HTFA papaya, mango, and eggplant to NZ;
- approval to export HTFA papaya, mango, and eggplant to Australia;
- a non-host protocol for the export of zucchini and rock melon to NZ;
- a protocol to export low risk fruit to South Korea;

- approval of non-host data for limes, pineapples, watermelons, cucumber for NZ;
- increased production and improved quality of some locally consumed fruits and vegetables.

'Possible' outputs over the next three years

- commercial production of protein by the brewery — utilised by the horticultural and livestock industries;
- approval to export HTFA breadfruit and vudi to NZ;
- approval to export HTFA papaya, mango, and eggplant to the United States;
- approval of a non-host protocol for the export of papaya to NZ.

Fiji's achieved RFFP outputs currently translates into an estimated $US90 000 in increased export earnings, increasing to $130 000 over the next five years. The 'likely' and 'possible' outputs translate into estimated increased exports of $2.3 million.

Tonga

Tonga does not have the same strategic advantages as Fiji in terms of transportation links. However, of all the Pacific island countries, Tonga has by far the most important horticultural sector. Tonga is unique in that its recent growth has been led by agricultural exports, with squash being by far the most important product.

The RFFP has identified six fruit fly species, of which three are of economic significance. One species, *B. facialis,* is a particularly damaging fruit fly with a wide host range. The project has been able to successfully establish and maintain fruit fly colonies which have been used to support active host status and quarantine treatment research programs.

Tonga's achieved, 'likely', and 'possible' outputs for the RFFP are listed as follows:

Achieved outputs

- confirmed that melon fly, cucumber fly, and other exotic species are not present in Tonga;
- effective field control system for watermelon.

'Likely' outputs over next two years

- commercial production of bait spray — protein utilised by both horticultural and livestock industries;
- increased production and improved quality of some locally consumed fruits and vegetables;
- approval to export HTFA papaya to NZ;
- approval to export HTFA papaya to Australia;
- a non-host protocol for the export of watermelon, zucchini and rock melon to NZ.

'Possible' output over the next three years

- approval to export HTFA breadfruit and plantain to NZ;
- approval to export HTFA papaya to the United States.

Tonga's achieved RFFP outputs currently translates into an estimated $US550 000 in increased export earnings. The largely results from the contribution of squash. The 'likely' and 'possible' outputs translate into estimated increased exports valued at $430 000.

Western Samoa

The trade situation confronting Western Samoa is among the most difficult of the Pacific island countries. As a result of cyclones and taro leaf blight, Samoa's agriculturally-based export sector virtually disappeared while imports of food rose to compensate for the loss of domestic production. The RFFP offered a timely opportunity for Western Samoa to generate desperately needed export earnings and to enhance domestic food production. However, Western Samoa has not, as yet, taken full advantage of this opportunity.

The RFFP has identified seven fruit fly species in Western Samoa, of which two are of economic significance. The fruit collection and trapping program provided the confidence for New Zealand Ministry of Agriculture and Fisheries (MAF) to negotiate a protocol for the importation of bananas. These data provide a basis for future negotiations of quarantine protocols with importing countries. Substantial colonies of both fruit fly species have been established but not consistently maintained. This has undermined Western Samoa's ability to undertake host status work. No heat tolerance studies have been done as yet.

Western Samoa's achieved, 'likely', and 'possible' outputs for the RFFP are listed as follows:

Achieved outputs

- Confirmed that banana fruit fly and other exotic species are not present in Western Samoa.

'Likely' outputs over next two years

- A non-host protocol for the export of watermelon, zucchini, cucumber, and rock melon to New Zealand.

'Possible' outputs over the next three years

- Increased production and improved quality of some locally consumed fruits and vegetables.

'Possible' outputs over the next five years

- A HTFA quarantine treatment for the export of banana, papaya, and bread fruit to New Zealand. Possible to have a hot water immersion treatment for bananas in a shorter period than for HTFA.

Western Samoa's achieved RFFP outputs currently translates into an estimated $US30 000 in increased export earnings. The 'likely' and 'possible' outputs for Western Samoa translate into estimated increased exports of $150 000.

Cook Islands

Cook Islands is in the midst of major structural reforms that are being implemented to restore financial stability. It has a long history of exporting horticultural products to New Zealand, with papaya in recent years being Cook Islands' major export earner. It has pioneered the use of HTFA quarantine treatment technology in the region, which can in part be attributable to RFFP. In the context of the small size of the economy, and the horticultural production and market opportunities that exist, Cook Islands stands to be a major beneficiary of the RFFP.

The RFFP confirmed that two fruit fly species occur in Cook Islands. Both of these species are of economic significance, with wide host ranges. Under the project, trapping and host surveys have been conducted and colonies of both species were established and have been maintained. Some host status research has been undertaken, but this has been less than what is justified given the export opportunities. Similarly, full advantage has not been taken of bait spray technology to improve fruit quality.

Cook Islands achieved, 'likely', and 'possible' outputs for the RFFP are listed as follows:

'Achieved' outputs

- proved that exotic species of fruit fly are not present in the Cook Islands;
- the NZ certification of a HTFA unit for papaya for export.

'Likely' outputs over next three years

- improved quality of papaya exports by using bait spray;
- HTFA treatment protocol for the export of mango to New Zealand;
- a non-host protocol for zucchini, rock melon, and pineapple to New Zealand.

Cook Island's achieved RFFP outputs currently translates into an estimated $US80 000 in increased export earnings. The 'likely' and 'possible' outputs for Cook Islands translate into estimated increased exports of $270 000.

Vanuatu

Vanuatu's participation in the RFFP commenced in 1994 and is already in a position to reap substantial benefits. Thanks to the work of the RFFP, Vanuatu now has a realistic opportunity of exporting squash to New Zealand. Furthermore, with some 40 000 tourist arrivals annually, there are opportunities for horticultural products for both export and local consumption. The establishment of squash exports to Japan, in the longer term, offers the opportunity to utilise the same transportation links for other horticultural exports.

The RFFP has identified 14 fruit fly species in Vanuatu, of which two are of economic significance. While Vanuatu has a manageable fruit fly status, it is in a vulnerable position. In the north lies the Solomon Islands with melon fly, and in the west New Caledonia with Queensland fruit fly. Despite the resignation of the UN volunteer and meagre resources, an impressive fruit survey and trapping program has been mounted, together with host status research and preliminary heat tolerance work.

Vanuatu's 'achieved', 'likely', and 'possible' outputs for the RFFP are listed as follows:

'Achieved' outputs

- Proved that exotic species of fruit fly are not present in Vanuatu.

'Likely' outputs over next year

- A non-host protocol for the export of squash, pineapples, and cucumber to New Zealand.

'Likely' outputs over the next three years

- a non-host protocol for zucchini and rock melon to New Zealand;
- commercial utilisation and production of bait spray and livestock protein supplements in Vanuatu;
- increased production and improved quality of some locally consumed fruits and vegetables.

Vanuatu's achieved RFFP outputs currently translates into an estimated $US270 000 in increased export earnings. This is entirely the result of squash exports to Japan. The 'likely' and 'possible' outputs for Vanuatu translate into estimated increased exports of $550 000.

Solomon Islands

A combination of fruit fly status and poor transportation links means that fresh horticultural exports are unlikely for the foreseeable future. However, the project has the potential for significantly contributing to domestic food production. Furthermore, the sustainability of RFFP activities in Solomon Islands is

important for the quarantine security of the whole region.

The fruit fly situation in Solomon Islands is the most complex and least favourable of the countries participating in the RFFP. Trapping and host surveys show that at least 40 fruit fly species occur, including melon fly.

Solomon Islands achieved, 'likely', and 'possible' outputs for the RFFP are listed as follows:

Achieved outputs

- The timely identification of the arrival of melon fly on Guadalcanal.

'Likely' outputs over next year

- containment of melon fly populations on Guadalcanal through the use of bait sprays and the introduction of a parasitoid;
- introduction of bait spray technology at the commercial and subsistence level.

'Likely' outputs over the next two years

- increased production and improved quality of some locally consumed fruits and vegetables;
- commercial utilisation and production of bait spray in Solomon Islands.

The benefits for the Solomon Islands are going to be in terms of increased production and improved quality of fruits and vegetables sold on the local market and consumed for subsistence. There are more substantial benefits accruing to the region as a whole from the containment of melon fly. The establishment of melon fly in Vanuatu or Tonga would see the closure of their squash industries.

Federated States of Micronesia (FSM)

FSM is the only Micronesia country with the potential to produce significant quantities of fruit and vegetables. The more immediate export market prospects are the atolls of Micronesia. Production possibilities, market opportunities, and fruit fly status mean that US developed quarantine treatment technology transfer becomes a future prospect.

FSM has a favourable fruit fly status, with the RFFP confirming that mango fly is the only fruit fly present. Exports based on a non-host status or a quarantine treatment protocol will require far better collaboration between the individual states of FSM and the RFFP than seem to have been the case so far. Furthermore, the preliminary heat tolerance research for mango fruit fly has just commenced in FSM due to the fruit fly colonies not being sufficiently large or stable.

FSM's 'achieved', 'likely', and 'possible' outputs for the RFFP are listed as follows:

Achieved outputs

- Confirmed that exotic fruit flies are not present in FSM, although quarantine surveillance for States of Kosrae and Yap is not satisfactory.

'Likely' outputs over next two years

- export of non-host status/low risk fruit to Guam, CNMI, Marshall Islands, and Kiribati;
- increased production and quality of produce at commercial and subsistence level.

'Possible' outputs over the next four years

- Export of HTFA papaya and mango to Guam and CNMI.

There have been no achieved benefits to date from the RFFP in FSM. The 'likely' and 'possible' outputs for FSM translate into estimated increased exports of $140 000.

Development of Protein Bait Spray for Field Control

The introduction of protein bait sprays as a field control measure has been an important component of the RFFP. Bait sprays can form the basis of an efficient, cost effective and environmentally benign means of reducing fruit fly infestation. Bait sprays have become an integral part of most border quarantine agreements (BQA) with New Zealand. They also offer the prospect of improving the quality of some export fruits and thus expanding markets. The efficacy of quarantine treatments, such as HTFA, depends on a low initial level infestation.

The benefits from the introduction of bait spray technology are not confined to expanding exports. There could be considerable benefits in terms of improved nutrition arising from improved quality and availability of fruit and vegetables.

Consolidated Benefit and Cost Analysis of the RFFP

The consolidated estimated benefits from the RFFP are divided into three categories:

- benefits based on 'achieved' outputs (e.g. Fiji exports of chillies to New Zealand on a non-host protocol);
- benefits based on 'likely' outputs over the next two years (e.g. Vanuatu's export of squash to New Zealand on a non-host protocol);

- benefits based on 'possible' outputs over the next three or more years (e.g. a protocol export HTFA treated papaya from Fiji to the United States).

RFFP benefits started to be realised in 1993 with Cook Islands exports of papaya to New Zealand. From 1994 onwards, the estimated project benefits exceed project costs. Currently (1996), project benefits are estimated at some $US1 million compared with costs of approximately $US640 000. Project outputs will accelerate over the next five years to reach an estimated $US5 million per annum compared with an annual expenditure of $US375 000. The estimated internal rate of return (IRR) from these projections is 37% (Tables 1 to 4). To this would have to be added the benefits arising from increased local consumption of fruit and vegetables and resulting in improved nutrition.

If the minimum funding to sustain the core RFFP activities is not forthcoming, then the estimated IRR would fall to 15% (Table 5). This IRR is based on the benefit and cost stream starting in 1990. However, for the Pacific island country decision makers deciding if they are to continue to invest in project activities the relevant benefit/cost stream starts in 1997. This would show that an annual investment of $330 000 in quarantine treatment research and bait development from 1997 would generates an estimated net present value (NPV) of $2.5 million over a six year period discounted at 11.5% (Tables 6 and 7).

The long time taken to generate the data required for the certification of HTFA quarantine treatment on a commodity by commodity (variety by variety) basis substantially reduces the commercial value of this technology. The efficacy tests required represents a major bottle neck. Accelerating the benefit stream through developing generic heat treatments substantially increases the internal rate of return of the project.

A major component of the RFFP is to undertake host status research in accordance with the New Zealand MAF Regulatory standard. Hitherto, New Zealand adopted the United States Department of Agriculture (USDA) plant host status methodology that required 100 000 fruit to be collected. The cost and resource requirements to meet this standard made it impractical for the small PIC export industries.

A non-host export protocol, where it is applicable, is the ideal quarantine treatment. It avoids the high cost and operating difficulties of heat treatment facilities. Most Pacific island countries have the prospect of having non-host protocols in place for a range of fruit in the cucurbit family and for pineapples. Markets could be expanded if the New Zealand host-status standard was adopted by other importing countries. The World Trade Organisation's phytosanitary provisions require a "level playing field" based on scientific determination and transparency. The Pacific island countries could argue that, if the host status methodology is acceptable to New Zealand, a country with no fruit flies and horticulture as its major export industry, it then should be acceptable to other importing countries such as Australia and the United States.

Mechanisms to Ensure Sustainability

Considerable economic benefits have been shown to accrue to the Pacific island countries from continuing the activities of the RFFP (Tables 8 and 9). The best way to ensure that the activities of the RFFP are maintained is to establish mechanisms that facilitate industry funding. Recommendations are made for industry funding on a country by country basis.

Continued technical assistance

Fiji, Tonga, and Cook Islands are now in a position to sustain the core activities established by the project. These countries will still need to have access on an on-going basis to technical advice on matters relating to quarantine surveillance, development of bait from brewery waste, quarantine treatment research, and emergency response plans for coping with outbreaks of exotic species. Western Samoa requires further injections of technical assistance if it is to develop non-host export protocols and the research data necessary for developing quarantine treatments.

Vanuatu, Solomon Islands, and FSM have only participated in the project for three years by the end of 1996. These are among the least developed of the Pacific island countries. It would be unreasonable to expect that they would be in a position to sustain project activities after three years, when it took more developed Pacific island countries such as Fiji and Tonga six years.

Table 1. Consolidated quantifiable benefits from the Regional Fruit Fly Project (US$'000).

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Benefits from 'achieved' RFFP outputs										
Fiji										
Chillies to NZ under a NHP (100% attributed to RFFP)		20	50	60	70	80	90	100	100	100
Eggplant to NZ under interim BQA (75%)		5	11	12	—	—	—	—	—	—
Eggplant, chilies, pumpkin to Canada via Hawaii (50%)		10	12	10	5	5	—	—	—	—
Improved quality of mango to Japan (10%)		4	—	8	10	15	20	25	30	30
Tonga										
Squash to Japan (5%)		500	500	500	500	500	500	500	500	500
Watermelon to NZ (25%)			47	50	60	60	70	70	80	80
Western Samoa										
Banana (green mature) exports to NZ (75%)		70	30	30	30	30	—	—	—	—
Cook Islands										
Papaya exports (HTFA) treated to NZ (20%)	80	80	80	80	80	80	80	80	80	80
Vanuatu										
Squash to Japan (5%)				270	270	270	270	270	270	270
Total benefits from 'achieved' project outputs	80	689	730	1020	1025	1040	1030	1045	1060	1060
Benefits expected from 'likely' project outputs (70%)										
Fiji										
Papaya to NZ (80%)				11	30	500	600	600	600	600
Papaya to Aust. (80%)						300	400	500	600	600
Mango to NZ (80%)					50	100	150	280	300	300
Eggplant (HTFA) to NZ (80%)					20	40	70	100	100	100
Eggplant (HTFA) to Aust.(80%)						30	70	120	120	120
Eggplant (HTFA) to Canada via Hawaii (100%)							10	20	30	40
Pineapple to NZ (20%)					7	10	12	15		
Zucchini and rockmelon (NH) to NZ (70%)					15	20	25	40	60	70
Tonga										
Papaya (HTFA) to NZ (80%)						50	100	100	100	100
Zucchini and rockmelon to NZ (70%)						25	50	50	50	50
Commercial bait spray production (100%)					30	50	60	70	70	70
Western Samoa										
Watermelon, zucchini, and rockmelon (NH) to NZ (70%)							25	50	50	50
Cook Islands										
Improved quality papaya (BS) to NZ (100%)					50	70	70	70	70	70
Mango to NZ (HTFA) (100%)					70	90	120	150	150	150
Zucchini, rock melon, pineapple (NH) to NZ						25	50	50	50	50
Vanuatu										
Squash to NZ (NH) (100%)					280	280	300	300	300	300
Zucchini, rock melon, pineapple (NH) to NZ					15	30	50	50	50	50
Commercial bait spray production (100%)						30	50	60	70	70
Solomon Islands										
Improved quality (BS) of domestic fruit and vegetable production (e.g. various gourds and melons (100%)					50	70	100	100	100	100
FSM										
Fruit and vegetables to Guam, CNMI, and Marshall Islands (NH) (50%)					35	70	100	100	100	100
Total benefits from 'likely' Project outputs		0	0	11	652	1790	2412	2825	2970	2990

Table 1 (continued). Consolidated quantifiable benefits from the Regional Fruit Fly Project (US$'000).

Benefits expected from 'possible' project outputs (20%)										
Fiji										
Breadfruit (HTFA) and vudi to NZ (80%)							20	60	100	100
Papaya, mango, and eggplant (HTFA) to US (80%)							30	90	300	300
Papaya and mango to S. Korea (100%)						30	50	50	50	50
Papaya (NH) to NZ (100%)									100	100
Tonga										
Breadfruit and plantain (HTFA) to NZ (80%)							15	45	150	150
Watermelon to Japan (10%)					14	14	20	20	20	20
Papaya (HTFA) to US (80%)								20	40	40
Western Samoa								50	100	100
Banana (hot water treated) papaya, breadfruit (HTFA) exports to NZ (80%)										
Vanuatu										
Papaya (HTFA) Aust. and NZ (50%)									30	50
Mango (HTFA) to Japan (40%)										80
FSM										
Papaya and mango (HTFA) to Guam and CMMI (50%)									20	40
Total benefits from 'possible' RFFP outputs					14	44	135	335	910	1030
Total estimated benefits from RFFP outputs	80	689	730	1031	1691	2874	3577	4205	4940	5080

Table 2. The funding of the RFFP.

Donor funding	US$	Counter part funding (in kind)*	$US equiv.
AusAID	1 032 700	Fiji	96 000
ACIAR	710 300	Tonga	142 000
UNDP	572 000	Western Samoa	80 000
USAID	340 000	Cook Islands	50 000
FAO	314 000	Vanuatu	76 000
New Zealand ODA	125 000	Solomon Islands	49 000
UK ODA	32 000	FSM	46 000
Japanese UN Trust Fund	96 000		
Total donor	$3 222 000	Total counter part	$539 000

Table 3. Minimum annual cost estimates of sustaining core activities of the RFFP (US$).

	Fiji	Tonga	W. Samoa	Cook Islands	Vanuatu	Solomon Islands	FSM	Total
Quarantine surveillance	5000	7000	2000	7000	7000	10 000	7000	45 000
Quarantine treatment research (including host status research	40 000	40 000	30 000	15 000	30 000	15 000	25 000	195 000
Bait spray development	5000	—	5000	5000	5000	5000	—	25 000
External technical assistance	—	—	20 000	—	30 000	30 000	30 000	110 000
Total	50 000	47 000	57 000	27 000	72 000	60 000	62 000	375 000

Table 4. Project benefits compared with costs.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Benefits				80	689	730	1031	1691	2874	3577	4205	4940	5080
Cost (Donor)	216	310	440	570	574	640	550	110	110	110	110	110	110
Costs (PIC)	61	61	61	89	89	89	89	275	275	275	275	275	275
Total costs	277	371	501	659	663	729	639	385	385	385	385	385	385
B-C	–277	–371	–501	–579	26	1	392	1306	2489	3192	3820	4555	4695
IRR =	37%												

Table 5. Benefits compared with costs with no RFFP funding after 1996 (US$ '000).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Benefits				80	689	730	1031	1542	1670	142	15	—	—
Cost (Donor)	216	310	440	570	574	640	550						
Costs (PIC)	61	61	61	89	89	89	89						
Total costs	277	371	501	659	663	729	639	0	0	0	0	0	0
B-C	–277	–371	–501	–579	26	1	392	1542	1670	142	15	0	0
IRR =	15%												

Table 6. Benefits compared with costs if only the quarantine surveillance component maintained after 1996.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Benefits				80	689	730	1031	1292	2270	2672	3060	3200	3210
Cost (Donor)	216	310	440	570	574	640	550						
Costs (PIC)	61	61	61	89	89	89	89	45	45	45	45	45	45
Total costs	277	371	501	659	663	729	639	45	45	45	45	45	45
B-C	–277	–371	–501	–579	26	1	392	1247	2225	2627	3015	3155	3165
IRR =	33%												

Table 7. Benefits compared with cost for future investment in quarantine treatment research and bait spray development (US$ '000).

	1997	1998	1999	2000	2001	2002
Expected benefits from quarantine surveillance, QT research, and BS development	1691	2874	3577	4205	4940	5080
Expected benefits from only quarantine surveillance	1292	2270	2672	3060	3200	3210
Net expected benefits from QT research and BS development.	399	604	905	1145	1740	1870
Cost of QT research and BS development (from table 16)	330	330	330	330	330	330
B-C	69	274	575	815	1410	1540
NPV (r(i) = 11.5%)	$US2478					

Table 8. Project benefits compared with costs (HTFA certification accelerated by 1 year).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001
Benefits (US$ '000)				80	689	741	1449	2666	3380	4192	4810	5070	5080
Cost (Donor) (US$' 000)	216	310	440	570	574	640	550	110	110	110	110	110	110
Costs (PIC) (US$ '000)	61	61	61	89	89	89	89	275	275	275	275	275	275
Cost total	277	371	501	659	663	729	639	385	385	385	385	385	385
B-C	−277	−371	−501	−579	26	12	810	2281	2995	3807	4425	4685	4695
IRR =	41%												

Table 9. Sensitivity summary.

Situation	IRR
Base case	37%
No funding after 1996	15%
Funding only provided for quarantine surveillance	33%
Accelerating benefit stream through generic quarantine treatments	41%
Benefits compared with cost for future investment in quarantine treatment and bait spray development	NPV (r(i) 11.5%) = $US2.5 million

Quarantine Treatment Options for Fruit Fly Host Commodities for Pacific Island Countries

J.W. Armstrong[1]

Abstract

The need for efficacious alternative quarantine treatments was underscored by loss of ethylene dibromide and, more recently, by the potential loss of methyl bromide, as post-harvest quarantine fumigants. Alternative quarantine treatment technologies and strategies include heat treatment methods, such as hot-water immersion, vapor heat or forced hot-air, refrigeration or flash-freezing, irradiation, combined treatments, non-host status, area freedom from fruit flies, and quarantine systems approaches. Although each of these alternative quarantine treatment technologies or strategies is either in use today or nearing approval for use, not all are suitable for every country for varying reasons. Pacific Island countries entering the global fresh fruit and vegetable export market must select quarantine treatment technologies and strategies that are acceptable to the regulatory agencies of importing countries, that meet export and economic needs and realities. Presented here is a discussion of quarantine treatment technologies and strategy options and their potential for use in Pacific island countries.

