

# Chinese Cabbage Management before and after Harvest

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## Abstract

Chinese cabbage (*Brassica rapa* var. *pekinensis*) cv. 'Yuki' was grown, harvested and stored under various conditions to optimise postharvest quality. Transient water stress, achieved by rewatering when tensiometer readings declined to  $-35$  to  $-40$  kPa (no stress),  $-55$  to  $-60$  kPa (medium stress) or  $-75$  to  $-80$  kPa (high stress), had no effect on water status, trimming loss, quality or sugar levels; neither did the time of day at which harvesting occurred, from dawn to dusk, influence these parameters. This was because of the protection provided by the wrapper and coarse outer leaves; temperature fluctuations were 150% higher in those leaves than the insulated head. Minor cooling delays of 0.5 hours in the field did not affect quality.

Postharvest changes in heads stored for up to 3 weeks at 20°C or up to 9 weeks at 0°C or 2°C were mainly a result of water loss and microbial infections on outer leaves, the base, and wound sites, resulting in trimming losses. Chlorophyll breakdown was a minor issue, as inner leaves contain little and outer leaves also generally showed other deteriorative symptoms as well. Postharvest disorders occurred, especially patchy papery necrosis (PPN). PPN was identified as a form of chilling injury; its incidence was most severe during storage at 0°C, little was found at 2°C, and none at 20°C. Injury induced through compression (under 3 kg for 42–48 hrs), dropping (twice from 50 cm), and repeated trimming, compared with not handled heads, induced little product failure such as splitting and did not produce any observable physiological differences. The only exception was that repeatedly trimmed heads produced much less ethylene, as senescing and rotting outer leaves were not present. However, this did not result in different quality or reduced trimming losses at the end of 9 weeks storage.

CHINESE cabbage (*Brassica rapa* var. *pekinensis*) is a relatively non-perishable crop that can be stored for 3 months or more under ideal conditions (Schouten 1985; Wang 1985). The respiration rate of Chinese cabbage is considered low (Zong and Morris 1986). Under long-term storage or unfavourable conditions, Chinese cabbage is prone to ethylene-induced leaf abscission (Wang 1985), petiole spotting, also known as gomasho, black fleck, or vein necrosis (Phillips and Gersbach 1988; Mathiassen 1986), rots (Peters et al. 1986; Pelleboer and Schouten 1984), and weight loss (Yong et al. 1993).

The final quality and storage life of Chinese cabbage is heavily dependent on a number of growing practices and selection of appropriate cultivars. The

main growing-related disorders are tipburn, bolting, and gomasho (Daly and Tomkins 1997). Control of these disorders is in part by using resistant varieties and in part by using appropriate cultural techniques (Daly and Tomkins 1997