MANY fresh commodities are hosts for a wide range of quarantine pest insects, including tephritid fruit flies. The purpose of having efficacious quarantine treatments against fruit flies and other quarantine pests is:

(1) to prevent the spread of these quarantine pests through normal marketing channels;
(2) to open or maintain exports markets by eliminating pests from fresh commodities that would otherwise be quarantined from entering export marketing channels; and
(3) to increase the marketability of fresh fruits by eliminating infestations that adversely affect fruit appearance and quality.

Much of the world's abundance of fresh commodities would be excluded from entering export marketing channels because of potential insect infestations without efficacious quarantine treatments.

In today's global economy, simple exclusion is not an acceptable approach to maintaining quarantine barriers and quarantine treatments are needed to maintain the flow of export commodities through marketing channels from one country to another. While much attention is paid to the larger world economic powers because of recent trade agreements, such as NAFTA and GATT, smaller economies also require access to export marketing channels. Similarly, just as larger economic powers expend scientific resources to research and develop efficacious quarantine treatments to move their fresh commodities through quarantine barriers to markets in other countries, smaller economies also need to research and develop quarantine treatments to export their fresh commodities.

In recent years, many Pacific Island countries (PICs) discovered the economic importance of opening and maintaining export markets in Australia, New Zealand, Japan, and the United States. To open and maintain many of these markets, PICs must have efficacious quarantine treatments or strategies in place to disinfest their commodities of tephritid fruit flies and other insect pests before export. PICs, however, face unique problems in developing and implementing new quarantine treatments. With the loss of ethylene dibromide and the impending loss of methyl bromide, new and sophisticated quarantine treatment methods and strategies are being developed by the larger economic powers. Not all of these quarantine

[1]US Department of Agriculture, Agricultural Research Service, Tropical Fruit and Vegetable Research Laboratory, PO Box 4459, Hilo, Hawaii 96720

treatment methods or strategies can be adopted for PICs because of economics, energy requirements, agricultural methods, or distance from technological support. Reviewed here are the available quarantine treatment technologies with discussion of the suitability of each for adaptation to the needs of PICs.

Before determining what quarantine treatment technologies are applicable, the attributes of an efficacious quarantine treatment must be defined. In general terms, the attributes of an efficacious quarantine treatment include:

1. The treatment meets the needs of the industry and exporters. The quarantine treatment must be economical or, more specifically, it must be cost effective. While it is obvious that the treatment cannot cost more that the market value of the commodity, the economics of cost effectiveness are more varied and frequently subtle. For example, irradiation facilities can treat tonnes of commodity very inexpensively, but the facility must be kept in constant use. As the amount of commodity for treatment decreases, the cost of irradiation treatment increases rapidly.

2. The treatment provides good fruit quality. Fresh fruits were never intended to suffer the consequences of quarantine treatment applications, and only rarely does a fresh commodity tolerate a quarantine treatment so well that there is no loss of quality. Usually, there is a trade-off in which some fruit damage is tolerated in order to obtain market access that would otherwise be closed. The quarantine treatment, however, must disinfest the commodity of the target pest without producing unacceptable damage. All quarantine treatments must be developed in parallel with quality studies to ensure that the commodity tolerates the treatment without unacceptable damage to fruit appearance, taste, or texture, loss of shelf-life, or increase in postharvest decay.

3. The treatment is relatively easy to administer. Generally, as the difficulty in applying a quarantine treatment increases, the expense of application and the chance for error also increase. This operative term is 'relatively' easy. Whereas the most sophisticated, technologically-advanced treatment equipment may be relatively easy to use for treatment application, a simple, non-host protocol for a fruit at a specific stage of ripeness based on surface color, texture, or hardness may be extremely difficult to execute or monitor in commercial situations.

4. The treatment meets the needs of the regulators. The quarantine treatment must provide adequate quarantine security and be relatively easy for regulatory agencies to monitor. Treatment equipment must also be relatively easy for regulatory agencies to certify regarding treatment accuracy and execution of regulatory protocols. Again, the operable term is, 'relatively' easy, and the same examples used above also apply here.

The available quarantine treatment technologies include fumigation; washes, waxes and insecticidal dips; heat treatments, cold treatments; irradiation; commodity resistance and non-hosts; pest-free areas; and systems approaches. Only those quarantine treatment technologies that are presently in use are listed; technologies being researched for potential use are omitted.

Fumigation

With the loss of ethylene dibromide and the eventual loss of methyl bromide, alternatives must be researched to replace the two most versatile quarantine treatment fumigants ever used for fresh commodities. Although carbonyl sulfide shows promise as a new fumigant for stored grains and other dry commodities, this compound is phytotoxic to fresh commodities and does not readily penetrate fruit surfaces. The probability that another compound with all the attributes of a good fumigant (inexpensive and easy to apply, not phytotoxic, readily penetrates commodity and aerates quickly, leaves no undesirable residues, and, most importantly, environmentally compatible) will be developed is very low at this time. Developing new quarantine fumigation treatments would be counter-productive for any country; those employing ethylene dibromide would be unusable and those employing methyl bromide would be short lived.

Washes, waxes and insecticidal dips

Although washes and waxes possess good potential for eliminating surface pests from some fresh commodities, they are not applicable against fruit fly eggs or larvae inside the host. Incorporating insect growth regulators or other insecticides into waxes may be effective against fruit flies, but these materials would have to penetrate into the fruit to reach the target insects and increase the potential for toxic residues. Likewise, the use of insecticidal dips leaves some toxic residues in treated fruits. One of the most important marketing trends today is to market edible products with no toxic residues. Therefore, developing quarantine treatments that employ toxic compounds is not recommended.

Heat treatments

Many tropical and subtropical fruits tolerate heat treatment to some extent. The widespread use of hot-water immersion, vapor heat, or forced hot-air for quarantine treatment purposes indicates that this treatment method has a good application potential

for most countries that need to develop quarantine treatments. Heat treatments would be the first treatment method recommended for evaluation by PICs.

Cold (refrigeration) treatment

Many fresh commodities will not tolerate the low temperatures and long holding times required for cold treatments to achieve quarantine security. Although cold treatment may be a viable option under some circumstances, fruit tolerance, long treatment times, and high energy costs for refrigeration should be considered before research with this quarantine treatment method is initiated. Researching a quarantine refrigeration treatment would be recommended only where commodity cold tolerance and market value are great enough to support using this disinfestation method.

Irradiation

The use of cobalt or cesium irradiation may be a viable quarantine treatment option where capital investment and commodity through-put are available, and generic radiation dosages for some fruit fly species are nearing acceptance. Unfortunately, irradiation is simply too expensive an option to be recommended for use in PICs at this time.

Commodity resistance and non-host status

Although this quarantine strategy would be preferable over all others, very few fruits or vegetables fall into resistant or non-host categories. However, for those commodities where this quarantine strategy does apply, the lengthy research efforts required to accumulate the necessary data are well worth the risk of failure. If successful, this quarantine treatment strategy provides the most cost-effective approach possible because there are no expenditures required for, or fruit damage associated with, the application of a quarantine treatment.

Area freedom

Only rarely are fruit fly-free areas found within or near 'normal' fruit fly habitats because of the abundance of alternative hosts, especially in tropical settings. However, this quarantine strategy may be useful for islands without fruit flies that are adequately isolated from others where fruit flies are found. Commodities exported from fruit fly-free areas must be adequately protected from infestation if they must trans-ship through non-pest-free areas, and adequate trap monitoring must be done to ensure that the isolated islands remain fruit fly-free.

Systems approaches

This holistic approach identifies all of the pre- and post-harvest conditions, treatments, and handling that reduce the potential risk of packing and shipping infested host commodities. Very detailed and long term research is required to develop the data to support the systems approach. Unfortunately, a quarantine treatment, albeit less severe than if used without the systems approach, may still be needed to disinfest a small but unacceptable potential for infestation that remains after all other measures to reduce infestation are employed.

Conclusions

A review of the available quarantine treatment technologies finds that not all of them are applicable to PICs. Irradiation, for the foreseeable future, is too expensive. Refrigeration, while less expensive than irradiation, is also too expensive. Refrigeration treatments also require treatment times at low temperatures that many tropical fruits cannot tolerate. Area freedom would only be applicable where geographical barriers prevent the quarantine pest from entering host commodity agricultural areas. Systems approaches would require years of intensive biological and host/pest studies. Commodity resistance and systems approaches are similar in that protocols devised from these strategies must be monitored over time to ensure that some biological factor does not enter the equation and render the quarantine strategy ineffective. Non-host status is the best approach, but only for those rare fresh commodities that actually are not hosts to fruit flies or other quarantine pests. The remaining, and possibly the best option, is to develop quarantine heat treatments for those fresh commodities that tolerate hot-water immersion, vapor heat, or forced hot-air treatment. Regardless of the treatment method that is ultimately chosen, particular attention must be given to any deleterious effects to fruit quality from the treatment.

Non-host Status as a Quarantine Treatment Option for Fruit Flies

V. Heimoana[1], L. Leweniqila[2], D. Tau[3], F. Tunupopo[4], P. Nemeye[5], A. Kassim[5], C. Quashie-Williams[5], A. Allwood[5] and L. Leblanc[5]

Abstract

The Regional Fruit Fly Project and the Ministry of Agriculture and Fisheries (Regulatory Authority), New Zealand, developed a standard for testing the susceptibility of fruits and vegetables at various stages of maturity — MAF Regulatory Standard 155.02.02: Specifications for Determination of Host Status as a Treatment. A large number of fruits and vegetables have been subjected to laboratory cage tests and/or field cage tests using this standard in the Cook Islands, Federated States of Micronesia (FSM), Fiji, Tonga, Vanuatu and Western Samoa.

In the Cook Islands, 'Bird's Eye' chilli is a non-host to *B. melanotus* and *B. xanthodes*. In FSM, limes and Yapese lemon (*Citrus hystrix*) are non-hosts to *B. frauenfeldi*. In Fiji, 'Ripley Queen', 'Vaimana' and 'Smooth Cayenne' pineapples, squash, 'Hot Rod' and 'Red Fire' chillies, and bottle, bitter and spongy gourds are non-hosts to *B. passiflorae* and *B. xanthodes*. In Tonga, 'Candy Red' and 'Sugar Baby' watermelon and cucumber are non-hosts to *B. facialis* and *B. xanthodes*. Testing in Western Samoa has not been completed, but there are promising results. Much of the testing has been at a laboratory cage test level and comparable field cage tests still need to be carried out. This may confirm some non-host commodities, such as Samoan bananas and limes.

QUARANTINE treatments usually involve the treatment of fresh fruit and vegetables in one way or another in order to move them to areas that are free of particular pests. Until recently, a number of chemical post-harvest treatments were acceptable. However, with the continuing trend towards non-chemical control methods, other methods are being investigated. Hot water dipping and vapour heat treatments are accepted to a certain extent but are not suitable for all types of fruit and vegetables. Declaration of an area as pest free eases the fruit fly control burden of growers but considerable monitoring activities are required to maintain the status. To supplement trapping and monitoring activities and avoid the limitations and costs of chemical and physical controls, scientists are looking at non-host status to achieve quarantine security. Determination of non-host status involves the testing of fresh fruit and vegetables for their susceptibility to fruit fly infestation to a specified standard. It is an important method in quarantine treatments as it is relatively fast and simple to do, less costly than other treatments, environmentally friendly, permanently established and acceptable by quarantine authorities.

[1]Ministry of Agriculture and Forestry, Research Division, Nuku'alofa, Kingdom of Tonga
[2]Ministry of Agriculture, Forests, Fisheries and ALTA, Koronivia Research Station, Nausori, Fiji
[3]Department of Agriculture and Horticulture, Port Vila, Vanuatu
[4]Ministry of Agriculture, Fisheries, Forestry and Meteorology, Apia, Western Samoa
[5]Regional Fruit Fly Project, South Pacific Commisssion, Suva, Fiji

Non-Host Status Determination

Determination of host status to fruit flies has been regarded as difficult. It usually involves sampling very large numbers of fruits at several stages of maturity and over several seasons. In small Pacific Island countries, this is not practical. Generally, a fruit is regarded as a host once eggs or larvae are found in it or flies are reared from it, with little

regard for whether the fruit was damaged or overripe. To overcome these problems, the Regional Fruit Fly Project in the South Pacific and the Ministry of Agriculture and Fisheries Regulatory Authority (New Zealand) developed a standard — MAF Regulatory Authority Standard 155.02.02: Specifications for Determination of Host Status as a Treatment. Infestation of fruit may be forced in laboratory cage tests (LCT) whereby infestation occurs due to a relatively high population of flies with an opportunity for oviposition into purposely damaged test and control fruits. In the case of a negative LCT where flies emerge from a control fruit but not from the test fruit, the fruit is declared a non-host. In the case of a positive LCT where flies emerge from the test fruit or from the test and control fruits, the fruit is considered to be a potential host and more fruits are exposed in a field cage test (FCT) to confirm the host status. In this case, the fruits are not damaged if the field cage test produces infestation, the fruit is considered a positive host; if the test is negative, the fruit is considered a non-host. This methodology does not take the concept of natural and artificial hosts into account, and thus may be biased against the use of artificial hosts for quarantine purposes. Vargas and Nishida (1985a,b) report an example where the Malaysian fruit fly, *Bactrocera latifrons* (Hendel), was successfully reared on Hawaiian papaya using artificial infestation. In nature, however, papaya is not a host for this species which normally infests cucurbitaceous and solanaceaous crops. Therefore, Hawaiian grown papaya for export should not require quarantine treatment for Malaysian fruit fly.

Merits and limitations of non-host status

The obvious advantage of being able to declare a fruit a non-host is that no other quarantine treatment is required. Non-host status, however, is specific and if applicable for a particular fruit fly species may not necessarily apply for another. For example, if Hawaiian papaya for export is not a host to Malaysian fruit fly, it may still be a host to *Bactrocera dorsalis* (Hendel) and will therefore still be subject to quarantine treatment. The advantage of knowing the host status of a fruit is that researchers need not produce data to prove disinfestation treatment efficacy for the non-host fruit fly species.

The acceptance of non-host status varies between countries. The United States may accept a particular fruit as a non-host based on a history of negative inspection records while Japan may declare the fruit as a host based on infestation reports in literature (Armstrong 1992). In some instances non-host status is conferred temporarily during such periods when the pest is absent. This occurs in Australia where the State of Victoria accepts produce from particular areas during the winter months without disinfestation treatment (Heather 1985). This strategy has been adopted by some Australian states on a national level but is unacceptable for produce exported to other countries.

Non-host status for a fruit species must take into account the susceptibility to infestation between varieties or at different stages of maturity. For example, *Citrus* species are known to be good fruit fly hosts but in the United States the 'Bearss' variety of lemons and the 'Persian' lime are resistant to infestation by the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Nguyen and Fraser 1989). Greany (1989) lists the determinants of resistance as: oviposition behaviour of the fruit fly, the oil content and presence of limonoids and naringin in the peel as well as the softness of the peel. In Australia and the United States green lemons are resistant to infestation by Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Sproul 1976; Spitler et al. 1984). Some fruits that are non-hosts at a particular stage of maturity may be harvested at that stage to avoid the need for quarantine treatment. For example, Japan permitted the importation of green bananas from Australia without quarantine treatment from regions south of Townsville. Species such as Queensland fruit fly, *Bactrocera tryoni* (Froggatt), do not infest green bananas, possibly because of a high tannin content in the sap (Armstrong 1983). However, banana fruit fly, *Bactrocera musae* (Tryon), which inhabits regions north of Townsville, will infest immature green bananas. After a recent outbreak, papaya fruit fly, *Bactrocera papayae*, a pest known for its ability to infest green fruit and vegetables, has been added to the list of quarantine pests in that region.

It is possible to develop quarantine protocols using a combination of non-chemical factors. It should be possible, for example, to export without quarantine treatment a fruit that is a relatively poor host or resistant fruit if it is harvested early in an area where protein bait sprays have been used, and where trapping detected no fruit flies. Quarantine protocols, however, still regard even relatively poor hosts as risks and will not consider them without treatment.

Non-Host Status in Tonga

Six tephritid fruit fly species pose quarantine risks to export in Tonga. Table 1 lists the fruit fly species of quarantine importance. Each species attacks a variety of tropical commercial fruit as well as local species utilised by Tongans. *B. passiflorae* and *B. obscura* are found only in the Niuas, the northernmost islands of the Kingdom. Neither commercial nor native hosts have so far been identified for *B. obscura*, despite extensive host surveys.

Table 1. List of tephritid fruit fly species of quarantine importance occurring in Tonga, Fiji, Western Samoa, Cook Islands, FSM and Vanuatu.

Country	Scientific name	Major hosts	Locality
Tonga	*Bactrocera facialis*	41 spp. incl. most commercial fruit	All of Tonga, except in the Niuas
	B. xanthodes	8 spp. incl. most commercial fruit	All of Tonga
	B. kirki	16 spp. incl. many commercial fruit	All of Tonga
	B. passiflorae	12 spp. mostly native species	Only in the Niuas
	B. distincta	8 spp. mostly Sapotaceae and Apocynaceae	All of Tonga
	B. obscura	No hosts on record	In the Niuas, not in 'Eua, other islands unknown
Fiji	*B. xanthodes*		
	B. passiflorae		
Western Samoa	*B. xanthodes*		
	B. kirki		
FSM	*B. frauenfeldi*		
Cook Islands	*B. melanotus*		
	B. xanthodes		
Vanuatu	*B. trilineola*		

Table 2. Host status testing summary for Tonga.

Fruit/vegetable	Test type	Fruit fly species	Host status
Kiwi fruit	LCT	*B. facialis, B. xanthodes*	+ve Host
Apple	LCT	*B. facialis*	+ve Host
Nectarine	LCT	*B. facialis*	+ve Host
Breadfruit	LCT/FCT	*B. facialis, B. xanthodes*	+ve Host
Tomato (MG/Export)	LCT	*B. facialis, B. xanthodes*	+ve Host
Eggplant (Export)	LCT/FCT	*B. facialis, B. santhodes*	+ve Host
Cucumber	**LCT**	***B. facialis***	**Non-Host**
	LCT	*B. xanthodes*	+ve Host
	FCT	***B. xanthodes***	**Non-Host**
Zucchini (Export)	LCT	*B. facialis*	+ve Host
	FCT	***B. facialis***	**Non-Host**
	LCT	*B. xanthodes*	+ve Host
	FCT	*B. xanthodes*	To be completed
Watermelon (Var. Sugar Baby)	LCT	*B. facialis, B. xanthodes*	+ve Host
	FCT	***B. facialis, B. xanthodes***	**Non-Host**
Watermelon (Var. Candy Red)	**LCT**	***B. facialis***	**Non-Host**
	LCT	*B. xanthodes*	+ve Host
	FCT	***B. xanthodes***	**Non-Host**
Bird's Eye/Super chilli	LCT	*B. facialis, B. xanthodes*	+ve Host
	FCT	*B. facialis, B. xanthodes*	To be completed
Cayenne chilli	LCT	*B. facialis, B. xanthodes*	+ve Host
Hot Rod chilli	LCT	*B. xanthodes*	+ve Host
	FCT	*B. xanthodes*	To be completed
	LCT	*B. facialis*	To be completed
	FCT	*B. facialis*	+ve Host
Red Fire chilli	**LCT**	*B. xanthodes*	+ve Host
	FCT	*B. facialis*	+ve Host[1]

[1] NZ MAF modified field cage design. MG = Mature green export stage.

Host status testing has been carried out over the past five years as part of the South Pacific Regional Fruit Fly Project. The results for the fruits and fruit fly species tested are given in Table 2. The testing procedure complies with the MAF Regulatory Authority Standard 155.02.02 which was prepared by the Ministry of Agriculture and Forestry (MAF) of New Zealand Regulatory Authority in conjunction with the Regional Fruit Fly Project.

The two species tested were *B. facialis* and *B. xanthodes*. Host status testing could not be carried out in the laboratory for *B. kirki*, since the species has not been reared successfully in the laboratory in Tonga. Negotiations based on host survey data that would exclude *B. kirki* from the list of fruit fly species that required host testing have not been concluded with New Zealand. These same data also support the exclusion of *B. kirki* from research to develop quarantine treatments for papaya and cucurbits as it has not been reared from either of these plant families during the past five years.

Host surveys have shown that *B. distincta*, which occurs throughout the Kingdom, attacks only eight fruit species, five of which belong to the Family Sapotaceae, two to the Family Apocynaceae and one to the Family Rubiaceae. None of these are export commodities. *B. passiflorae*, which occurs only in the Niuas, and *B. obscura*, which occurs mainly in the Niuas (but not in 'Eua, current status on other islands unknown), have not been tested as no export fruit and vegetables have been sent from the Niuas.

Host testing shows that watermelon (var. Candy Red and Sugar Baby) as well as cucumbers are non-hosts to both *B. facialis* and *B. xanthodes*. Zucchini is a non-host to *B. facialis* while tests for its susceptibility to *B. xanthodes* are still being carried out. Other fruits tested proved to be hosts through either laboratory cage tests (and observed evidence from field collections) or a combination of laboratory cage tests and field cage tests (Table 2). Field cage tests for Bird's Eye/Super chilli and Hot Rod chilli are being carried out this year to complete their testing. Host testing on papaya varieties at colour break is also planned for the next production season, as Tonga is looking at export possibilities for this crop.

Non-Host Status in Fiji

The two species of concern in Fiji are *B. xanthodes* and *B. passiflorae*. Seventeen different fruit and vegetable species and varieties have so far been tested for their host status to one or both of the fruit

Table 3. Host status testing summary for Fiji.

Fruit/vegetable	Test type	Fruit fly species	Host status
Small White chilli	**LCT/FCT**	***B. xanthodes***	**Non-Host**
	LCT/FCT	*B. passiflorae*	+ve Host
Long Cayenne chilli	LCT	*B. xanthodes*	+ve Host
	FCT	*B. passiflorae*	+ve Host
Hot Red chilli	**FCT**	***B. xanthodes, B. passiflorae***	**Non-host**
Red Fire chilli	**FCT**	***B. xanthodes, B. passiflorae***	**Non-Host**
Bottle Gourd	**LCT**	***B. xanthodes, B. passiflorae***	**Non-Host**
Bitter Gourd	LCT	*B. xanthodes*	+ve Host
	FCT	***B. xanthodes***	**Non-Host**
	LCT/FCT	***B. passiflorae***	**Non-Host**
Spongy Gourd	LCT	*B. xanthodes*	+ve Host
	FCT	***B. xanthodes***	**Non-Host**
	LCT	***B. passiflorae***	**Non-Host**
West Indian lime	**LCT**	***B. xanthodes, B. passiflorae***	**Non-Host**
Meyer lemon	LCT	*B. xanthodes, B. passiflorae*	+ve Host
Capsicum	LCT	*B. xanthodes, B. passiflorae*	+ve Host
Cucumber	**FCT**	***B. xanthodes***	**Non-Host**
	FCT	***B. passiflorae***	**Non-Host**
Zucchini	LCT	*B. xanthodes, B. passiflorae*	+ve Host
Squash	**LCT**	***B. xanthodes, B. passiflorae***	**Non-Host**
Eggplant	**FCT**	***B. xanthodes***	**Non-Host**
	FCT	*B. passiflorae*	+ve Host
Pineapple	**LCT**	***B. xanthodes, B. passiflorae***	**Non-Host**
Waimanalo Papaya	**FCT**[1]	***B. xanthodes, B. passiflorae***	**Non-Host**
Sunrise Papaya	**FCT**[1]	***B. xanthodes, B. passiflorae***	**Non-Host**

[1] Tests conducted at colour break (export stage), mature green, quarter ripe and half ripe.

fly species (Table 3). Ten of these are non-hosts to both *B. xanthodes* and *B. passiflorae*, and comprise: Sunrise papaya, Waimanalo papaya, pineapple, squash, West Indian lime, spongy gourd, bitter gourd, Red Fire chilli and Hot Rod chilli.

Non-Host Status in Vanuatu

B. trilineola is the main fruit fly species in Vanuatu that poses quarantine risks. Of the seven fruit and vegetable species tested (Table 4), three were non-hosts and included squash, pineapple (Var. Queen) and cucumber (Var. Conqueror). Hosts were namely capsicum, watermelon (Var. Candy Red), tomato (Var. Money Maker) and eggplant (Var. Early Long). The test list is not as extensive as that of islands such as Fiji, as Vanuatu does not grow many export crops.

Table 4. Host status testing summary for Vanuatu.

Fruit/vegetable	Test type	Fruit fly species	Host status
Capsicum	LCT	*B. trilineola*	+ve Host
Squash	**LCT**	***B. trilineola***	**Non-Host**
Watermelon (Var. Candy Red)	LCT/FCT	*B. trilineola*	+ve Host
Tomato (Var. Money Maker)	LCT/FCT	*B. trilineola*	+ve Host
Pineapple (Var. Queen)	**LCT/FCT[1]**	***B. trilineola***	**Non-Host**
Eggplant (Var. Early Long)	LCT/FCT	*B. trilineola*	+ve Host
Cucumber (Var. Conqueror)	**LCT/FCT**	***B. trilineola***	**Non-Host**

[1] Tested at colour break and fully ripe.

Non-Host Status in Western Samoa

Fruit fly workers in Western Samoa have tested a wide range of fruit and vegetables comprising 26 different species and varieties. Most of these have been tested against *B. xanthodes* and *B. kirki*, the two important fruit fly species (Table 5). Six species are non-hosts to *B. xanthodes* (Samoan banana, carambola, bilimbi, West Indian lime, Waimanalo papaya and Polynesian plum) and two species are non-host to *B. kirki* (abiu and rambutan). Eight species and varieties are hosts to both *B. kirki* and *B. xanthodes*. They include Misiluki banana, Bird's Eye, Hot Thai and Big Star chillies, eggplant, Tahitian lime, pomelo and grapefruit. There are six plant species and varieties that are host to only one of the two fruit flies. *B. xanthodes* infests abiu, Mysoe banana, green pepper, tomato, Sunrise papaya and local papaya while *B. kirki* attacks carambola, West Indian lime, strawberry, canistel, zucchini and avocado. Several tests were not valid as insufficient replicates were tested or no adult flies emerged from control fruit. Such tests were carried out on star apple, strawberry and tomato. Not all fruits tested were subjected to both fruit fly species and further work has to be carried out to extend and/or complete the list of host status testing.

Conclusion

Host status testing and non-host status present an option in the formulation of quarantine protocols and agreements. Declaration of a fruit as a non-host eliminates the need for chemical treatments, reducing production costs and easing access to export markets. The status may be used in combination with other techniques, such as area freedom and bait spraying to increase quarantine assurance. Limitations are posed by specificity of host and infesting species whereby a fruit may be a non-host to one fruit fly species but be a host to another fruit fly species.

Host status testing in Tonga has identified certain cucurbits as non-hosts to *B. facialis* and/or *B. xanthodes*. If presented to MAF New Zealand for evaluation the status of *B. kirki* may still be questioned and additional data requested. New Zealand may accept the elimination of *B. kirki* from host status testing, but other potential exporting countries may not. To respond in this case, staff of the Fruit Fly Project in Tonga continue their efforts to rear *B. kirki* in the laboratory. Further testing may be warranted only for exotic crops with export potential such as squash, loofah, okra, etc.

Papaya has not been tested in Tonga or in Vanuatu. In Western Samoa and Fiji, Waimanalo papaya is a non-host to *B. xanthodes* under this testing regime. Sunrise papaya is also a non-host to *B. xanthodes* and *B. passiflorae* in Fiji again, under this regime. However it is a host to *B. xanthodes* in Western Samoa. No papaya variety has yet been tested against *B. kirki* in Western Samoa. In Tonga, Nemeye (pers. commun.) listed papaya as a major host of *B. xanthodes* (and as a minor host of *B. facialis*) as a result of repeated host collection. There is no immediate explanation for the differences in host status of certain varieties or the host preference of the same fruit fly species in different countries. It is likely to be a combination of fruit characteristics and stage of maturity when sampled.

In general, cucurbits are relatively free of fruit fly pests in Pacific islands that lack *B. cucurbitae*. Solanaceous crops tend to be readily attacked, so fruit species of major importance and commercial

Table 5. Host status testing summary for Western Samoa.

Fruit/vegetable	Test type	Fruit fly species	Host status
Abiu	LCT	*B. xanthodes*	+ve Host
	LCT	***B. kirki***	**Non-Host**
Misiluki Banana	LCT/FCT	*B. xanthodes, B. kirki*	+ve Host
Samoan Banana	**LCT**	***B. xanthodes***	**Non-Host**
	LCT	*B. kirki*	+ve Host
Mysoe Banana	LCT	*B. xanthodes*	+ve Host
Carambola	LCT	*B. xanthodes*	+ve Host
	FCT	***B. xanthodes***	**Non-Host**
	LCT	*B. kirki*	+ve Host
Bilimbi	**LCT**	***B. xanthodes***	**Non-Host**
Bird's Eye chilli	LCT/FCT	*B. xanthodes, B. kirki*	+ve Host
Big Star chilli	LCT/FCT	*B. xanthodes*	+ve Host
	LCT	*B. kirki*	+ve Host
Hot Thai chilli	LCT/FCT	*B. xanthodes*	+ve Host
	LCT	*B. kirki*	+ve Host
Green Pepper	LCT	*B. xanthodes*	+ve Host
Eggplant	LCT/FCT	*B. xanthodes, B. kirki*	+ve Host
Tomato	LCT	*B. xanthodes*	+ve Host
	LCT	*B. kirki*	Test not valid[1]
Tahitian lime	LCT	*B. xanthodes, B. kirki*	+ve Host
West Indian lime	**LCT**	***B. xanthodes***	**Non-Host**
	LCT	*B. kirki*	+ve Host
Pomelo	**LCT**	*B. xanthodes, B. kirki*	+ve Host
Grapefruit	LCT	*B. xanthodes, B. kirki*	+ve Host
Strawberry	LCT	*B. xanthodes*	Test not valid[1]
	LCT	*B. kirki*	+ve Host
Waimanalo	LCT[3]	*B. xanthodes*	+ve Host
Papaya	**FCT[4]**	***B. xanthodes***	**Non-Host**
Sunrise Papaya	LCT[3]/FCT[4]	*B. xanthodes*	+ve Host
Local Papaya	LCT[3]	*B. xanthodes*	+ve Host
Canistel	LCT	*B. kirki*	+ve Host
Star Apple	LCT	*B. xanthodes*	Test not valid[2]
Zucchini	LCT	*B. kirki*	+ve Host
Rambutan	**LCT**	***B. kirki***	**Non-Host**
Avocado	LCT	*B. kirki*	+ve Host
Polynesian Plum Vi (*Spondias dulcis*)	**LCT**	***B. xanthodes***	**Non-Host**

[1] Test not valid as no adult flies were reared from control fruit.
[2] Test not valid as only 2 replicates were tested.
[3] Tests conducted at quarter ripe stage of maturity.
[4] Tests conducted at colour break.

potential are likely to be excluded from non-host lists. Citrus fruit have not been tested in Tonga and Vanuatu. In Tonga most citrus are local varieties that are unlikely to be exported. Host status testing on citrus is unwarranted as Nemeye (pers. commun.) lists citrus fruit as the major hosts of *B. facialis* and *B. kirki* in Tonga. In Western Samoa, *B. kirki* also attacks many citrus species.

To avoid unnecessary testing, host lists and host records should be studied first to evaluate the likelihood of a plant species being a non-host. As comparisons show, though, non-host records from certain countries do not necessarily hold true for the same fruit fly species in other countries and this should be considered as well when evaluating for host-status testing.

References

Armstrong, J.W. 1983. Infestation biology of three fruit fly species in 'Brazilian;, 'Valery' and 'William's' cultivars of banana in Hawaii. Journal of Economic Entomology, 76: 539–543.

Armstrong, J.W. 1992. Fruit fly disinfestation strategies beyond methyl bromide. New Zealand Journal of Crop and Horticultural Science, 20: 181–193.

Greany, P.D. 1989. Host plant resistance to tephritids: An under-exploited control strategy. In: Robinson, A.S. and Hooper, G., eds, World crop pests, vol. 3A, Fruit flies, their biology, natural enemies and control. Elsevier; New York, 353–362.

Heather, N.W. 1985. Alternatives to EDB fumigation as post-harvest treatment for fruit and vegetables. Queensland Agricultural Journal, 111: 85–87.

Nguyen, R. and Fraser, S. 1989. Lack of suitability of commercial limes and lemons as hosts of *Anastrepha suspensa*. Florida Entomologist, 72: 718–720.

Spitler, G.H., Armstrong, J.W. and Couey, H.M. 1984. Mediterranean fruit fly host status of commercial lemons. Journal of Economic Entomology, 77: 1441–1444.

Sproul, A.N. 1976. Green lemons safe from fruit fly. Journal of Agriculture for West Australia, 17: 32.

Vargas, R.I. and Nishida, T. 1985a. Life history and demographic parameters of *Dacus latifrons* (Hendel). Journal of Economic Entomology, 78: 1242–1244.

— 1985b. Survey for *Dacus latifrons* (Hendel). Journal of Economic Entomology, 78: 1311–1314.

Whole Systems Approach for Export of Zucchini from Queensland to New Zealand

R.A.I. Drew[1]

Abstract

The long-held concept for post-harvest disinfestation treatments is that they should meet a level of efficacy called Probit 9 in order to guarantee quarantine security against fruit flies. Only at Probit 9 have most countries (or markets) been prepared to accept horticultural produce that has been declared potential fruit fly host material. Different countries have slightly different definitions of Probit 9. However, New Zealand standards expect that such a treatment should induce a mortality of 99.9968% of flies treated.

No commercially produced fruits and vegetables, under normal insect control programs, would have fruit fly infestation levels that demand Probit 9 efficacy in post-harvest disinfestation treatments. Consequently, the Whole Systems Approach is proposed to facilitate trade in horticultural produce based on security in all aspects of the production system and thus reduce dependence on the post-harvest disinfestation treatment alone.

The Whole Systems Approach has been proposed and pioneered by Dr R. Baker, Dr J. Cowley and Dr C. Whyte, MAF Quality Management, New Zealand. Their initiative and research led to the Queensland zucchini experiment.

THE Whole Systems Approach, proposed by Baker et al. (1993), combined a number of requirements that had to meet specific high standards. The combination of these requirements must be proven to be able to meet quarantine assurance for any particular fruit fly host produce before acceptance by importing markets. The basic requirements are site selection, host status, quality production systems, post-harvest disinfestation treatment, packing shed quality control, transport system security, importing market inspections.

For the Queensland zucchini study, the core components were the quality production system, packing shed quality control and transport security. The first was assessed through a field Pest Risk Analysis (PRA), the second and third by sampling cartons of zucchinis from the packing shed on arrival at the Brisbane Markets. All samples were based on zucchinis harvested from the same crop on the same day over a number of weekly sampling periods.

[1] Queensland Department of Primary Industries, 80 Meiers Road, Indooroopilly, 4068, Australia

Pilot Study

Before carrying out the major PRA, a pilot study was undertaken at the Queensland Department of Primary Industries (QDPI) Redlands Horticulture Research Station near Brisbane. The aim of this study was to assess the relationship of the cucumber fly, *Bactrocera cucumis* (French), to the same variety of zucchini that was grown and assessed in the commercial plantation. An area of zucchinis was planted comprising five rows each 70 m long and left unsprayed for the duration of the experiment. Within and around the plot, McPhail traps baited with orange-ammonia lure were placed. Flies were taken from the traps and new lure added at weekly intervals. Also at weekly intervals, zucchinis were sampled at different size categories above 10 cm long and the fruit fly infestation levels assessed. The infestation levels were measured by setting each piece of fruit separately on sawdust within plastic fruit holding containers with aerated lids and then counting the number of pupae produced.

In this trial, the traps set in surrounding vegetation collected most flies, the traps within the

zucchinis very few. This was consistent with the activity of *Bactrocera cucurbitae* (Coquillett) (melon fly) which resides in vegetation surrounding cucurbit plantations and enters the host areas primarily for oviposition (Nishida and Bess 1957). Also the percentage infestation levels in the zucchinis increased with size of fruit, the export size (10–13 cm long) being approximately 5% infested. The data from this pilot study were used to design the main experiment carried out in the large commercial plantation.

Pest Risk Analysis

The PRA on the commercial field production system was carried out on two five hectare plantations of zucchini that were grown near Bundaberg, Queensland, for export to New Zealand. One plot was grown from mid-winter to early spring and the other from early spring to late spring/early summer. This was designed to cover the main export production season. The crops were grown under the normal commercial spray treatments for diseases and insect pests and the grower kept a record of these in his production diary.

Within each 5 hectare plantation, three sets of 50 plots were subdivided and the plants within each plot numbered. Then using random numbers, the export size zucchinis were harvested weekly from selected plants. This sampling system was designed to meet specific requirements for statistical analyses.

Concurrently, unsprayed control plots were cultivated at the QDPI Bundaberg Research Station within 20 km of the commercial plantation.

A total of 15 346 export size fruit were sampled from the commercial plantations and 1956 from the unsprayed control plots. From zucchinis sampled on the same days and from the same plantations, a total of 15 575 fruit were taken in the cartons packed for export in the packing shed. These were collected from the Brisbane Markets in order to further assess the transport security system.

Orange-ammonia baited McPhail traps were set in and around the commercial plantations and control plots and serviced weekly.

Results

There was zero infestation of fruit flies in the commercial plantations, zero flies in the McPhail traps in these plantations, heavy infestations of flies in the control plots at the research station and large numbers of flies in the McPhail traps at the unsprayed control plots particularly those suspended in the surrounding vegetation.

The data were assessed and analysed by Dr Carolyn Whyte (NZ-MAF). Analyses indicated that a post-harvest disinfestation treatment of only 7.05 was required for the commercially produced zucchinis in order to meet quarantine security for export.

In conclusion, if agreement can be reached on the levels of security required for each stage of the Whole Systems Approach, then it is feasible that this system would allow international export of fruit fly host material while guaranteeing quarantine security equivalent to that achieved by post-harvest disinfestation treatments that achieve Probit 9. A major benefit would be that post-harvest disinfestation treatments of lower Probit values would have little chance of causing physiological damage to the commodities. Also, the dependence on post-harvest treatments would be greatly reduced.

Acknowledgement

The Whole Systems Approach was pioneered by Dr R. Baker, Dr J. Cowley and Dr C. Whyte (MAF Quality Management, New Zealand). They also worked in the development, conduct and data analyses of the zucchini project.

References

Baker, R.T., Cowley, J.M. and Harte, D.S. 1993. Pest risk analysis: a process for the assessment and management of pest risk associated with the importation of plants and plant products into New Zealand. Lynfield Plant Protection Centre Publication No. 1, 16 p.

Nishida, T. and Bess H.A. 1957. Studies on the ecology and control of the melon fly *Dacus (Strumeta) cucurbitae* Coquillett (Diptera: Tephritidae). Hawaii Agricultural Experiment Station Technical Bulletin No. 34, 44 p.

Heat Tolerances of Immature Stages of *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* (Broun) in Fiji

E. Tora Vueti[1], L. Ralulu[1], L. Leweniqila[1], A. Balawakula[1], and C.M. Frampton[2]

Abstract

As a prerequisite to the development of quarantine treatment using High Temperature Forced Air (HTFA), the heat tolerances of several immature stages of *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* (Broun) were determined at the Koronivia Research Station Fruit Fly Laboratory, in Fiji. The immature stages studied were egg stage (<10 hours old, >27 hours but <36 hours old eggs and >40 hours old eggs) and first and third (feeding and jumping) larval stages.

Heat tolerances were determined by exposing eggs and larvae to temperatures of 44–49°C for varing periods of time in a static hot water bath. The effectiveness of treatments were determined by assessing percentage survival. The study showed that *B. passiflorae* early eggs (<10 hours old and >40 hours old) were the most heat tolerant stages.

A comparison of the most heat tolerant stages of the Fiji species with those in Cook Islands showed that *B. passiflorae*, the most heat tolerant species in Fiji, was less heat tolerant than *B. melanotus* (Coquillett), the most heat tolerant in the Cook Islands. This study has been the basis of the current HTFA treatment parameters of 47.2°C for 20 minutes for pawpaws exported to New Zealand.

THE worldwide ban or restrictions on the use of the fumigant, ethylene dibromide (EDB) and the pending restrictions on the use of methyl bromide, as post-harvest treatments of fresh fruits and fleshy vegetables have imposed an urgency on the development of alternative, environmentally sound quarantine treatments for fresh fruits and vegetables destined for export in the Pacific. The development of alternative quarantine treatments has also become an urgent task in the Pacific because of the increased interest in growing fresh fruits and vegetables for export, as a means of agricultural diversification and improving the small economies of the island countries.

The recent incursions of world major pest species of fruit fly (Tephritidae: Dacinae) into the Pacific has resulted in the imposition of justifiably strict quarantine constraints on travellers and the trade of fresh fruits and fleshy vegetables. The threat of introductions of exotic fruit flies into the Pacific Island countries is very real. This is amply demonstrated by the outbreaks in this region, such as Mediterranean fruit fly *Ceratitis capitata* (Wiedemann), Oriental fruit fly *Bactrocera dorsalis* (Hendel), melon fly *B. cucurbitae* (Coquillett) and *B. latifrons* (Hendel) into Hawaii from Southeast Asia, Oriental fruit fly and papaya fruit fly *B. papayae* (Drew and Hancock) into Papua New Guinea (PNG) from Irian Jaya, melon fly and Oriental fruit fly into Nauru from Taiwan, melon fly into Guadalcanal in Solomon Islands from the Western Province of Solomon Islands, papaya fruit fly into the Torres Strait Islands and northern Queensland from PNG, Mediterranean fruit fly into New Zealand from Hawaii and Oriental fruit fly into French Polynesia from Hawaii and Palau (Allwood, pers. comm.).

In 1991, the Regional Fruit Fly Project in the South Pacific (RFFP) established laboratory colonies of fruit flies in the Cook Islands, Fiji, Tonga and Western Samoa to facilitate research on protein bait sprays and quarantine treatment development. The introduction of the use of the High Temperature

[1]Ministry of Agriculture, Fisheries, Forests and ALTA, Koronivia Research Station, PO Box 77, Nausori, Fiji
[2]Lincoln University, Christchurch, New Zealand

Forced Air (HTFA) treatment for the export of fresh fruits and fleshy vegetables into the South Pacific was a collaborative effort by the RFFP and the United States Aid (USAID) Commercial Agriculture Development (CAD) Project. The development of the HTFA treatments was done in Cook Islands by Hort + Research, New Zealand and in Fiji and Tonga by the RFFP and USDA-Agricultural Research Services staff from Hilo, Hawaii. It involved determining the heat tolerances of the immature stages of the major economic species, conducting efficacy tests using experimental HTFA chambers, and conducting commercial sized tests using a commercial unit.

In quarantine entomology, statistical analyses are used to estimate the probability that a commodity treatment will succeed. Laboratory experiments are generally followed by large scale confirmatory tests to validate the estimated treatment parameters which are suggested as the most suitable by the results of the laboratory trials (Robertson et al. 1994). Bioassays of temperature — time effects for *C. capitata*, *B. cucurbitae* and *B. dorsalis* were conducted in Hawaii to determine the temperature and time parameters required for heat treatments (Armstrong, 1982). This study provided data that was relevant for the determination of thermal death of various stages of fruit fly species in Hawaii (Hansen et al. 1990).

In September 1996, technical assessments of the heat tolerance data for immature stages of *Bactrocera passiflorae* (Froggatt) and *B. xanthodes* (Broun) in Fiji by New Zealand Ministry of Agriculture and Fisheries (MAF) Regulatory Authorities were completed and the data were approved. These assessments, together with a comparison between the heat tolerance of the most heat tolerant stage of *B. passiflorae* (the most heat tolerant species in Fiji), and that of the Cook Island species, *B. melanotus* (Coquillett) and *B. xanthodes*, have resulted in the current quarantine treatment schedule of 47.2 °C fruit centre temperature for 20 minutes for pawpaws exported to New Zealand..

Methods and Materials

The heat tolerance studies of *B. passiflorae* and *B. xanthodes* were conducted for <10 hours old, >27 hours old but <36 hours, and >40 hour old eggs, first instars and feeding and non-feeding (jumping or popping) third instars. Each treatment consisted of 100 eggs or 25 larvae immersed in water at specified temperatures at various time intervals and replicated 10 times.

Although the procedures followed were similar for the six life stages studied, there were variations to suit the life stage that was being tested. Intial immersion times and temperature combinations were used for egg of two ages, <10 hours old and >27 hours old. The initial combination consisted of temperature range 44–49 °C and 6–8 time intervals ranging from 0.5–128 minutes. After 5 replications of these egg stages, more precise temperature and time intervals were determined for *B. passiflorae* and *B. xanthodes*. The precise temperatures and time intervals were then tested for eggs, first and third instar stages. Each replicate consisted of treated eggs and larvae at all temperature and time intervals and included controls and checks.

Laboratory colonies of *B. passiflorae* and *B. xanthodes* were reared on a pawpaw/sugarcane bagasse diet from 1991 to 1993 at the Koronivia Research Station. From 1994, bagasse was excluded from the diet, thus relying on a diet based on pawpaw. Methods of laboratory rearing were discussed by Walker et al., this Symposium.

Eggs

Eggs were obtained from gravid females that were 3–5 weeks old and from the same cohort. The ages of fruit fly eggs were calculated from the time that the egging device was placed into the fruit fly cages to the time the device was removed from the cage. Hollowed out pawpaw domes (egging devices) were placed in cages for 1–2 hours for <10 hours old eggs and 4–8 hours for >27 and >40 hours old eggs. Eggs used for percentage egg hatch and those used for the study were held at optimum rearing temperatures of 26 ± 2°C. Only eggs that were normally coloured and turgid were used for controls, checks and treatments. The eggs were handled very gently with fine tipped camel hair brushes. The black filter paper on which eggs were held was moistened to prevent the dessication of eggs.

More than 100 eggs were immersed for a designated period of time in hot water at precisely controlled temperature, then cooled for one minute in ambient temperature water immediately after treatment. Floating eggs were removed because the eggs may not have received full time × temperature treatment. After cooling, 100 eggs or less were plated on moist, black filter paper and kept in an enclosed, dark environment at temperatures 25 ± 1 °C for over 48 hours. Eggs that hatched were ones that had a ruptured clear chorion.

First instar larvae were obtained from eggs that were held for 48 hours on moistened black filter paper in a petri dish. Feeding third instars were obtained from pawpaw diet 6–7 days after eggs were seeded onto the diet by washing the artificial diet

through a sieve or floating them off in a saturated sugar solution. Non-feeding third instars were obtained after 8–9 days after seeding of eggs on the diet and were separated by allowing them to exit the diet naturally into a tray of water.

Precise temperature and time combinations obtained from the egg stages were replicated 10 times for larval stages. Only healthy, mobile larvae that appeared normal were used for treated, controls and checks. Larvae were handled very gently with fine-tipped paint brushes or soft forceps for the third instars. 25 larvae were immersed in heated water for a designated period of time at precisely controlled temperatures. Treated larvae were cooled for at least one minute in ambient temperature and seeded on diet in 30 g cups. After treatment first and third instars were seeded on pawpaw diet. Jumping third instars were placed in pupation media, sterilised, sieved sawdust.

Number of survivors were determined by the number of pupae counted for first instar and pupal numbers were determined for feeding and jumping third instars 12–16 days after treatment.

Statistical Analysis

The initial temperature and time regimes were used to conduct tests on the egg stages and data from these initial tests was sufficient to carry out regression analyses. After regression, a final temperature and time regime was determined for all stages. Data generated from this study was analysed using the complementary log-log method.

Results and Discussion

The mortality response to heat curve of *B. passiflorae*, Figure 1, shows that early eggs (<10 hours old) are most heat tolerant at 44 °C and late eggs (>40 hours old) are most heat tolerant at 45 °C. There are no significant differences in the mortality responses of early eggs and late eggs at 47 °C or at higher temperatures.

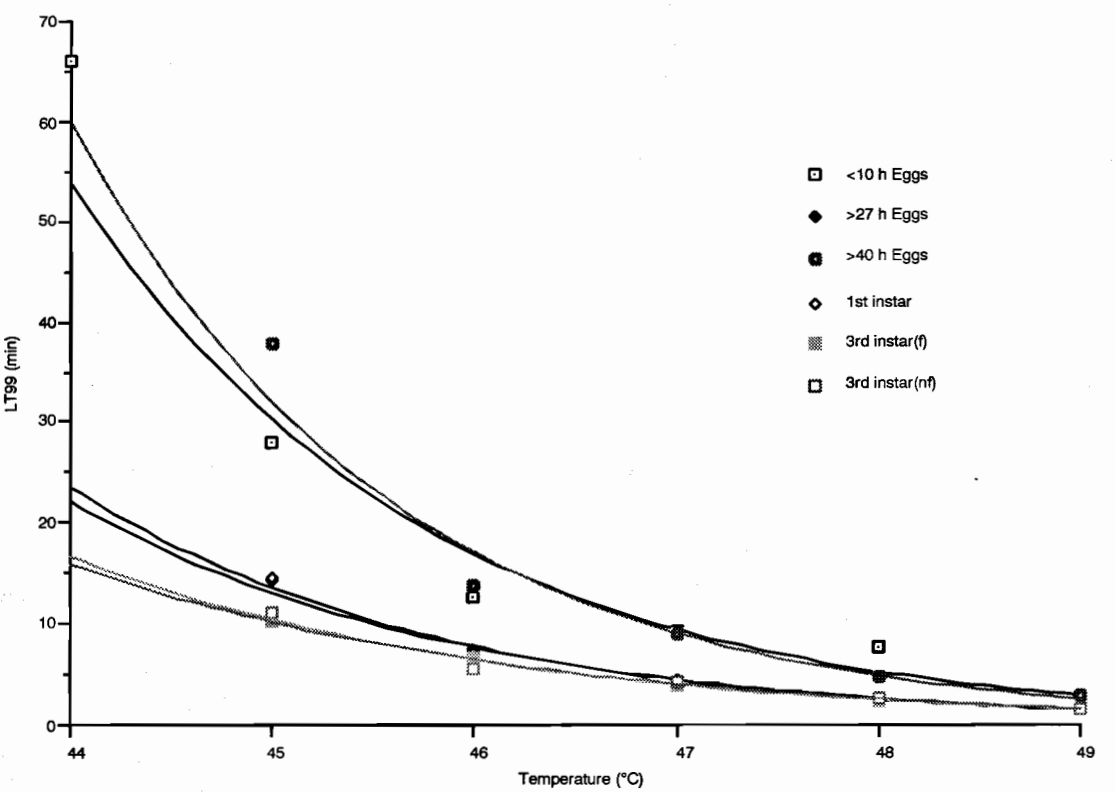


Figure 1. Mortality response of *Bactrocera passiflorae* to heat (Fiji).

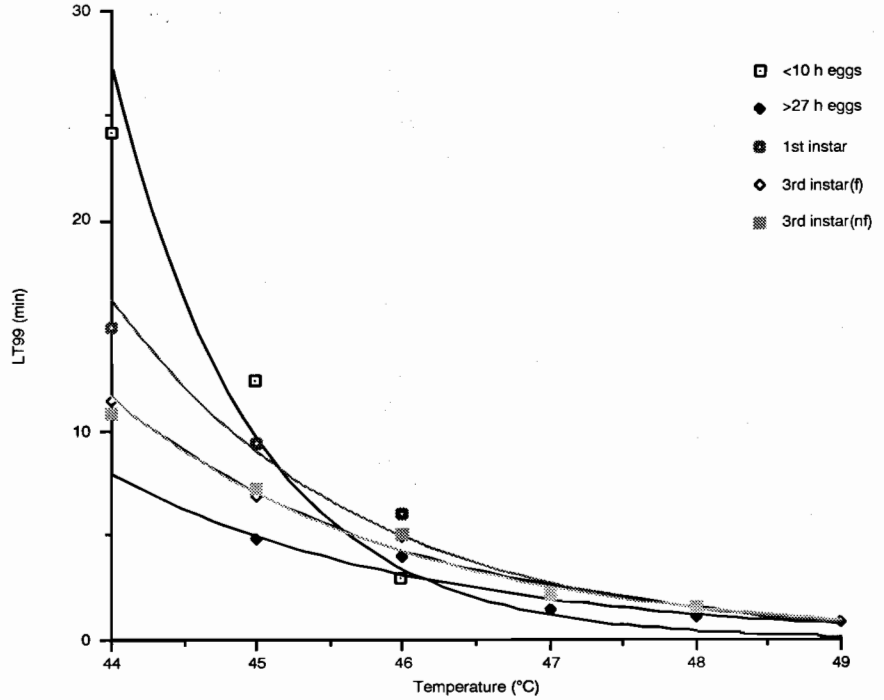


Figure 2. Mortality response of *Bactrocera xanthodes* to heat (Fiji).

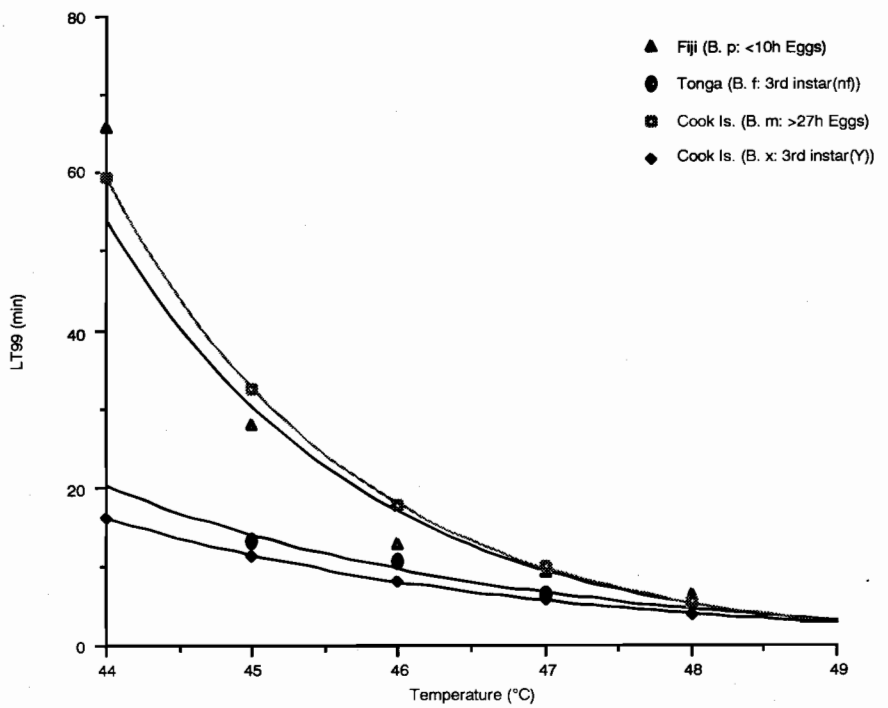


Figure 3. Response curves for the most resistant stages and species from Cook Islands, Fiji and Tonga.

For *B. xanthodes*, Figure 2, early eggs (<10 hours old) is most heat tolerant at 44–45 °C, first instars are most heat tolerant at 46–47 °C and third instars (feeding) is most heat tolerant at 48 °C. The lethal times LT99 for *B. passiflorae* and *B. xanthodes* at 44 °C is 66 minutes and 24 minutes respectively. This study has concluded that *B. passiflorae* early eggs (<10 hours old) are the most heat tolerant species and stage in Fiji.

A comparison, Figure 3, was carried out on the heat tolerances of the late egg stage of *B. melanotus*, the most heat tolerant species and stage in the Cook Islands with the early eggs of *B. passiflorae* and has shown that *B. melanotus* late eggs are more tolerant than *B. passiflorae* in Fiji.

This study has been the basis of tests carried out on the commercial HTFA treatment for pawpaws. Fiji is currently exporting pawpaws to New Zealand using the HTFA treatment at 47.2 °C for 20 minutes.

References

Armstrong, J.W. 1983. Infestation Biology of Three Fruit Fly (Diptera: Tephritidae) Species on 'Brazilian', 'Valery' and 'Williams' Cultivars of Banana in Hawaii. Journal of Economic Entomology, 76: 539–543.

Hansen, J.D., Armstrong, J.W., Benjamin, K.S.H.U., Brown, S.A. 1990. Thermal Death of Oriental Fruit Fly (Diptera: Tephritidae) Third Instars in Developing Quarantine Treatments for Papayas. Journal of Economic Entomology, 83: 160–167.

Robertson, J.L., Preisler, H.K., Frampton, R.E. and Armstrong, J.W. 1994. Statistical Analyses to Estimate Efficacy of Disinfestation Treatments. In: Quarantine Treatments for Pests of Food Plants. Edited by Sharp, J.L. and Fallman, G.J.

Walker, G.P., Vueti, E.T., Hamacek, E.L. and Allwood, A.J. 1996. Laboratory rearing techniques for Tephritid fruit flies in the Pacific. In: Proceedings of Regional Symposium on Management of Fruit Flies in the Pacific: Now and Into the 21st Century.

Heat Tolerances of Immature Stages of *Bactrocera facialis* and *B. xanthodes* (Diptera: Tephritidae)

S. Foliaki[1] and J.W. Armstrong[2]

Abstract

The effects of time and temperature on the egg and larval stages of two fruit fly species, *Bactrocera facialis* (Coquillett) and *B. xanthodes* (Broun), were studied using hot water immersions at temperatures of 44°C to 49°C and for 0 to 30 min depending on the treatment, lifestage, and immersion temperature. Separate tests (169 total) were done with eggs (all ages, early-aged, or late-aged), first instars, and third instars (feeding and non-feeding).

B. facialis were significantly more heat tolerant than *B. xanthodes* for all life stages at all temperatures. For temperatures <46°C, first instars were the most tolerant (LT99 = 21 min at 45°C). At 46°C, late-aged eggs were the most tolerant (LT99 = 12 minutes at 46°C). At temperatures >46°C, third instar were the most tolerant and the non-feeding third instars were more tolerant (LT99 = 6.4 min at 47°C) than the feeding third instars. The late-aged eggs were the most tolerant of all egg ages, and there was some evidence that above 46°C, they were less tolerant than any of the larval instars.

QUARANTINE controls on the export of agricultural produce are required to prevent the spread of tephritid fruit flies (Diptera: Tephritidae). Unfortunately, these controls create a major obstacle to the export of fruit fly hosts, such as avocado (*Persea americana*), breadfruit (*Artocarpus altilis*), capsicum (*Capsicum annum*), chilli pepper (*Capsicum frutescens* or *C. annum*), citrus (*Citrus* spp.), cucumber (*Cucumis sativus*), eggplant (*Solanum melongena*), mango (*Mangifera indica*), melons (*Cucumis* spp.), papaya (*Carica papaya*), tomato (*Lycopersicon esculentum*), and watermelon (*Citrullus lanatus*). Importing countries insist on effective disinfestation of fruits and vegetables from areas where exotic fruit flies are found.

Until recently, ethylene dibromide (EDB) fumigation was an approved disinfestation treatment for fruit fly host fruits exported to New Zealand and Australia. However, in January 1994 both countries decreased the allowable EDB residues found in fumigated fruits to <1 part per million (R. Paton, pers. commun.). These statutory reductions in allowable EDB residues cannot be met and therefore they effectively ban the use of EDB. Similarly, the United States Environmental Protection Agency stopped the use of EDB as a quarantine fumigant in 1984 (Anon. 1985). Therefore, alternative quarantine treatments must be developed to maintain the export of Tongan agricultural produce that are also hosts of fruit flies.

Various studies showed that fruit fly eggs and instars are readily killed by heat, especially temperatures of 45°C or above (Jang 1986, 1991; Sharp and Chew 1987). Heat, used as a disinfestation treatment against fruit flies, was first developed in the late 1920s with the advent of vapor heat treatment (Baker 1952). Later, hot-water immersion (Armstrong 1982, Couey and Hayes 1986, Sharp et al. 1988) and high-temperature forced-air (Armstrong et al. 1989) technologies were developed as quarantine disinfestation treatments. Armstrong et al. (1989) and others found that tolerance to heat varied between different fruit fly species and their life stages. Therefore, the effects of heat on fruit fly mortality must be studied to determine the most heat tolerant species and life stages in Tonga before beginning any development of quarantine disinfestation treatments using heat.

[1] Quarantine entomologist, Ministry of Agriculture and Forestry, PO Box 14, Nuku'alofa, Tonga

[2] Research entomologist, USDA-ARS, Tropical Fruit and Vegetable Research Lab, PO Box 4459, Hilo, HI 96720, USA

Materials and Methods

Equipment consisting of static-temperature water bath (PolyScience ®, model 7300) and related equipment such as digital counter/Mini-Alarm Timer, a 95 mm mercury-in-glass thermometer and an electronic digital thermometer were used to develop heat tolerance data by immersing fruit fly eggs and larval stages in heated water at precise temperatures for selected periods of time. Eggs and larval survival/mortality were recorded after prescribed treatment (time × temperature) combinations of hot water immersion, cooling periods and post-treatment handling periods.

Colonies of adult *Bactrocera facialis* and *B. xanthodes* were reared and maintained in the fruit fly culture laboratory on yeast (protein autolysate), rain water, sugar and bacteria (non-pathogenic) under natural light supplemented with artificial light at a temperature range of 25–28 °C and about 80% RH. Eggs of the two fruit fly species were collected from mature females (21–30 days old) during a 2 hour period, using an optimum egging technique. The egging devices used for the collection of eggs were ripe papaya domes. Eggs collected were then immediately divided into three equal portions, two-thirds were placed onto artificial diet for the culturing of feeding third and non-feeding third instars for later tests, and one-third was placed on black-moist filter paper for first instar tests.

All larval instars used in each test replication were from the same cohort of eggs. First instars were collected within 4 to 6 hours after hatching from eggs approximately 2–2.5 days from oviposition that were held on moist filter paper at standardised optimum temperature (26 °C ± 1 °C).

Feeding third instars were collected from the larval diet approximately 6–7 days after oviposition and held at the same standardised optimum temperature (26° ± 1 °C). They were removed from larval diet by careful mixing with a concentrated sugar-water solution. The feeding third instars floated to the surface of the sugar-water solution and were then collected and carefully rinsed with fresh water to remove any remaining sugar-water.

Non-feeding (or 'popping') third instars were collected after leaving ('popping out') the larval diet, approximately 12–13 days from oviposition. They were collected by holding a container of infested larval diet over a container of water. The non-feeding third instars will leave the larval diet and crop or jump into the tray of water where they will remain quiescent. Non-feeding third instars were used for tests within 2 hours after leaving the larval diet.

The artificial larval diet used was based on locally available substrates of papaya and bagasse (dried finely graded or crushed sugarcane fibre) (Hamacek 1995). Eggs were incubated on larval diet at a rate of approximately 100 eggs per 50 grams of diet. This gave maximum numbers of pupae of average pupal weight. Heat treated coconut sawdust was used for pupation and culturing. The sawdust was collected from a chemical-free coconut sawmill. It was sieved to remove fine particles, and heat treated (120 °C + 85% RH/24 hours). Sawdust was moistened before being used and was never re-used without being pre-treated with heat.

Static-temperature water bath tests for both species were done with all ages, early-aged and late-aged eggs. The water bath tests for the larval stages, first instars, feeding and non-feeding third instars, were initiated after completion of all tests with eggs. The best determined final time × temperature treatment combinations used for eggs which gave 100% mortality were used as the initial time × temperature treatment combinations against which instars were tested.

A total of 169 trials (replicates) were carried out immersing each stage of each species of fruit fly in water maintained at one or more temperature of 44, 45, 46, 47, 48 or 49 °C using the static-temperature water bath. A total of 86 and 83 trials were carried out for *B. facialis* and *B. xanthodes*, respectively. A minimum range of 5–10 trials per life stage was carried out or based on, and determined by, adequate data recorded to determine more precisely the times at which 100% mortality occurred.

The three egg stages of *B. facialis* tested were early-aged (1–3 hours old), late-aged (45–52 hours), all ages (1–26 hours) eggs, and the three larval stages tested were first, feeding third and non-feeding third instars. For *B. xanthodes*, three egg stages of early-aged (1–3 hours old), late-aged (41–48 hours), and all ages (1–26 hours) eggs, and three larval life stages first instars, feeding third, and non-feeding third instars.

Eggs and larvae were heat-treated in plastic syringe black muslin cloth containers (25 mm internal diameter by 110 mm length) fully submerged in static-temperature water baths. The black muslin containers were constructed from a frame of open plastic syringe tubes (30 mL). This arrangement permitted free circulation of water. Containers containing 100 eggs or 25 larvae were placed in the static-temperature water bath at various preset constant temperatures from 44 °C to 49 °C ± 0.1 °C. All treatments at a given temperature were immersed simultaneously; individual tubes were removed at specified time intervals which varied with the severity of the treatment. Temperatures both inside

and outside each container were monitored during each experiment, using in-glass or digital thermometers. Treated eggs were counted after holding them on the moistened black filter paper for 2 days in petri dishes. Per cent survival was calculated based on the number of larvae emerging from the eggs.

Control treatments were immersion in water at ambient temperature (21–22 °C) for the duration of the longest immersion of the heat-treated eggs or larvae. (Controls help to ensure that observed effects were due primarily to heat and not immersion in water.) Checks were eggs removed from egging domes and directly plated on moist, black filter paper in petri dish. (Checks help to determine if any mortality was caused by handling conditions between the time the eggs were removed from the egging domes and the time the static-temperature water bath tests were initiated.) Checks for larval stages were placed directly on the larval diet or sawdust. This was to determine the normal survival of larvae that were not immersed in water, either as control or treated insects. Immediately after removal from the treatment water bath, eggs and larvae were placed in ambient temperature water for at least one minute to reduce continued cumulative heat effects. First instars of the two species were exposed to treatments within four hours of emergence from the egg.

Feeding third instars were returned to fresh diet in small 40 mL cups. These were held over a bed of sawdust in individually capped 250 mL plastic rearing containers. Non-feeding third instar larvae were placed directly on sawdust for pupation after treatment. Controls and checks were handled similarly. A minimum of five replications of each treatment was conducted for each time × temperature study. Survival rate for larvae was calculated from the number of pupae counted after sieving from the sawdust. After treatment larvae were immediately immersed in ambient temperature water to remove latent heat and placed on larval diet, as described for checks and controls.

Water temperatures were monitored for accuracy in the water bath itself and in the individual immersion containers to observe any temperature discrepancies. Larvae that floated on the surface of the water during treatment were removed as these 'floaters' may not have received the full time × temperature treatment. Treated larvae were cooled for at least one minute in ambient temperature water immediately after treatment to remove latent heat that could have added to larval death.

Observations for egg hatch were made approximately 24–36 hours later than normal egg hatch. Again, hatched eggs were those eggs with a ruptured, clear chorion. Dead eggs were discoloured, the chorion ruptured with dead larvae seen within the chorion, or the eggs looked healthy but they were not hatched. Larvae within ruptured chorions that did not move when touched were scored as dead. Survival of first and feeding or non-feeding third larvae again were based on the ability of the larvae to pupate. However, the pupae were held from the checks, controls and treatments and adult emergence was recorded. When relatively few pupae are found in treatments and adult emergence never occurs, dissection of pupae may show a lack of pupal development beyond formation of the puparium. The phenomenon of dead or 'hollow' puparia is associated as an effect of latent, treatment-induced mortality. Pupation normally occurred within a few days. Pupae were carefully counted after the media had been sieved. Counted pupae were scored as survival.

The data (number of survivors) recorded for *B. facialis* include three egg ages (early-aged (1–3 hours), late-aged (45–52 hours) and all ages (1–28 hours)) and three larval stages (first larvae, feeding third and non-feeding third larvae). *B. facialis* was tested at temperatures 45 °C–49 °C for all stages except the 'all age' eggs which were tested in the range 44 °C–49 °C. Between 3–10 replicates were done for each age-temperature-time combination, although some combinations were repeated giving between 6–20 effective replicates. For each larval stage, approximately 25 to 100 individuals were tested per replicate. For egg ages, approximately 100 individuals were tested per replicate.

The number of individuals surviving the 'control' treatment was assumed to represent the number exposed at each temperature-time combination. Percentage survival was calculated at each time by dividing the number of surviving individuals by the number of individuals surviving the 'control' treatment and multiplying this by 100.

Statistical methods

The statistical analyses reported were carried out by Dr C.M. Frampton and A. Evans of Lincoln University, New Zealand. The time survival data were analysed using the complementary log-log model (Preisler and Robertson 1989). The model used time as the independent variable rather than log (time) as used by Preisler and Robertson.

Survival = exp (– exp (a+b*time))

For each temperature-life stage combination, a complementary log-log survival function, relating survival to exposure time, was fitted. From the parameters estimated for this model, the LT99 (time until 99% mortality) and their confidence intervals

could be calculated. Parameters were estimated using a maximum likelihood routine with the variance assumed to be proportional to that of a binomial distribution. Deviance values were used to assess the adequacy of the fit of the complementary log-log functions, by comparison with the appropriate Chi-square value from tables (Preisler and Robertson 1989). Alternative survival functions typically used with data of this form (e.g. Logit, Probit or Weibull) were also trialled on subsets of the data but did not consistently provide a better fit to the survival data. The estimates of the LT99 for each temperature were then used to generate temperature mortality relationships for each life stage. The relationship between temperature and LT99 was consistently in the form: *Log(LT99) = a + b * temperature*. For this reason estimates of the slope (b) and the intercept (a) were made using standard linear regression methods.

Results and Discussion

Complementary log-log survival functions and their associated deviance values were calculated for each temperature-life stage combination. Statistically significant deviance values showed a poor fit for the complementary log-log functions for the following sets of data: *B. xanthodes* first larvae at 47 °C, 48 °C and 49 °C, feeding third larvae 49 °C and non-feeding third larvae 47 °C. *B. facialis* first larvae 46 °C, 48 °C and 49 °C, third larvae feeding 46 °C, 47 °C, 48 °C, 49 °C and third larvae non-feeding 45 °C, 46 °C, 47 °C, 48 °C, 49 °C.

These combinations showed either considerable extra-binomial variability e.g. *B. facialis* feeding third larvae 47 °C or an inadequate range of survival at the times tested e.g. *B. xanthodes* first larvae 48 °C and 49 °C. The differences in the colonies used over time, slight differences in the incubation temperature prior to treatment, and slight variations in handling techniques may have contributed to the variability.

These problems with the data could not usefully be remedied by fitting alternative models, which suggests that there are inadequate exposure times with a range of survival that is greater than 0 and less than 100%. To usefully fit a survival function it is essential that a range of survival values (e.g. approx. 0, 25, 50, 75, 100) are present in the data. Estimates of the LT99s and their confidence intervals are presented in Table 1, for those combinations where sufficient data allowed computation. For some combinations where the log-log survival function provided a poor fit to the data, estimates of the LT99s were still possible although confidence intervals could not be estimated. The LT99s for *B. facialis* are consistently longer than those for *B.*

Table 1. Estimated LT99 (min) and 95% C.I. for each life-stage temperature combination for *B. facialis* and *B. xanthodes*.

Temperature (°C)	Lifestage	Time for 99% mortality	
		B. facialis (95% C.I.)	*B. xanthodes* (95% C.I.)
44 °C	Late-aged eggs	—	—
	All aged eggs	15.758 (14.974–16.543)	6.536 (6.285–6.787)
	1st instar	—	—
	3rd instar (F)	—	—
	3rd instar (NF)	—	—
45 °C	Late-aged eggs	19.650 (18.684–20.616)	14.165 (13.492–14.837)
	All ages eggs	8.954 (8.451–9.457)	3.563 (3.424–3.702)
	1st instar	21.249 (17.288–25.210)	9.068 (7.018–11.118)
	3rd instar (F)	16.959 (14.727–19.190)	8.108 (7.151–9.055)
	3rd instar (NF)	13.270 —	9.137 (8.505–9.769)
46 °C	Late-aged eggs	12.020 (11.103–12.937)	7.214 (6.889–7.539)
	All ages eggs	4.106 (3.925–4.286)	2.605 (2.512–2.699)
	1st instar	8.371 —	5.886 (5.572–6.200)
	3rd instar (F)	9.840 —	5.437 (5.102–5.772)
	3rd instar (NF)	10.685 —	5.967 (5.522–6.412)
47 °C	Late aged eggs	4.971 (4.607–5.335)	3.071 (2.933–3.209)
	All ages eggs	2.712 (2.616–2.809)	1.598 (1.548–1.649)
	1st instar	5.056 (3.680–6.432)	3.353 —
	3rd instar (F)	5.685 —	3.482 (3.015—3.949)
	3rd instar (NF)	6.366 —	— —
48 °C	Late-aged eggs	2.533 (2.302–2.764)	2.068 (1.949–2.187)
	All ages eggs	1.926 (1.849–2.003)	0.853 (0.789–0.917)
	1st instar larvae	—	—
	3rd instar larvae (F)	—	1.976 (1.678–2.275)
	3rd instar larvae (NF)	—	2.218 (1.964–2.471)
49 °C	Late-aged eggs	1.512 (1.404–1.619)	1.102 (1.046–1.158)
	All ages eggs	1.175 (1.135–1.215)	—
	1st instar	—	—
	3rd instar (F)	—	—
	3rd instar (NF)	—	1.833 (1.615–2.451)

xanthodes indicating the greater tolerance of this species.

Again, the LT99s for *B. facialis* are consistently longer than those for *B. xanthodes* indicating the greater tolerance of this species. Several fruit fly species that have been treated in similar water bath studies, showed similar mortality responses even though they were analysed using different statistical models (Probit and Logit). Survival assessments were typically carried out 24–36 hours or longer after eggs had hatched and larvae ability to pupate. Oriental fruit flies have been identified by Armstrong et al. (1989) as more heat tolerant than melon fly.

There was insufficient survival at all times for the early-aged (1–3 hour) eggs. Although this did not enable an estimate of the LT99 it is evident from the data that this egg age group is highly sensitive, with no survivors at 45 °C exposed for two minutes. As for *B. facialis*, there was insufficient survival at all times for the early-aged (1–3 hour) eggs. Although this did not enable an estimate of LT99 it is again evident from the data that this egg age group is highly sensitive with no survivors at 45 °C exposed for three minutes. Among the two egg stages for which LT99s were estimated, late-aged eggs always had statistically significant longer LT99s than the 'all age' egg stage.

Corcoran (1993) in his studies of the heat mortality relationships for eggs of *B. tryoni* at varying ages, identified a similar response, as the mortality was dependent on age with eggs becoming generally more tolerant of heat as embryonic development progressed. *B. tryoni* mature eggs were identified as more heat tolerant than young eggs, even though the mortality was assessed as pupal emergence rather than larval mortality (Heard et al. 1991). *B. melanotus* mature eggs, however, stand out as the most tolerant of all stages and also compared to *B. xanthodes* (Waddell et al. 1993).

The LT99s for *B. facialis* show no consistent patterns in terms of a most resistant stage at all temperatures. At 45 °C the first instar is the most resistant followed by the feeding third instar and then the non-feeding third instar. At 46 °C and 47 °C this order is reversed with the non-feeding third instar being the most resistant followed by the feeding third instar and then the first instar. This pattern is evident in the slopes and intercepts of the LT99 versus temperature relationships for this species (Table 2, Fig. 2). The intercepts reflect the pattern seen at 45 °C where the first instar has the highest value

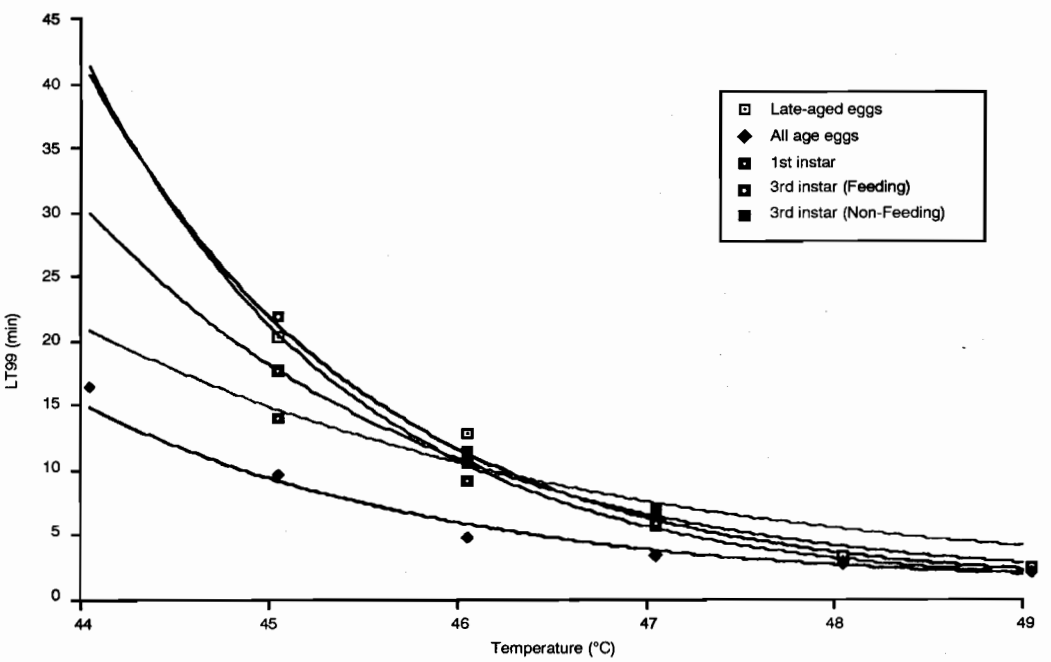


Figure 1. Mortality response of *Bactrocera facialis* to heat.

Table 2. Estimated slopes, intercepts and standard errors for the response line relating LT99 (min) to temperature.

Species	Life stage	Intercept (S.E.)	Slope (S.E.)
B. facialis	Late-aged eggs	33.109	−0.669
		(1.675)	(0.036)
	All ages eggs	25.285	−0.514
		(1.584)	(0.034)
	1st instar	35.289	−0.718
		(5.677)	(0.123)
	3rd instar (F)	27.424	−0.546
		(0.590)	(0.001)
	3rd instar (NF)	19.065	−0.367
		(4.000)	(0.087)
B. xanthodes	Late-aged eggs	31.190	−0.636
		(1.865)	(0.040)
	All ages eggs	23.310	−0.488
		(1.352)	(0.029)
	1st instar	24.612	−0.497
		(1.732)	(0.038)
	3rd instar (F)	23.192	−0.468
		(1.251)	(0.027)
	3rd instar (NF)	21.101	−0.420
		(1.755)	(0.037)

followed by the feeding third instar and then the non-feeding third instar. The first instar however has the steepest decline followed by feeding third instar and non-feeding third instar. This means that at 47 °C the patterns in the LT99s are reversed from those seen at 45 °C. Although the data do not provide sufficient precision to distinguish among the different larval instar and the late eggs at 47 °C, the statistically significant differences between the slopes provide a strong indication that the non-feeding third instar will be the most resistant from this temperature upwards. Despite the lack of estimates in the higher temperatures for *B. facialis* there is no indication from the slopes and intercepts of the LT99 versus temperature relationships that this species will be less resistant than *B. xanthodes* in the 47 °C–49 °C range (Tables 1 and 2, Figs. 1 and 2).

The intercepts and slopes for the equations relating temperature to LT99 are given in Table 2. These curves and the data points are presented in the Figures. Figures 1 and 2 provide summaries of the life stages for each species independently. The different slopes of lines indicate differences in heat susceptibility of life stages to changing temperature.

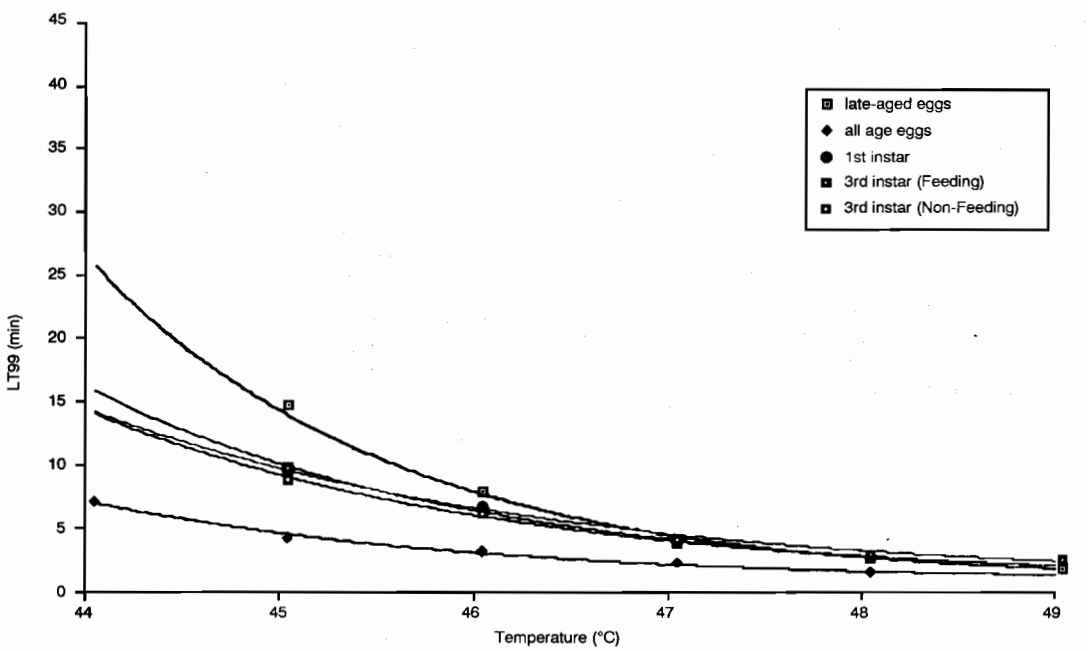


Figure 2. Mortality response of *Bactrocera xanthodes* to heat.

Heard et al. (1991) identified the similar pattern of susceptibility is temperature dependent.

The slope for the late-aged egg for *B. facialis* is statistically significantly steeper than for the other stages of this species except the first instar. Additionally, the feeding third instar and first instar had significantly steeper slopes than the non-feeding third instar. For *B. xanthodes* the slope for the late egg age is statistically significantly steeper in comparison to all other stages. No other slope comparisons between the life stages reached statistical significance within either species. Only the feeding third instar was significantly different between the two species, where *B. facialis* had the steeper slope.

This study showed that *B. facialis* has significantly greater heat tolerance than *B. xanthodes* for all life stages and temperatures. For the lower temperatures (<46 °C) the first instar is the most tolerant. For temperatures above this (>46 °C) the third instar is the most heat resistant with a strong indication that the non-feeding third instar is more heat tolerant than the feeding third instar. The late eggs are clearly the more resistant of the egg ages and there is some evidence that above 46 °C they are less resistant than any of the larval instars.

A similar result indicated by Jang (1991) that 'popping' third instar of the oriental fruit fly appeared more heat resistant than feeding third instar. The supportive argument based on observations during these studies was that non-feeding third instars have the probability that puparium formation prior to treatment could assist in their ability to tolerate heat better than other stages. In contrast, Armstrong et al. (1989) reported that oriental fruit fly eggs were more tolerant than larvae in tests using HTFA treatments of infested papaya, while Jang (1986) reported that first instar were more tolerant than eggs of oriental fruit fly in water bath studies and subsequently identified non-feeding third instar as ore tolerant than either first instar or eggs of this species.

Reported differences between the studies point to differences in he experimental methods, including the developmental stage of the insect treated, insect-fruit interactions, and possibly variability in the number of insects treated.

Conclusions

B. facialis showed significantly greater heat tolerance than *B. xanthodes* for all life stages and temperatures. For the lower temperatures (<46 °C) the first instar is the most tolerant. For temperatures above this (>46 °C) the third instar is the most heat tolerant with a strong indication that the non-feeding third instar is less sensitive than the feeding third instar. The late eggs are clearly the more tolerant of the egg ages and there is some evidence that above 46 °C they are less tolerant than any of the larval instar.

Overall, especially at high temperature, precise estimates of the LT99's were not possible. However, at 47 °C the non-feeding third instar of *B. facialis* was the most heat tolerant stage. This stage also had the smallest slope for the response curve LT99 versus temperature. Although the confidence intervals for the non-feeding third instar were not available at 47 °C and no estimate of the LT99 was possible at 48 °C, it seems highly likely that at these two temperatures it will be less tolerant than the most tolerant stage of *B. melanotus* from Cook Islands, *B. dorsalis, B. cucurbitae* and *C. capitata* of Hawaii and *B. tryoni* of Australia.

The most important temperatures for the comparison of heat tolerance are 47 °C and 48 °C, i.e., the temperatures close to that which is likely to be adopted for any heat disinfestation treatment. It would appear that at the temperatures below 49 °C, HTFA disinfestation treatment is likely to be effective in Tonga on *B. facialis* and *B. xanthodes*. However, given the high degree of variability in mortality in the data, this conclusion is largely unsubstantiated.

Acknowledgment

This research was funded jointly by the Regional Fruit Fly Project in the South Pacific, the USAID CAD Project and the Tongan Government.

References

Anon. 1985. Animal and Plant Health Inspection Service. Plant Protection and Quarantine Treatment Manual, section III, part 9, 1–3, Section VI-T106, 24, US Government Printing Office, Washington, DC.

Armstrong, J.W. 1982. Development of a hot-water immersion quarantine treatment for Hawaiian-grown 'Brazilian', 'Valery', and 'William's' bananas. J. Econ. Entomol. 75: 787–790.

Armstrong, J.W., Hansen, J.D., Hu, B.K.S. and Brown, S.A. 1989. High-temperature forced-air quarantine treatment for papayas infested with tephritid fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 82: 1667–1674.

Baker, A.C. 1952. The vapor-heat process, in Insects: The Yearbook of Agriculture. US Dept. Agric. US Government Printing Office, Washington DC, 401–404.

Corcoran, R.J. 1993. Heat-mortality relationships for eggs of *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) at varying ages. Journal Australian Entomology Society, 1993, 32: 307–310.

Couey, H.M. and Hayes, C.F. 1986. Quarantine procedures for Hawaiian papaya using fruit selection and a two-stage hot water immersion. J. Econ. Entomol. 79: 1307–1314.

Hamacek, E.L. 1995. Fruit Fly Culturing. Lecture No. 8. FAO/SPC/UNDP Regional Fruit Fly Project Technical Notes, S.P.C. Plant Protection, Suva, Fiji.

Heard, T.A., Heather, N.W. and Corcoran, R.J. 1991. Dose-mortality relationships for eggs and instar of *Bactrocera tryoni* immersed in hot water. J. Econ. Entomol. 84(6): 1768–1770.

Jang, E.B. 1986. Kinetics of thermal death in eggs and first instar of three species of fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 79: 700–705.

Jang, E.B. 1991. Thermal death kinetics and heat tolerance in early and late third instar of oriental fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 84: 1298–1303.

Preisler, H.K. and Robertson, J.L. 1989. Analysis of time-dose-mortality data. J. Econ. Entomol. 82: 1534–1542.

Sharp, J.L., Ouye, M.T., Thalman, R., Hart, W., Ingle, S. and Chew, V. 1988. Submersion of 'Francis' mangoes in hot water as a quarantine treatment for the West Indian fruit fly and the Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 81: 1431–1436.

Sharp, J.L. and Chew, V. 1987. Time/mortality relationships for *Anastrepha suspensa* (Diptera: Tephritidae) eggs and instar submerged in hot water. J. Econ. Entomol. 80: 646–649.

Waddell, C.G.K., Maindonald, J.H. 1992/1993. Postharvest disinfestation of *Bactrocera melanotus* and *B. xanthodes* in the Cook Islands: Report 2 and 3. Horticulture and Food Research Institute of New Zealand. Palmerston North. New Zealand.

Comparison of Egg and Larval Stage Mortality of Three Fruit Fly Species (Diptera: Tephritidae) After Immersion in Hot Water

F. Sales[1], D. Paulaud[1] and J. Maindonald[2]

Abstract

In this study, the time-mortality response, under exposure to hot water at temperatures in the range 44–48°C, was determined for young eggs (at 10% of the final development), for mature eggs (80% of the development) and for the first, second, and third instar larvae of three fruit fly species: *Bactrocera tryoni* (Froggatt), (Queensland fruit fly), *Bactrocera curvipennis* (Froggatt) and *Bactrocera psidii* (Froggatt). At all temperatures, for all species, the mature eggs and the first instar larvae were more tolerant than any other stage. At 44°C and 45°C, the treatment would have to be directed against *B. curvipennis* mature eggs as well as against first instar larvae of all three species, while at 46°C and 47°C it would need to be directed against *B. curvipennis* mature eggs. At 48°C, it would need to be directed against *B. curvipennis* mature eggs and first instar larvae. The times of exposure leading to 99% mortality for each of the temperatures 44, 45, 46, 47 and 48°C are given. These results will be useful in determining the necessary heat treatment for fruits infested with these insects.

NEW Caledonia hosts a number of species of fruit fly, (Diptera: Tephritidae) (Cochereau 1970; Drew 1989, Drew and Hancock 1995; White and Elson-Harris 1992). The three species of economic importance are *Bactrocera tryoni* (Froggatt), *Bactrocera curvipennis* (Froggatt) and *Bactrocera psidii* (Froggatt). *B. tryoni* has diverse hosts and poses the greatest risks. However, *B. curvipennis* which is purported to be found also in Vanuatu, and *B. psidii* which is endemic to New Caledonia, are potential serious risks. These pests have hindered the export of mango *(Mangifera indica* L.*)* and of capsicum *(Capsicum annum* L.*)*. Because treatment with ethylene dibromide has been banned and because of a permanent reduction of acceptable residue levels in fruit after any chemical post-harvest treatment, alternative non-chemical treatments are increasingly being developed. These include hot water immersion, and exposure to hot water vapour. In the research reported here, the relative tolerance of all stages of the fruit fly species which infest the fruit was determined. The identification of the stages and species most tolerant to heat then makes it possible to limit much of the subsequent research effort to those stages.

The change in time-mortality response with temperature has previously been studied for *Bactrocera melanotus* (Coquillett) and *Bactrocera xanthodes* (Brown) in the Cook Islands, with a view to developing a treatment for papaya (Waddell et al. 1992, 1993). There have been comparable studies for mango, with *Ceratitis capitata* (Wiedemann), *Bactrocera dorsalis* (Hendel) and *Bactrocera cucurbitae* (Coquillett) (Jang 1986, 1991). Finally, initial research has already been undertaken by Heard et al. (1991) on *Bactrocera tryoni* (Froggatt). This study also has relevance to the development of the vapour heat treatments, and is the first study that examines *B. psidii* and *B. curvipennis.*

Materials and Methods

Colonies of the three fruit fly species have been developed at the Pocquereux Research Station,

[1] CIRAD-FHLOR, Station de Recherches Fruitières de Pocquereux, BP 32, 98880 La Foa, New Caledonia
[2] Department of Statistics, University of Newcastle, Newcastle NSW 2299, Australia

giving access to live material as needed for the experiments. For making laying devices incisions were made in small plastic boxes, which were then coated inside with the flesh of a host fruit. Eggs were collected after allowing two hours of laying. The eggs obtained were then placed in a breeding room (25 °C, 60-70% RH), either on moist filter paper in petri dishes so as to obtain eggs, or on a larval rearing medium based on mashed bananas and yeast extract in order to obtain second and third instar larvae.

The resistance to heat of very young eggs (10% of the final development), of mature eggs (80% of the final development), and of first, second and third instar larvae was studied, using at least two replicates for each species and development stage at each of five temperatures (44, 45, 46, 47 and 48 °C). The organisms were immersed in a thermostatically controlled 50 litre bath (Techne®) at a range of exposure times that were designed to generate mortalities between 30% and 100%. For immersion, the insect material was placed in cylindrical plexiglass tubes with an internal diameter of 34 mm and a length of 50 mm. Fine wire mesh at the extremities of the tubes allowed water to penetrate rapidly while preventing the loss of the smaller organisms. Before immersion, both extremities of the tubes were carefully wiped to prevent the formation of air bubbles inside the tubes.

After counting, a very fine brush was used to transfer the eggs onto black filter paper. A fine water spray was used to move them in containers. For the very young eggs, this happened five hours after laying, while for mature eggs the waiting period was 32 hours after laying. After hatching, first instar larvae were transferred one by one into the tubes with the aid of a very fine brush. The second and third instar larvae were collected by rinsing out the larval rearing medium with water, whenever the required stage of development was reached. White and Elson-Harris's (1992) description of the morphological character of the larval stages was used to confirm the state of development. Tweezers were used to transfer the individuals into containers.

For eggs, 60 individuals were taken at the shorter immersion periods and 150 individuals at the longer immersion periods which give high mortalities. For the larvae, the numbers were 30 and 70 for the short and long immersions times respectively. After the required time the containers were taken out of the hot water bath and immediately immersed into water at 25 °C for two minutes, in order to prevent further heating. At the same time, control samples consisting of two sets of eggs or larvae were plunged into water at 25 °C for a time corresponding to the longest length of time of immersion under treatment, in order to verify that mortality was due to heat and not to the immersion into water.

Following the treatment, eggs were recovered on a piece of very fine gauze which was then placed on a piece of black filter paper, inside of a petri dish. After three days at 25 °C, mortality was assessed by counting the number of hatched eggs. Larvae were placed on a piece of moist black filter paper in a petri dish. After 24 hours at 25 °C, mortality was assessed by sustained observation with a high magnification binocular magnifying glass. The larvae were considered dead when they did not react to light picking with a fine point.

To assess the time of immersion giving a 99% mortality rate (LT99), the results were analysed according to a loglog model, the immersion time being used as the explanatory variable (Statistical Science Inc. 1993; Chambers and Hastie 1992). For modelling the result, the equation:

$$\log (- \log (1-p)) = a + bt$$

was used, where p = expected mortality and t = immersion time.

This model was chosen after studying several alternatives. It allows accurate estimation of the immersion time needed for high mortality.

Results

From the relationship given by the complementary log-log LT99 estimates were determined. Table 1 gives LT99s for the five maturity stages of the three species studied at the five different temperatures, with their associated 95% confidence intervals. Figure 1 shows the curves obtained after statistical analysis of all given data. Whatever the species and at all temperatures, the mature eggs (32 hours development) and the first instar larvae show a greater tolerance to heat than all other stages. At all temperatures, *B. curvipennis* mature eggs are significantly more resistant than the mature eggs of the two other species. From 44 °C to 47 °C the first instar larvae of the three species show a similar response. At 44 °C and 45 °C no difference can be detected between the most tolerant stages, which are *B. curvipennis* mature eggs, and the first instar larvae of the three species. At 46 °C and 47 °C, *B. curvipennis* mature eggs are most resistant, whatever the species or the development stage. Finally at 48 °C, the authors could not differentiate *B. curvipennis* mature eggs and first instar larvae, which were both more tolerant than other species-stage combinations.

Table 1. Calculated LT99s and 95% confidence intervals for five immature development stages of *Bactrocera tryoni*, *B. curvipennis* and *B. psidii* at five water bath temperatures.

Temperature	Stage	Calculated LT99 (95% confidence interval)		
		B. tryoni	*B. curvipennis*	*B. psidii*
44°C	5 h eggs	9.4 (8.1–11.0)	14.0 (11.1–17.6)	10.6 (7.5–15.1)
	32 h eggs	58.9 (52.3–66.3)	85.3 (77.8–93.5)	49.4 (38.6–63.4)
	1st instar	80.8 (67.0–97.5)	97.8 (87.5–109.0)	85.1 (68.2–106.3)
	2nd instar	28.0 (25.1–32.4)	26.0 (23.6–28.7)	25.2 (19–33.6)
	3rd instar	28.5 (25.2–32.4)	32.2 (26.1–39.7)	19.9 15–26.6)
45°C	5 h eggs	5.3 (4.5–6.2)	8.4 (7.2–9.9)	5.0 (3.5–7.1)
	32 h eggs	36.6 (33.6–39.7)	53.0 (49.6–56.7)	34.2 (26.7–43.9)
	1st instar	45.0 (39.3–51.5)	45.4 (42.1–48.9)	44.5 (34.8–57.1)
	2nd instar	18.3 (16.9–19.8)	18.2 (17.0–19.4)	—
	3rd instar	15.9 (14.6–17.3)	23.3 (20.1–27.1)	15.0 (11.7–19.2)
46°C	5 h eggs	3.7 (3.1–4.6)	5.1 (4.4–5.8)	3.8 (2.3–6.2)
	32 h eggs	22.7 (21.1–24.4)	33.0 (31.2–34.8)	15.4 (12.4–19.3)
	1st instar	25.0 (22.5–27.7)	24.8 (22.8–27.0)	24.1 (19.3–30.1)
	2nd instar	11.9 (11.1–12.8)	12.7 (12.0–13.4)	5.6 (4.0–8.0)
	3rd instar	10.6 (9.6–11.7)	16.9 (15.0–19.1)	11.4 (8.9–14.7)
47°C	5 h eggs	3.4 (1.9–6.2)	3.1 (2.6–3.6)	2.5 (1.9–3.4)
	32 h eggs	14.1 (12.9–15.4)	20.5 (19.3–21.8)	8.3 (6.2–11.1)
	1st instar	13.9 (12.4–15.5)	15.9 (14.8–17.1)	11.2 (8.9–13.9)
	2nd instar	7.8 (7.1–8.5)	8.9 (8.0–9.5)	5.1 (3.6–7.2)
	3rd instar	8.4 (7.7–9.2)	12.2 (10.6–14.2)	6.9 (5.4–8.8)
48°C	5 h eggs	—	1.8 (1.5–2.3)	1.1 (0.8–1.6)
	32 h eggs	8.7 (7.7–9.9)	12.7 (11.7–13.8)	6.5 (5.1–8.4)
	1st instar	7.7 (6.6–9.0)	12.0 (10.7–13.4)	6.4 (5.1–7.9)
	2nd instar	5.1 (4.5–5.8)	6.2 (5.7–6.8)	2.8 (2.0–4.0)
	3rd instar	8.0 (6.8–9.4)	8.9 (7.2–10.9)	4.1 (3.1–5.5)

Discussion

In developing a post-harvest heat treatment, knowledge of the relative heat resistance of the different species-stage combinations makes it possible to limit further research to the most resistant stages.

Even though the confidence intervals do not show a significant difference between the mature eggs and the first instar larvae at 44°C and 45°C, it is nevertheless interesting to note that the mean for *B. curvipennis* is greater than that for the two other species. For comparison, the work undertaken by Waddell et al. (1993) following an identical protocol on *B. melanotus* and *B. xanthodes* shows that these two species are less tolerant than *B. curvipennis*. *B. tryoni* and *B. psidii* are at least as resistant as the two fruit fly species of the Cook Islands.

The criteria used to determine mortality may underestimate mortality. This may partly explain the smaller LT99 values for *B. tryoni* obtained by Heard et al. (1991), who used as the mortality criterion failure to survive through to emergence as adults. Note also that the probit model which Heard et al. used will affect the LT99 estimates. It would be interesting to let the larval stages develop further to get alternative mortality assessments for comparison. This method gives an assurance that in practice mortalities will be at least as high as predicted. However it will be necessary to verify these results by exposing artificially infested fruit to hot air. A complicating factor is that the LT99 for insect stages which are inside the fruit must relate to the internal fruit temperature. An additional consideration is that where the temperature increases to the endpoint temperature over a substantial time, this may affect the response.

Depending on the chosen temperature, disinfestation treatments will have to be directed either against *B. curvipennis* mature eggs and the first instar larvae of the three species at 44°C and 45°C, or against *B. curvipennis* mature eggs at 46°C and 47°C, or finally against *B. curvipennis* mature eggs and first instar larvae at 48°C.

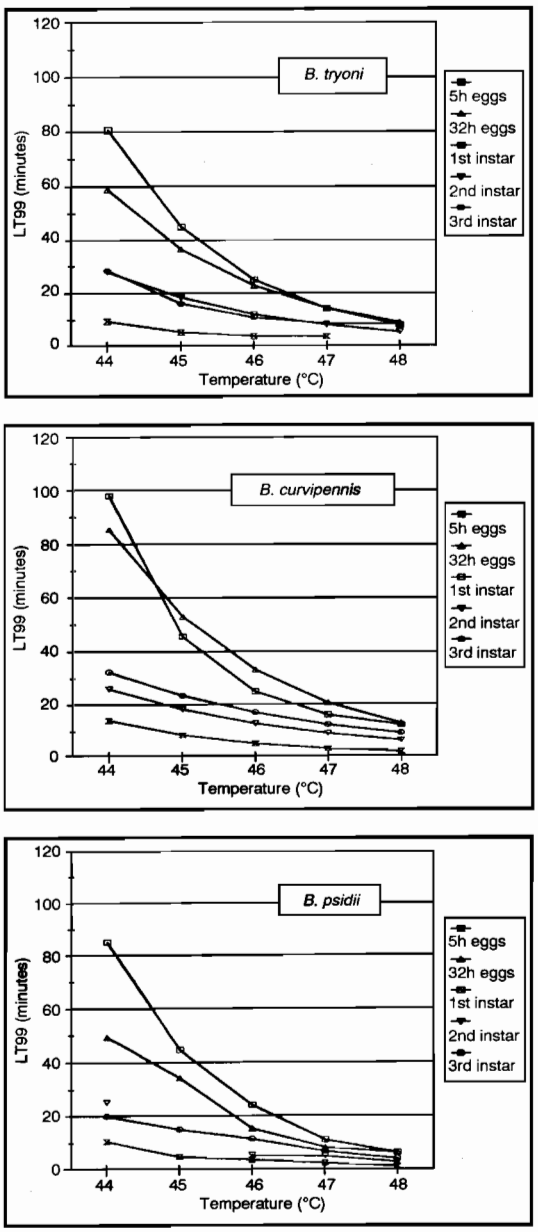


Figure 1. LT99s for five immature development stages of *Bactrocera tryoni, B.curvipennis* and *B.psidii* at five waterbath temperatures.

Acknowledgment

This project could not have been achieved without the financial support of the Territory of New Caledonia. The authors thank Mrs B. Waddell (HortResearch) and Mr P. Connolly (HortResearch) for their advice and their assistance.

References

Chambers, J.M. and Hastie, T.J. 1992. Statistical Models in S. Wadsworth and Brooks/Cole, Pacific Grove.

Cochereau, P. 1970. Les mouches des fruits et leurs parasites dans la zone indo-australo-Pacifique et particulièrement en Nouvelle-Calédonie. Cahiers ORSTOM, Série Biologie. 12: 15–50.

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceania regions. In: Memoirs of the Queensland Museum. Brisbane. 26, 521 p.

Drew, R.A.I. and Hancock, D.L. 1995. New species, subgenus and records of *Bactrocera* Macquart from the South Pacific (Diptera: Tephritidae: Dacinae). Journal of the Australian Entomology Society, 34: 7–11.

Heard, T.A., Heather, N.W. and Corcoran R.J. 1991. Dose-Mortality relationships for eggs and larvae of *Bactrocera tryoni* (Diptera: Tephritidae) immersed in hot-water. Journal of Economic Entomology, 84: 1768–1770.

Jang, E.B. 1986. Kinetics of thermal death in eggs and first instars of three species of fruit flies (Diptera: Tephritidae). Journal of Economic Entomology, 79: 700–705.

Jang, E.B. 1991. Thermal death kinetics and heat tolerance in early and late third instars of the Oriental fruit fly (Diptera: Tephritidae). Journal of Economic Entomology, 84: 1298–1303.

Statistical Sciences Inc. 1993. S-PLUS User's Manual, version 3.2. Statistical Sciences Inc. Seattle, Washington.

Waddell, B.C., Clare, G. and Maindonald, J.H. 1992. Post-harvest disinfestation of *Bactrocera melanotus* and *B. xanthodes* in the Cook Islands. Reports 2. HortResearch client report No.92/89, 41 p.

Waddell, B.C., Clare, G. and Maindonald, J.H. 1993. Post-harvest disinfestation of *Bactrocera melanotus* and *B. xanthodes* in the Cook Islands. Reports 3. HortResearch client report No.93/270, 70 p.

White, I.M. and Elson-Harris, M.M. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. Oxon: C.A.B. International, 601 p.

Quarantine Heat Treatment for *Bactrocera melanotus* (Coquillett) and *B. xanthodes* (Broun) (Diptera: Tephritidae) in Waimanalo Papaya in the Cook Islands

B.C. Waddell[1], G.K. Clare[1], R.J. Petry[1], J.H. Maindonald[1], M. Purea[2], W. Wigmore[2], P. Joseph[2], R.A. Fullerton[1], T.A. Batchelor[3] and M. Lay-Yee[1]

Abstract

Changes in the quarantine treatment technology used for disinfesting Cook Islands fruit were necessitated by the lowering of the maximum allowable residue level of ethylene dibromide (EDB) detected in fumigated papaya destined for the New Zealand market. This paper describes a forced-air heat treatment now being used as an alternative to EDB fumigation for control of the fruit fly species *Bactrocera melanotus* and *B. xanthodes* in Cook Islands papaya. The treatment involves raising the fruit centre temperature to 47.2°C and maintaining this temperature or higher for 20 minutes, followed by hydro-cooling to a fruit centre temperature of about 30°C. Complete kill of 17 750 *B. melanotus* mature eggs, previously identified as the most tolerant fruit fly species and life stage, was achieved in two verification trials conducted using a commercial scale treatment unit.

POST-HARVEST heat treatment of fruit was investigated over a two-year period as an alternative to ethylene dibromide (EDB) fumigation which was used to disinfest Cook Islands papaya (*Carica papaya* L. cv. Waimanalo solo) potentially infested with fruit flies. Legislation, which came into effect in New Zealand on 1 January 1994, set a maximum residue level for EDB of 0.1 ppm (Anon. 1992) which effectively rendered fumigation impractical. Heat treatment was investigated as an alternative to fumigation to allow the continuation of commercial exports of papaya from the Cook Islands.

A heat treatment schedule was developed and is now in use for papayas grown in Hawaii based on hot air treatment (Armstrong et al. 1995) for controlling potential fruit fly infestations in papaya exported from Hawaii to mainland USA (Anon. 1989). The Cook Islands fruit fly species and fruit cultivar differ from those found in Hawaii and therefore a new heat treatment schedule was required under the New Zealand Ministry of Agriculture (MAF) — Regulatory Authority Standard 155.02.03.

The treatment parameters to be used in the commercial application of the heat treatment were determined from a series of laboratory trials. Initially, laboratory colonies of fruit flies were established and a rearing management system developed to provide the necessary insect material (Clare 1996). Fruit fly eggs and larvae of a range of known ages were immersed in hot water and the mortality determined in response to different temperatures. The relative heat tolerance of the two species and the various life stages that may potentially be found in the fruit at the time of harvest was determined (Waddell et al. 1996). Once identified, the most tolerant species/life stage was included in all subsequent research conducted in fruit to develop the treatment parameters

[1]The Horticulture and Food Research Institute of New Zealand Ltd, Mount Albert Research Centre, Private Bag 92 169, Auckland, New Zealand
[2]Cook Islands Ministry of Agriculture, Totokoitu Research Station, PO Box 57, Rarotonga, Cook Islands
[3]Enza New Zealand (International), PO Box 1101, Hastings, New Zealand

that effectively killed the pest without damaging the fruit (Waddell et al. 1993).

Two verification tests are described which used the most tolerant life stage (mature eggs) of the more tolerant Cook Island fruit fly species (*B. melanotus)* (Waddell et al. 1996). The aim of the tests was to assess the performance of the commercial unit and demonstrate the effectiveness of the proposed treatment under commercial conditions.

Materials and Methods

Fruit supply

Papaya for the trials were harvested from commercial orchards and the Totokoitu Research Station. All fruit was free of insecticidal and fungicidal sprays. The overall weight range for the treated infested fruit was 969 to 1099 g. In any one trial the weight range did not exceed 65 g. Infested fruit was quarter- to half-ripe and 'filler' fruit were at the colour break stage of maturity. All fruit used was firm and without damage or rots.

Insect supply and fruit infestation

Eggs were collected from a laboratory colony of *B. melanotus* using specially prepared fruit egging devices. Ripe papaya were prepared for egg laying by halving the fruit and hollowing out the centre leaving only the skin which formed a dome-like structure. Adults oviposited into the domes over a 2 hour period and the eggs were retrieved and kept in petri dishes at 26°C until inoculation into test fruit the following morning.

Fruit were infested and treated on the same day. Four thin flaps of fruit tissue were cut and removed from the widest part of the fruit near the blossom end. Small channels were made in the exposed flesh (2 mm deep by 20 mm long) with a cork borer (4 mm internal diameter). One channel was made under each of three flaps and two channels were made under the fourth flap. Approximately 80 eggs were dispensed into each channel using a calibrated pipette making a total of about 400 eggs per infested fruit. The removed flaps of skin were carefully repositioned and taped in place around the cut edge with masking tape. Tape was not placed over the area containing the eggs. Eggs were 26–28 hours old at the time the treatment began.

Two treatments were completed in the commercial chamber on 21 and 22 October 1993. On each treatment day 30 fruit were inoculated, 24 for treatment in the unit (400 eggs per fruit giving a total of 9600 eggs) and six fruit (400 eggs per fruit giving a total of 2400 eggs) as non-treated controls. After inoculation at the Research Station the fruit were transported to the commercial heat treatment unit at the Rarotonga airport. The infested fruit were individually probed and the temperatures logged at 5 minute intervals throughout the treatment using Grant Squirrel® data loggers (Model 1206). Two loggers were used to measure the fruit temperatures independent of the chamber monitoring system. Three infested fruit were placed centrally in the top layer of fruit in each of eight treatment bins. The treatment unit was loaded to capacity for both runs. The chamber air was circulated from the bottom of the treatment bin to the top and so all infested fruit was located where the fruit temperatures would be coldest (Williamson and Winkelman 1994).

Treatment unit

The commercial treatment unit was designed by M.R. Williamson (Aquanomics International Inc., 1741 Ala Moana Blvd., Suite 34, Honolulu, Hawaii). Electrical power for the unit can be sourced from either the mains or from a diesel generator. In addition to producing power, the co-generator produces heat as a by-product which is harnessed and used to heat the chamber thereby reducing running costs. The stainless steel treatment unit has two identical chambers which can be run independently or concurrently. Each chamber contains four bins, each capable of holding about 400 kg of papaya. Bins are placed in one end of each chamber and are guided by a rail into the correct position for treatment. Chamber air is heated by hot water pumped through heat exchangers located horizontally and centrally in each chamber. The bins, together with the heat exchanger, form a continuous barrier that ensures that the recirculating air passes through the heat exchangers or the fruit. Air movement is driven by a large fan which pulls air down through the heat exchangers. The air then moves horizontally to the space under the fruit bins, up through the perforated base of the bins and into the space above the bins where it is then drawn into the centre of the chamber and reheated by circulating hot water in the heat exchangers. After treatment, the bins are unloaded through a second door at the other end of the chamber and into an insect-proofed area.

Eight temperature probes were associated with each chamber and the readings logged by the computer control system. Four probes were used to monitor the fruit centre temperature (one per bin), and four to measure the air temperature. One of the chamber air probes was used to regulate the rate of air heating at the start of the treatment while the fruit probes were used to determine the time when the treatment terminated. Humidity was also monitored.

After treatment, a water shower was used to drench the fruit to rapidly reduce fruit temperature.

The water collects in the bottom of the chambers in a sump, and is pumped through a cooling tower and recycled into the top of the chambers.

A computer was used to control and monitor each treatment. The software was developed by P. Winkelman (Aquanomics International Inc., Hawaii). The conditions used in the two verification tests were set so that the chamber air was ramped from 35°C to 48.5°C over a 3 hour period. The relative humidity was maintained above 70%. The parameters were chosen to ensure that the fruit centre temperature of all the fruit was increased to at least 47.2°C. The readings from the chamber fruit probes were used to define the finish point of each treatment run in each treatment chamber by automatically initiating hydro-cooling. The finish point occurred 20 minutes after the last chamber fruit probe attained the target temperature of 47.2°C.

When the laboratory-determined treatment parameters were transferred into the commercial setting a slight modification of the target temperature was required. Previously completed research trials conducted in a laboratory heat treatment unit showed that complete mortality of fruit flies could be achieved when the fruit centre temperature was raised to 47.0°C and held for 20 minutes at or above this temperature (Waddell et al. 1993). In the commercial version of the treatment the target temperature was increased to 47.2°C while the time at target remained at 20 minutes. This was necessary to allow for the observed variation in the location of the coldest fruit both between bins within a run, and between runs (Williamson, unpublished data). While the coldest fruit were always located in the top layer of each bin the exact location varied between the corners and the centre of the top layer. Increasing the target temperature by 0.2°C lengthened the treatment time and therefore increased the likelihood that all fruit were at or above the experimental target of 47.0°C. The chamber fruit probe location in the commercial operations was consistently located in the centre of the top layer of fruit in each bin, thereby simplifying the operational procedures.

All probe calibrations were made against a Julabo® Eintauchtiefe 95 mm mercury-in-glass reference thermometer which was in turn calibrated against a digital thermometer (Fluke Model 2180-A). The Fluke was independently certified for accuracy under the Measurements Standards Act 1992 by the Measurements Standards Laboratory of New Zealand, Industrial Research Limited, Wellington.

Post-treatment handling

Immediately following hydro-cooling the infested fruit were transported to the Research Station. The eggs were retrieved from each fruit by removing the fruit flap and carefully washing them onto fine gauze material. They were then sorted under a microscope to remove any damaged eggs which could later be confused with hatched eggs. Papaya diet (Clare 1996) was provided to sustain any emerging larvae while the eggs were incubated at 26 ± 1.0°C.

Mortality assessment

Heat-treated eggs were assessed for mortality three days after treatment. Non-treated eggs were assessed at the same time. Egg hatch as a mortality criteria provided a rigorous and rapid assessment of the treatment efficacy. While adults represent the potential risk to an importing country, the presence of moribund larvae at the time of border inspection would raise questions over the efficacy of the treatment.

Results and Discussion

Treatment conditions

The first trial on 21 October 1993 was completed using mains power. The mean fruit centre temperature at the start was 26.84°C ± 0.26(sd). The treatment was terminated 20 minutes after the last chamber fruit probe attained the target temperature of 47.2°C. The total treatment time was 6 hours 06 minutes in the left-hand side (LHS) chamber and 6 hours 15 minutes in the right-hand side (RHS) chamber. Hydro-cooling was applied for 1 hour 25 minutes in the RHS chamber and 1 hour 35 minutes in the LHS chamber until the mean fruit centre temperature of the 24 infested fruit reached 33°C ± 2.6(sd). The relative humidity was measured in the LHS chamber only and did not decline below 86.2% and was mostly above 90%.

The second trial completed on 22 October 1993 used the diesel generation capacity of the unit. The mean fruit centre temperature at the start was 26.81°C ± 0.41(sd). Again the treatment was terminated 20 minutes after the last chamber fruit probe attained the target temperature of 47.2°C. The total treatment time was 7 hours 14 minutes in the LHS chamber and 7 hours 0 minutes in the RHS chamber. Hydro-cooling was applied for 1 hour 20 minutes. The relative humidity again was measured in the LHS chamber only and did not decline below 90.6% and was around 99% for the last 1.5 hours.

The mean fruit centre temperatures of the infested fruit at termination of treatment were 48.32°C ± 0.20(sd) for the first trial and 48.57°C ± 0.26(sd) for the second trial. The ranges were 47.75°C to 48.7°C and 48.05°C to 48.95°C for the first and second trials respectively. The temperature overshoot

Table 1. Mortality of *B. melanotus* mature eggs when heat treated in papaya in a commercial heat treatment unit located at Rarotonga airport, Cook Islands. The chamber air was ramped from 35°C to 48.5°C over a 3 hour period which raised the fruit centre temperature to 47.5°C (or more) for 20 minutes.

Replicate No.	Control				Treated			
	No. of fruit	Eggs Total No.	Eggs No. Dead	% Mortality	No. of fruit	Eggs Total No.	Eggs No. Dead	% Mortality
1	6	2562	898	35.1	24	10098	10098	100
2	6	2394	556	23.2	24	7652	7652	100
Total	12	4956	1454	29.3	48	17750	17750	100

occurred because the chamber fruit temperature probes used to indicate the completion of the treatment (which were part of the chamber control system) were located in slightly larger fruit (1250–1300 g) compared to the infested fruit (969–1099 g) which were independently monitored. The first infested fruit to satisfy the treatment specification (i.e. to reach 47.2°C plus 20 minutes) in the first trial did so 1 hour 35 minutes before the treatment was terminated whereas the last infested fruit to complete the 47.2°C plus 20 minutes did so 40 minutes before the treatment was terminated. In the second trial, the first infested fruit to reach 47.2°C plus 20 minutes did so 2 hours 20 minutes before the treatment was terminated, whereas the last fruit to complete the treatment did so 1 hour 15 minutes before hydrocooling began, at the termination of the treatment.

The difference in treatment duration between the two trials may in part be attributed to the difference in the initial water temperature in the heat exchangers. In the first trial, the water was preheated to 60°C and so maximum heat was delivered to the air and therefore to the fruit from the outset of the treatment. In the second trial, the water temperature was initially at ambient and reached 60°C once the run had been operating for 2 hours. The operating conditions have subsequently been standardised for all commercial treatments.

Fruit fly mortality

Complete kill of 17750 *B. melanotus* mature eggs was achieved in the verification trials (Table 1). This compared to a mean control mortality of 29.3%. Therefore the treated population of eggs that was live at the time of treatment was 12549.

Conclusions

On the basis of the reported commercial scale trials, heat treatment where the fruit centre temperature is raised to 47.2°C and maintained at this temperature or more for 20 minutes, has been demonstrated to be effective for disinfesting Cook Islands papaya of any potentially infesting fruit flies of the species *B. melanotus* and *B. xanthodes* .

The first commercial application of the heat treatment for disinfestation took place on 3 January 1994. Working to the approved Cook Islands Bilateral Quarantine Agreement (BQA, 1994), in the two years to January 1996 approximately 800 tonnes of papaya have been exported to New Zealand, which is comparable with the quantities previously exported using fumigation technology.

Acknowledgments

The authors thank the Totokoitu Research Station personnel for technical assistance and the New Zealand Ministry of Foreign Affairs and Trade and the New Zealand Foundation for Research, Science and Technology for funding this project.

References

Anon. 1989. Dry-heat disinfestation treatment for fruit fly control on papaya exports. USDA-APHIS Quarantine Treatment Manual, 1989 update.

Anon. 1992. Ethylene dibromide residue limit reduction. Sentinel 24: 8.

Armstrong, J.W., Hu, B.K.S. and Brown, S.A. 1995. Single-temperature forced hot-air quarantine treatment to control fruit flies (Diptera: Tephritidae) in papaya. Journal of Economic Entomology, 88 (3): 678–682.

BQA. 1994. Appendix 2: Pawpaw (*Carica papaya*) Var. 'Waimanalo'. Ministry of Agriculture Regulatory Authority, PO Box 2526, Wellington, N.Z.

Clare, G.K. 1996. Rearing of *Bactrocera melanotus* (Coquillet) and *B. xanthodes* (Broun) (Diptera: Tephritidae) for post-harvest disinfestation research. New Zealand Journal of Zoology. Submitted.

MAF Regulatory Authority Standard 155.02.03. Specification for the Determination of Fruit Fly Disinfestation Treatment Efficacy. Ministry of Agriculture — Regulatory Authority, PO Box 2526, Wellington, N.Z. 14 p.

Waddell, B.C., Clare, G.K., Maindonald, J.H. and Petry, R.J. 1993. Postharvest Disinfestation of *Bactrocera melanotus* and *B. xanthodes* in the Cook Islands: Report 3. HortResearch Client Report No. 93/270. 70 p.

Waddell, B.C., Clare, G.K. and Maindonald, J.H. 1996. Comparative mortality response of two Cook Islands fruit fly (Diptera: Tephritidae) species to hot water immersion. Journal of Economic Entomology. Accepted.

Williamson, M.R. and Winkelman, P. 1994. Heat treatment facilities. In: Paull, R.E. and Armstrong, J.W., eds, Insect Pests and Fresh Horticultural Products: Treatment and Responses. CAB International, Wallingford, Oxon, OX10DE, U.K. 249–271.

Prospects for Generic Quarantine Heat Treatments in the Pacific Region

E.B. Jang[1]

Abstract

Of the many quarantine treatments developed for post-harvest disinfestation of fruit flies, heat treatments appear to meet the needs and requirements of many countries interested in a potential export market for their produce. Among these requirements are: that the treatment be effective, relatively simple and timely, and economically feasible. During the past several years, heat treatments for fruit fly disinfestation have been developed for many types of fruits and vegetables against a number of fruit fly species. In order to expedite the development of heat-based quarantine treatments a world-wide database is being developed which will allow for comparisons of fruit fly thermotolerance using standard test parameters. The database will allow for comparisons between species of fruit flies as well as among different developmental stages and 'strains' of the same species. It is anticipated that this information will be useful to those developing treatments, ensuring that treatments exist in the event of pest introductions and facilitating regulatory decisions which may require scientific data in support of proposed heat treatments.

TEPHRITID fruit flies have had a major impact on agricultural economies where the flies are present. In addition to requiring strict quarantine restrictions in areas where the fly is not present, fruit flies have several secondary impacts where they exist, such as:

- limiting the types of fruits and vegetables which can be grown economically in some areas;
- increasing the amount of pesticides used in pre-harvest production, and
- requiring the development and implementation of post-harvest quarantine treatments to insure that flies do not become established in new areas where host fruits are exported.

The loss of many post-harvest fumigants and the large capital costs needed for the development and registration of new toxic pesticides has resulted in the development of several physical treatments which are based on thermal mortality of the fruit flies (Armstrong 1994). Examples of heat treatments include hot water dips, vapor heat, and high temperature forced air treatments.

Development of heat-based treatments have historically been accomplished empirically and as a result are usually specific for each commodity and fruit fly species tested. Few studies have attempted to compare directly the thermotolerance of different fruit fly species, stages or even strains of the same species from different areas of the world. This is largely due to the fact that no uniformly accepted methodology has been developed to assess thermotolerance. As a result, when a commodity considered for export is found or known to be a host of fruit flies, much time and effort is spent by researchers to determine (empirically) the parameters which will result in effective disinfestation of fruit flies without undue phytotoxicity to the commodity being exported.

The acceptance of standardised methodology for determining effects of heat treatment is not new and has been used in the food industry to determine the proper heat treatment parameters necessary to safely treat processed foods (e.g. canning and pasteurisation) to kill micro-organisms. The system was developed through a basic understanding of thermal kinetics (Stumbo 1973) and has enjoyed an international acceptance.

[1] USDA-ARS, Tropical Fruit and Vegetable Research Laboratory, PO Box 4459, Hilo, Hawaii, 96720, USA

Predictive Models for Understanding Thermotolerance of Fruit Flies

Predictive models can be useful in estimating the initial treatment parameters necessary to kill fruit flies effectively. As in dose-mortality studies using insecticides early predictive models such as probit analysis (Finney 1971) utilised linear modelling of survivorship data to predict the effectiveness of a treatment at a given dose. The use of probit analysis for assessment of efficacy of quarantine treatments was proposed by Baker (1939) who suggested that treatments meeting a probit 9 level of security or 99.9968% mortality would be effective against fruit flies. However, predictive models can also be used to gain a more detailed understanding of how heat treatments affect fruit flies and this knowledge can be used to support trade. Recently, other predictive models such as the thermal kinetic model proposed by Jang (1986) and the complementary log-log function used by Jones et al. (1995) have been used to study how heat treatments used in quarantine treatments affect the insects targeted. In all cases, estimated treatment times needed to achieve a given mortality vary depending on the methodology used to generate the data, the accuracy and variability of the data produced, and the particular function or model used to predict the results.

In order to compare accurately the relative thermotolerance of different fruit fly species, developmental stages and even strains of the same species, one must first standardise the methodology used to develop the thermal mortality data. The insects must be exposed to heat under similar experimental conditions, using insects of a comparable physiological state and using standardised numbers of test insects. Large variations in any of the above parameters can result in variability of the experimental results and difficulty in making valid comparisons.

Experimental conditions such as whether to test the naked fruit fly eggs or larvae or whether to test them in the fruit need to be determined. Testing naked insects reduces the variability encountered when testing in fruit but must be carefully factored into the development of a realistic quarantine treatment where the fruit flies will be in the fruit. Temperature can be tested by exposing the fruit flies to heat at a set temperature (static) or under treatment-like conditions where heat is applied gradually (transient). Both methods have been used to test fruit fly thermal tolerance. The precise methodology used to expose insects to heat can vary tremendously and should be carefully regulated in order to assure comparability of the results. Finally the question of whether to remove the heat after the proper exposure time is reached (cooling down) or to allow the insect to retain heat (latent heat) needs to be consistent. The assessment of effectiveness needs to be standardised in order to ensure uniformity for comparisons. Immediate death (acute mortality) as opposed to failure to pupate or emerge (chronic mortality) should be determined in advance or both types of information developed to compare the effects of heat.

Functional Form of Predictive Models

After all of the experimental work is done it is the functional form of the model which will serve as the basis for any comparison between species, developmental stages, or strains. The functional forms equations used to model mortality in fruit flies should be supported by the data. As mentioned earlier, the probit model was used for many years to fit mortality data of fruit flies without strong justification as to why it was used. Other models which are not dependent on linearisation of the data are more complex but may fit the data better. Thermal kinetic analysis of micro-organisms treated with heat showed that a non-linear function may be better than a linear fit of the data. Jang (1986) showed that fruit fly mortality data also could be fit, using non-linear functions. By comparing data using different functional forms one can see that predictions of mortality can vary widely or be quite similar, depending on the variability of the data and the form of the equation used.

Regardless of the final form used to determine the predictive models, if the data are gathered in such a way as to make the results comparable, any future improvements or revisions of the model can compare the different species, stages, etc., as long as the raw data are available for analysis.

Development of a World-Wide Fruit Fly Mortality Database

The use of standardised methodology to determine the relative heat tolerance of fruit flies from around the world and a central repository for such information accessible to researchers and regulatory agencies could vastly streamline the research needed to support heat-based quarantine treatments, provide regulatory agencies with comparable data from which to make informed decisions relative to the effectiveness of proposed quarantine treatments, and prevent the sudden and economically devastating losses that might occur as a result of the introduction of new fruit fly species into areas where the flies had not previously existed. Such a database would

facilitate trade and at the same time ensure that costly quarantines would be minimised. Two examples of the usefulness of such a database are described:

Example 1: emerging economies

If country A (in which fruit flies are present) desires to export its commodities to country B which is accepting similar commodities from country C (which also has fruit flies) assessment of the thermal tolerance of the fruit flies could result in acceptance of fruit by country B from country A if it can be shown that the species of fruit fly in country A is less tolerant to heat than country C and the treatment utilised successfully by country C is used by country A.

Example 2: exotic pest invasions

If country C which currently exports its prized fruits to country B using an approved quarantine treatment were to suddenly find that fruit flies from country A have invaded, it is likely that country B would immediately initiate a quarantine against the importation of fruit from country C. Such a quarantine could have a severe economic impact on growers. If it could be shown that the fruit fly species in country A were less tolerant to heat that the species in country C, the existing treatment for country C may be sufficient to disinfest fruits of the newly introduced species, thus preventing a costly shutdown.

The use of predictive models for estimating fruit fly disinfestation can be expanded to include estimates of fruit quality as well (Jang and Chan 1993; Laidlaw et al. 1996). Such predictive tools may enable researchers to expand beyond empirical approaches to more scientifically-based information needed to accurately develop quarantine systems for exports.

References

Armstrong, J.W. 1994. Heat and cold treatments. In: Paull, R.E. and Armstrong, J.W., eds, Insect Pests and Fresh Horticultural Commodities. CAB International, Wallingford UK, 103–119.

Baker, A.C. 1939. The basis for treatment of products where fruit flies are involved as a condition of entry into the United States. USDA Circular 551, Washington DC.

Finney, D.J. 1971. Probit Analysis. Third edition. Cambridge University Press, UK.

Jang, E.B. 1986. Kinetic of thermal death in eggs and first instars of three species of fruit flies (Diptera: Tephritidae) J. Econ. Entomol. 79: 700–705.

Jang, E.B. and Chan, H.T. 1993. Thermal death kinetics: Importance in development of heat-based quarantine treatments. In: Aluja, M. and Leido, P., eds, Fruit Flies: Biology and Management. Springer-Verlag, NY, 345–351.

Jones, V.M., Waddell, B.C. and Maindonald, J.H. 1995. Comparative mortality responses of three tortricid (Lepidoptera) species to hot water. J. Econ. Entomol. 88: 1356–1360.

Laidlaw, W.G., Armstrong, J.W., Chan, H.T. and Jang, E.B. 1996. The effect of temperature profiles in heat treatment disinfestation on mortality of pests and on fruit quality. In: Vijaysegaran, S., Pauziah, M., Mohamed, M.S. and Tarmizi, S., eds, Proceedings of the International Conference on Tropical Fruits, Kuala Lumpur Malaysia, 343–352.

Stumbo, C.R. 1973. Thermobacteriology in Food Processing. Second edition. Academic Press, NY.

The Eradication Program for Papaya Fruit Fly (*Bactrocera Papayae* Drew and Hancock) in North Queensland

H.A.Fay[1], R.A. Drew[2] and A.C. Lloyd[3]

Abstract

Bactrocera papayae Drew and Hancock, a species in the Oriental fruit fly complex, was bred out of papaya from a farm near Cairns in mid-October 1995. A quarantine area of about 75 000 km^2 was subsequently declared, roadblocks set-up near its southern and western boundaries and fruit treatment protocols established. Within two days of identification, 286 methyl eugenol traps were laid out to 70 km north, 150 km south and 80 km west of Cairns. Initial trap catches suggested that Cairns (79% of flies), Mareeba (14%) and Mossman (3.5%) were the main fly foci. Soon after suppression treatments commenced in mid-November, *B. papayae* had been detected over almost 10 000 km^2.

Male annihilation has been the principal method of control, with 5 cm^2 canite blocks each receiving 15 g methyl eugenol and 5 g maldison ULV. Over 1 million blocks had been nailed to trees by October 1996, with areas reblocked at six week intervals. Limited protein-bait spraying of known fruiting hosts and breeding hot spots has also been used. Suppression treatments have resulted in trap catches falling by more than 99% throughout the detection area from peak levels in November. During this period trap numbers have increased to >1400. Percentage positive traps in the quarantine area have fallen from a high of 23% to <0.2%/week. Extensive sampling has failed to detect *B. papayae* in fruit in rainforest, despite the collection of males in some rainforest traps. Of other fruits sampled, 32 out of >200 spp. produced *B. papayae* (3.1% of samples). Twenty-six million dollars will have been invested against this fly by June 1997.

Detection and Initial Response

Bactrocera papayae, an economic species in the Oriental fruit fly complex, was first detected in Australian territory on Boigu and Darnley Islands in Torres Strait in March 1993. There were no detections on the Australian mainland until October 1995, when flies were bred from papaya off a farm just east of Cairns. Species identification was confirmed by Drew and Hancock in Brisbane on 17 October 1995, and a taskforce was established to co-ordinate a response.

Traps were immediately deployed at 5 km intervals to 70 km north, 150 km south and 80 km west of Cairns. A quarantine area of 20 km radius around the Cairns post office was declared to regulate the movement of fruit and vegetables. On 26 October 1995 a Pest Quarantine Area (PQA) was legislated, bounded in the west by longitude 144° 15′E and in the south by latitude 18°20′S. This allowed the enforcement of 80 km (subsequently 50 km) radius Suspension Zones around fly detection points and the use of roadblocks. Within these zones fruit had to be dipped, fumigated, otherwise treated or declared 'host free' if moving beyond the PQA boundaries. On 27 October 1995 roadblocks to control fruit movement were established near Silkwood, south of Cairns, and near Mt Garnet, towards the western edge of the PQA. The southern roadblock was subsequently re-located further south at Rollingstone when the southern PQA boundary was realigned at 19°S (Fig. 2). An extensive public awareness/information campaign was launched involving TV and radio interviews and advertisements, roadsigns, handouts at DPI offices, shopping centres and airports, wide newspaper coverage and fruit producer gatherings. A free telephone hotline was set up to handle all manner of enquires, including fruit

[1] Queensland Dept. Primary Industries, Mareeba Q. 4880
[2] Faculty of Environmental Sciences, Griffith Universty, Nathan Campus, Qld, 4111
[3] Queensland Dept. of Primary Industries, Indooroopilly, Qld, 4068

treatment and certification requirements. Some preliminary discussions were undertaken with various environmental agencies to address concerns about this fly and the likely treatments needed for its containment and /or eradication. The eradication campaign commenced in Mareeba (west of Cairns) on 16 November 1995.

Containment/Eradication Methods

Male annihilation has been the principal control method in which 5 cm^2 canite blocks (each containing 15 g methyl eugenol and 5 g maldison ULV) have been nailed to trees with a target intensity of 400 per km^2 in rural areas up to 600 per km^2 in urban centres. Areas which are currently not treated include most world heritage rainforest, sugarcane, swamp and open grazing. Reblocking occurs at 6 week intervals, although where recoverable, blocks are left in place for 12 weeks.

Treatments were first applied in Mareeba, Mossman and the greater Cairns area, as 96.5% of flies were trapped in these areas in the first month. Most other detections or high risk areas have subsequently been treated, with priority initially based on four *B. papayae* (PFF) in a single trap within two consecutive trap clearances. Dispersal protection barriers (1 km wide) containing blocks were also put in place south of Cairns near Deeral, Bingil Bay/El Arish and Kennedy/Cardwell.

Limited protein bait spraying has also been used, and has intensified as the control program has progressed. Sprays contain 2.5% (initially 5%) yeast autolysate and 2% maldison 500 EC per 100 L of mix, and are applied in 100 mL spots (of up to four per tree) to the undersides of leaves of fruiting trees at weekly intervals while fruit is susceptible. They have been applied in non-commercial fruit growing situations in all blocking areas, particularly targeting 'hot spots' and specific hosts (mangoes, guavas etc). Additional recent treatments have concerned commercial coffee crops near Mareeba in which PFF have been breeding. Coffee has few insect problems and generally receives no pre-harvest insecticides in north Queensland.

Planning has been initiated on the Sterile Insect Technique (SIT) in case it needs to be implemented should male annihilation fail as an eradication tool. A decision on this option will be taken sometime after the 1996/97 summer fruiting season. A colony of PFF currently used for post-harvest research in Cairns would provide the core of the SIT colony.

Monitoring in the PQA

An extensive network of methyl eugenol (ME) baited traps and a fruit sampling program are relied upon for PFF detection and to measure control treatment impact. Steiner or Lynfield traps have been placed out on a 1 km grid basis in most eradication areas, and at 5 km intervals through intervening areas, reaching 10 kms in very remote areas or in temporary trapping lines. In addition, 1–4 traps have been placed on particular farms or in remote towns/ islands. Trapping occurs in all areas except inaccessible or treeless ones. Traps are cleared weekly, with lures changed monthly. In the PQA 13 tephritid species are attracted to methyl eugenol, but only four commonly. The maximum weekly catch per trap of all species is about 4000 flies.

Both cultivated and rainforest fruits have been collected in the fruit sampling program. Some other fruits have also been targeted, such as *Terminalia* spp. and feral guavas. Collections initially focused on trapping 'hot spots' but have since become systematic through all areas. In addition, fruit from more than 100 markets are sampled per month because of the large quantities of organically-grown produce sold. Rainforest fruits were extensively sampled along 11 transects north and south of Cairns between January and June. Some revision of these transects occurred in July, which saw the current emphasis placed on rainforests north of Cairns. All sampled fruits are held in gauze-topped containers over heat-treated saw dust using standard procedures to recover adult flies for identification.

Data Management

GPS (Global Positioning System) readings are used to accurately identify trap locations for mapping, eradication and regulatory purposes. Fruit collections are linked to trap locations or map co-ordinates derived from 1:50000 topographical maps. All trap locations and fly catch data are entered onto an Access database, with a separate fruit collection/fly emergence database in R-base. These databases, plus another in Access containing canite block numbers and protein bait spraying details, are linked using ArcView mapping software to provide accurate geographic information.

Some Program Statistics

The PQA covers approximately 75 000 km^2. Since its detection in October 1995, *B. papayae* has been trapped over about 20 000 km^2.

By 1 October 1996, 1 077 737 canite blocks had been placed on trees and 13 269 litres of protein bait spray used. Over 220 personnel are involved in the program, including 125 applying the control measures. An additional 200 or so casual inspectors have monitored commercial fruit treatments. Some 65

vehicles and 26 motor bikes are being used. By October 1996 three permanent roadblocks were operating (with another planned for November) with others deployed intermittently. The largest roadblock at Rollingstone was processing about 70 000 vehicles/ month, with around 1500 kg of fruit /month confiscated at all points. Although the horticultural industry within the PQA was largely continuing to trade beyond its boundaries over $100 million has been lost to the region due to the incursion of PFF. The program against *B. papayae* was projected to cost $26 million to June 1997, of which $19 million was to be contributed by the various State and Commonwealth Governments through the Standing Committee on Agriculture and Resource Management.

Monitoring Results

More than 1400 ME traps had been deployed in the PQA by October 1996, with trap numbers increasing constantly to enhance coverage. Traps had caught 8421 *B. papayae* by 1 October 1996, with 816 recorded from a single trap near Cairns. The number of PFF positive traps peaked in December 1995 at 254, dropping to 6 by September 1996 (Fig. 1). The respective numbers of PFF trapped for these months were 2540 and 10, a change of >99.5%. There have only been two single fly detections outside the PQA, at Gumlu in the Burdekin region south of Townsville in February and at Mt Isa in the north-west of Queensland in May.

Despite analyses showing about a 15% increase in PFF spread in the PQA since control treatments commenced, the trapping data also indicate significant clustering of detections. In fact, Cairns and Mareeba have contributed around 50% or more of positive traps through the entire program. Figure 2 shows some changes in the distribution of positive traps over time. Notable is that the coastal area south of Cairns has had no PFF detections between late June and October.

PFF infested fruit has been sampled from an area of about 7500 km^2 (or about 37.5% of the trap detection area). There have only been four single fruit detections south of the Cairns and Mareeba areas, and none since the end of February. By 1 October 1996 samples of rainforest, cultivated and other fruits numbered 13 094, representing more than 675 plant species (Table 1). While no fruits collected in rainforest have produced PFF, a native rainforest species *Eugenia reinwardtiana* (Beach cherry) growing in a rural residential area at Oak Beach produced PFF in October 1996. Table 1 provides a breakdown of PFF infestation levels for cultivated and other fruits, and some details of other fruit fly species.

Table 1. A summary of fruit sampling in the PQA to October 1996, including recovery levels for *B. papayae* and other fruit fly (ff) species.

	Rainforest fruits	Cultivated + other fruits		
Fruits				
No. samples	7640	5454		
Species no.	475	> 200		
Flies				
PFF +ve samples	0%	3.1%		
Other ff present	24 spp.	20 spp.		
Fruits		Terminalia	Guava	Other
Propn. of samples	—	7.5%	7.8%	84.7%
Flies				
PFF +ve samples	—	7.8%	4.5%	2.5%
Other ff present	+/–1%	52%	53%	65%

The following is a list of 28 fruit hosts for PFF recorded from the field in Australia to October 1996: Abiu, Banana, Beach cherry, Brazil cherry, Bush lemon, Canistel, Capsicum, Carambola, Cashew apple, Chilli, Coffee, Cumquat, Guava, Grapefruit, Jaboticaba, Malay apple, Mango, Meyer lemon, Papaya, Passionfruit, Peach mango, Pummelo, Santol, Soursop, Star apple, *Terminalia catappa*, Tomato, White sapote.

Future Developments

1. Fruit sampling within eradication areas will become the main means for detecting PFF, as trap effectiveness will diminish as male annihilation treatments continue. At this stage in the campaign, locating all PFF breeding sites over such a vast area is one of the most difficult tasks.
2. If areas to the south of Cairns remain PFF-free over the 1996/97 summer period, protocols will be developed to establish Area Freedom, which may then lead to a retraction of the most southerly roadblock and/or a change in the southern boundary of the PQA.
3. Very low numbers of PFF in a handful of clustered traps, with minimal detections in fruit through the 1996/97 fruiting season, will likely see a delay in a decision on SIT and a continuation of the male annihilation program.
4. A revelation of PFF breeding in rainforest or an increase in PFF numbers and breeding sites through the 1996/97 summer season will warrant support for a SIT program.

National and Regional Needs for Future Activities on Fruit Flies (Diptera: Tephritidae) in the Pacific Region

A.J. Allwood[1] and R.A.I. Drew[2]

THE combined efforts of the FAO/AusAID/UNDP/SPC Regional Fruit Fly Project, the ACIAR-funded projects and the USAID's Commercial Agricultural Development Project have vastly improved the technical knowledge on fruit flies in Cook Islands, Federated States of Micronesia (FSM), Fiji, Solomon Islands, Vanuatu and Western Samoa. The awareness of the enormity of the fruit fly problem regionally has created interest in understanding and managing representatives of the Tephritidae in almost all countries in the south Pacific region. The advantages of knowing the fruit fly fauna in each country, their host ranges, the economic significance of the species, their seasonal abundances, the effects of parasitoids on populations, and the stages of maturity at which fruits and vegetables become susceptible, becomes obvious when countries wish to negotiate quarantine protocols with with importing countries.

Having environmentally sound, inexpensive field control systems based on bagging of fruits, harvesting at stages of maturity when fruits are not susceptible to fruit fly attack, sound crop hygiene, and protein bait sprays also gives importing countries a degree of confidence in the standard of management of fruit flies. Ultimate confidence occurs when countries have developed acceptable quarantine treatments based on area of freedom, non-host status or forced hot air or hot water immersion treatments and these systems withstand scrutiny by quarantine officials from importing countries.

All of this effort may be placed in jeopardy unless permanent quarantine surveillance systems using trapping and host surveys and emergency response plans are in place in all exporting countries. A catch cry of 'No quarantine surveillance, no overseas trade' adopted by some countries in the Pacific region is very appropriate.

Some countries in the Pacific region have made enormous strides in understanding and managing their fruit fly problems. Others, however, have not started to address the problem. Regionally, advances have been made, but there are still significant gaps in knowledge and technologies to control this pest group. This paper attempts to identify some of the deficiencies and the options to overcome them. This list of activities was developed as part of the general discussion session during the symposium and was gleaned from discussions and questions posed during the course of the symposium. In this context, the topics raised reflect the needs identified by participants and countries.

[1]Regional Fruit Fly Project, South Pacific Commission, Suva, Fiji
[2]Faculty of Environmental Sciences, Griffith University (Nathan Campus), Brisbane

Regional Approach to Management of Fruit Flies

There are about 4500 species of fruit flies worldwide. Of these, 50 species are categorised as major pests of fruits and vegetables and another 30 species are regarded as minor pests. Of the 50 major pest species, 22 occur in countries and territories in the Pacific region. In comparison, Southeast Asia has 12 of the 50 species, the Indian sub-continent has 10 species and Africa has 11 species. Some species are common to more than one region of the world.

Fruit flies are very mobile and are notable for their ability to breach quarantine barriers. Examples of fruit flies being recently introduced and becoming established in new countries or areas of the south Pacific region are:

- Oriental fruit fly (*Bactrocera dorsalis* Hendel) and melon fly (*Bactrocera cucurbitae* Coquillett) became established in Nauru probably from Taiwan in the late 1980s.
- Papaya fruit fly (*Bactrocera papayae* Drew and Hancock) spread from Indonesia through PNG in 1989–92 and to the Torres Strait islands and the Cairns area of Queensland in about 1993.
- Melon fly became established in the Western Province of Solomon Islands from PNG in 1984–1985.
- Melon fly spread through the Western Province and other northern and central provinces of Solomon Islands, arriving in Guadalcanal in November, 1995.

- Melon fly spread from PNG into the Torres Strait islands in early 1996.
- Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) introduced into Auckland, New Zealand probably from Hawaii in April, 1996.
- Oriental fruit fly introduced and became established in Tahiti and Moorea in late 1995 or early 1996.
- Oriental fruit fly recorded in Palau in October, 1996.

As well as these incursions, there have been fruit flies intercepted in fruits disposed of in amnesty bins at international airports, e.g., Queensland fruit fly (*Bactrocera tryoni* Froggatt), papaya fruit fly and *Bactrocera passiflorae* (Froggatt) in New Zealand. Also, exotic fruit flies have been recorded in quarantine surveillance traps in some countries, e.g., melon fly in a Cue-lure trap in Perth, Western Australia.

These occurrences clearly show that fruit flies are moving across quarantine borders. The only way to tackle this problem is to adopt a regional approach to managing fruit flies. This approach should:

- expand quarantine surveillance, using trapping and host surveys;
- strengthen quarantine capacity across the region;
- conduct training on pest risk analysis;
- ensure existing data on fruit flies are readily available to all countries;
- provide training for farmers and exporters on field control; and
- develop a database on the thermo-tolerances of immature stages of fruit flies, with the view of formulating a generic quarantine heat treatment.

Training, and Development of Quarantine Procedures

Because of the risk of incursions of exotic economically important fruit fly species increasing with greater movement of tourists and other travellers, quarantine expertise needs to be regularly upgraded. Topics for training and development need to include:

- early warning systems (quarantine surveillance systems);
- development and documentation of emergency response capacity in each country;
- border quarantine;
- internal quarantine; and
- expansion of surveys for fruit flies in PNG, Solomon Islands and Vanuatu.

Specific Taxonomy Training Workshops

Plant protection, quarantine and extension officers must be familiar with the fruit fly species that occur in their respective countries and the symptoms of damage caused by them. They must also be familiar with exotic species of fruit flies. To achieve this level of expertise, a series of taxonomy workshops at a sub-regional or national level needs to be held. Four workshops will cover the following countries:

- PNG, Solomon Islands, Vanuatu;
- French Polynesia, New Caledonia and Wallis and Futuna;
- Cook Islands, Fiji, Tonga, Western Samoa, American Samoa, Niue, Tuvalu, Tokelau, Nauru;
- Palau, Guam, Commonwealth of the Northern Mariana Islands, Federated States of Micronesia, Marshall Islands and Kiribati.

Protein Bait Spray Technology

The effectiveness of protein bait sprays needs to be improved to cope with high incidence and intensity of rain during the summer months and periods when high populations of fruit flies occur. This may be achieved by investigating the application methods, the formulation, rates of application and the use of thickeners or stickers to reduce the losses during heavy rainfall.

Eradication Techniques

Staff from all countries recognised the need to be exposed to hands-on training in eradication techniques. In Nauru, Oriental fruit fly, a fly attracted to methyl eugenol, and melon fly, a fly attracted to Cue-lure, have been recorded. The opportunity is available to eradicate both species to reduce risk of spread to other countries in the Pacific region. Also, the eradication effort could be carried out by plant protection or quarantine staff from other countries, who will gain hands-on experience in eradication techniques. An alternative may be to use French Polynesia, which is conducting a very large eradication program for Oriental fruit fly, using a combination of male annihilation, protein bait spraying and fruit destruction.

Fruit Flies in PNG

PNG has at least 180 species of fruit flies of which 10–12 species are of economic importance. The risk of some of these species spreading into Australia, through Solomon Islands and Vanuatu, and to other Pacific island countries is quite high. For this reason, it is necessary to expand project activities to:

- understand the PNG fruit fly fauna;
- elucidate the pest status of the species present;
- review and enhance quarantine systems;
- transfer field control technology; and
- generate heat tolerance data for immature stages of the economically important species.

Standardisation of Methodologies

Assuming that there is a willingness to develop generic quarantine treatments for fresh fruits and vegetables across the Pacific region, it is necessary to standardise techniques used in generating data. Standardisation of the following need to be addressed:

- laboratory rearing techniques;
- heat tolerance testing procedures;
- techniques for assessment of egg and larval mortality; and
- statistical methods for treatment of data.

Estimations of the Value of Production at All Levels and Losses due to Fruit Flies

There are adequate data on the value of export markets for fresh fruits and vegetables and the possible losses caused by fruit flies to these commercial crops. However, there is inadequate information on the real value of horticulture production at all levels (subsistence, backyard, small-scale and large-scale commercial production). Because this information is not available, it is not possible to estimate the dollar value of losses caused by fruit flies in Pacific island countries. A consultant should be engaged to generate these data.

Linkages with Southeast Asia

The regional approach being adopted by the Regional Fruit Fly Project should take into account what is happening in Southeast Asian countries such as Indonesia, Malaysia, Philippines, Thailand, Vietnam, Taiwan and China. Linkages through FAO and ACIAR should be fostered. Involvement in the PEACESAT 'FLYNET' program in the Pacific region should be encouraged.

Integrated Pest Management

Future efforts in fruit fly management should highlight the focus on integrated pest management systems being utilised in the Pacific region. Certainly, if cooperation in Southeast Asia is being fostered, emphasis will have to be placed on an integrated approach to control.

Stockpile of Chemicals and Supplies for Eradication Programs

One of the major difficulties in improving preparedness for eradication programs for exotic fruit flies is to overcome funding shortages to procure and store emergency supplies of attractants, traps, protein autolysate, and other supplies by national governments. One option is for a regional organisation or a country like New Zealand to build-up and hold stocks of essential materials that would allow Pacific island countries to commence an eradication program as soon as an incursion or outbreak has been confirmed. The use of stockpiled materials would be on the basis of replacement.

Pacific Fruit Fly Newsletter

Communication between Pacific island countries on fruit fly occurrences, outbreaks, new techniques, new records and results of quarantine surveillance or eradication programs would enhance the effectiveness of the regional approach that is being adopted. Regular and transparent exchange of information will help all workers on fruit flies. One way to do this is to compile a six-monthly newsletter with inputs from as many countries as possible in the Pacific region and Southeast Asian area. Professor Drew has offered to provide an Editor.

Conclusion

This listing of deficiencies is not exhaustive, but it highlights the needs of the Pacific island countries as seen by the participants at this symposium. Many of these topics or activities have been included in the Regional Fruit Fly Project funded by UNDP and AusAID and the projects funded by ACIAR. Consequently, they should be addressed during the next three years of fruit fly activities in this region.

List of Participants for Symposium on Fruit Flies 28–31 October, 1996

Mike Ahern
Guest Speaker, Crawford Fund,
PO Box 458, Caloundra,
Queensland, Australia
Phone: 61 7 54917645
Fax: 61 7 54917826

Lloyd Ali
Associate Researcher — Entomology,
ASCC Land Grant Program,
PO Box 5319 Pago Pago 96799,
American Samoa
Phone: 684 6991394
Fax: 684 6995011

Allan Allwood
Chief Technical Adviser,
Regional Fruit Fly Project,
South Pacific Commission,
Private Mail Bag
Suva
Phone: 679 400344
Fax: 679 322800
E-mail: allwood@is.com.fj

Remy Amice
Plant Protection Officer,
Direction de l'Agriculture et de la Foret,
BP256, 98845 Noumea Cedex
New Caledonia
Phone: 687 274102
Fax: 687 251112

Shirley Antrea
Project Assistant,
Regional Fruit Fly Project,
South Pacific Commission,
Private Mail Bag,
Suva
Phone: 679 400344
Fax: 679 400262/679 322800

Jack Armstrong
Research Entomologist — Quarantine Treatments,
Tropical Fruit & Vegetable Research Laboratory,
US Dept. Agriculture — Agricultural Research Service,
PO Box 4459,
Hilo, Hawaii, 96720
USA
Phone: 1 808 9594336
Fax: 1 808 9594323 or 9595470
E-Mail: jwa@aloha.net

Apenisa Balawakula
Technician,
Ministry of Agriculture, Fisheries, Forestry & ALTA,
Koronivia Research Station,
PO Box 77
Nausori, Fiji
Phone: 679 477044
Fax: 679 400262

Richard Drew
Faculty of Environmental Sciences,
Griffith University,
Nathan Campus,
Brisbane 4111
Queensland, Australia
Phone: 61 7 38753696
Fax: 61 7 38753697
E-mail: D.Drew@ens.gu.edu.au

Crispina Fakanaiiki
Senior Plant Protection & Quarantine Officer,
Department of Agriculture, Forestry & Fisheries,
PO Box 74, Alofi
Niue Island
Phone: 683 4032
Fax: 683 4079

Paul Ferrar
Research Program Co-ordinator (Crop Sciences),
ACIAR, GPO Box 1571,
Canberra, ACT 2601
Australia
Phone: 61 2 62170500
Fax: 61 2 62170501
E-mail: ferrar@aciar.gov.au

Sione Foliaki
Quarantine Entomologist,
Ministry of Agriculture — Tonga
Tonga
Phone: 676 24257
Fax: 676 24922/24271

Ruth Frampton
National Advisor (Plant Pest Surveillance and EDPR),
Ministry of Agriculture,
MAF Regulatory Authority,
PO Box 24, Lincoln
New Zealand
Phone: 64 3 3253924
Fax: 64 3 3253919
E-mail:
framptonr@lincoln.mqm.govt.nz

Wesley Garnett
Area Director — APHIS — International Service,
US Embassy — Canberra,
1 Moonah Place,
Yarralumla ACT 2600
Australia
Phone: 61 2 62705820
Fax: 61 2 62733334
E-Mail: USDA.APHIS.IS@cs.net.au

Eddy Hamacek
Technical Officer,
QDPI, Entomology Building,
80 Meiers Rd, Indooroopilly 4068
Queensland
Australia
Phone: 61 7 38969369
Fax: 61 7 38969600
E-mail: hamacee@dpi.qld.gov.au

Viliami Heimoana
Entomologist — In charge of Fruit Fly Project,
Research Division,
Ministry of Agriculture & Forestry,
PO Box 14, Nuku'alofa
Tonga
Phone: 676 32125
Fax: 676 32132

Sailas Henry
Adm. Div. of Agriculture,
Dept of Resources & Development,
PO Box PS12, Palikir,
Pohnpei, 96941
FSM
Phone: 691 3202697
Fax: 691 3205854

Robert Hollingsworth
United Nations Volunteer Entomologist,
Regional Fruit Fly Project/UNDP,
PO Box R-20, Ranadi
Solomon Islands
Phone: 677 31111 (w) 31012 (h)
Fax: 677 31007

Eric Jang
Research Scientist, USDA-ARS,
PO Box 4459, Hilo, Hawaii 96720
USA
Phone: 1 808 9594340
Fax: 1 808 9595470
E-mail: jang@aloha.net

Luc Leblanc
UNV Entomologist.
Regional Fruit Fly Project.
Department of Resources and Development.
PO Box PS12, Palikir, Pohnpei, 96941
FSM
Phone: 691 3202697
Fax: 691 3205854

Losalini Leweniqila
Graduate Trainee (Entomologist),
Ministry of Agriculture, Fisheries, Forestry & ALTA,
Koronivia Research Station,
PO Box 77, Nausori, Fiji
Suva
Phone: 679 477044
Fax: 679 400262

Peter Lynch
Publications Manager ACIAR,
ACIAR,
GPO Box 1571, Canberra ACT 2601
Australia
Phone: 61 2 62170534
Fax: 61 2 62170501
E-Mail: lynch@aciar.gov.au

Atoloto Malau
Agricultural/Plant Protection Officer,
Service de l'Economie Rurale, BP19
Wallis & Futuna
Phone: 681 722823
Fax: 681 722544

Andrew McGregor
Director,
Trade & Development Office,
PO Box 2413, Government Buildings
Suva
Phone: 679 305844
Fax: 679 305668
E-Mail: mcgregor@kula.usp.fj

Sam Panapa
Plant Protection Officer,
Tuvalu Government,
Agriculture Dept.,
Nanumaga Is.
Tuvalu
Phone: 688 203002
Fax: 688 2033001

Albert Peters
Biological Control Adviser,
South Pacific Commission,
Private Mail Bag,
Suva, Fiji
Phone: 679 370733
Fax: 679 370021

Bernard Pilon
Plant Protection Training Officer,
South Pacific Commission,
Private Mail Bag,
Suva, Fiji
Phone: 679 370733
Fax: 679 370021

Matairangi Purea
Director of Research,
Ministry of Agriculture,
PO Box 57, Rarotonga
Cook Islands
Phone: 682 28720
Fax: 682 29719

Rudolph Putoa
Entomologist,
Service du Developpement Rural,
BP100 Papeete,
Tahiti
Phone: 689 574004
Fax: 689 574690

Laisa Ralulu
Agricultural Assistant,
Regional Fruit Fly Project,
Ministry of Agriculture, Fisheries, Forestry & ALTA,
Koronivia Research Station,
PO Box 77, Nausori, Fiji
Phone: 679 477044
Fax: 679 400262

Meredith Romig
Senior Research Assistant,
Faculty of Environmental Sciences,
Griffith University,
Nathan Campus, Brisbane 4111
Queensland, Australia
Phone: 61 7 38753696
Fax: 61 7 38753697
E-mail: M.Romig@ens.gu.edu.au

Frederic Sales
Entomologist CIRAD,
BP32 LAFOA,
New Caledonia
Phone: 687 443088
Fax: 687 443094

Gerard C.U. Schulten
Senior Officer (Entomology),
Food and Agriculture Organisation of the United Nations (FAO),
Viale delle Terme di Caracalla,
Rome 00100
Italy
Phone: 39 6 57053551
Fax: 39 6 57056397
E-mail: Gerardus Schulten@fao.org

David Tau
Plant Protection Officer,
Regional Fruit Fly Project,
Agriculture Department & Horticulture,
PMB 040, Port Vila
Vanuatu
Phone: 678 26585

David Tenakanai
Entomologist,
Department of Agriculture & Livestock,
PO Box 417, Konedobu
PNG
Phone: 675 3281068
Fax: 675 3281075

Nakabuta Teuriaria
Plant Protection Officer,
Ministry of Natural Resources,
Division of Agriculture,
PO Box 267, Bikenibeu, Tarawa
Kiribati
Phone: 686 28108
Fax: 686 28121

Elisapeta Toleafoa
Senior Quarantine Officer,
Department of Agriculture,
American Samoa Government,
Pago Pago, American Samoa 96799
American Samoa
Phone: 684 6999119
Fax: 684 6994031

Francis Tsatsia
Assistant Research Officer — Entomology,
Dodo Creek Station,
Ministry of Agriculture & Fisheries,
PO Box G13, Honiara
Solomon Islands
Phone: 677 31111
Fax: 677 31037

Timothy Tumukon
Assistant Plant Protection Officer,
Vanuatu Plant Quarantine and Inspection Service,
Dept. Agriculture & Horticulture,
PMB 040, Port Vila
Vanuatu
Phone: 678 26585

Fa'alelei Tunupopo
Research Assistant,
Regional Fruit Fly Project
Western Samoa
Phone: 685 23416/20605
Fax: 685 23426

Maclean Vagalo
Senior Entomologist,
Research Department,
Dodo Creek Station,
Ministry of Agriculture & Fisheries,
PO Box G13, Honiara
Solomon Islands
Phone: 677 31111
Fax: 677 31037

Richard Vickers
Research Scientist,
CSIRO/Entomology,
PB3 Indooroopilly, Queensland 4068
Australia
Phone: 61 7 3214 2824
Fax: 61 7 32142885
E-mail: rvickers@brs.ento.csiro.au

S. Vijaysegaran
Assistant Director, MARDI,
GPO Box 12301,
50774 Kuala Lumpur
Malaysia
Phone: 603 9437267
Fax: 603 9487590
E-mail: svijay@mardi.my

Ema Tora Vueti
Research Officer,
Ministry of Agriculture, Fisheries,
Forestry & ALTA,
Koronivia Research Station,
PO Box 77, Nausori,
Fiji
Phone: 679 477044
Fax: 679 400262

Barbara Waddell
Scientist, Market Access Science,
Mt. Albert Research Centre,
120 Mt. Albert Road,
Private Bag 92169, Auckland
New Zealand
Phone: 64 9 8493660
Fax: 64 9 8154239
E-mail: bwaddell@hort.cri.nz

Graham Walker
Entomologist,
Crop & Food Research,
Mt. Albert Research Centre,
120 Mt. Albert Road,
Private Bag 92169, Auckland
New Zealand
Phone: 64 9 8493660
Fax: 64 9 8154201
E-mail: walkerg@crop.cri.nz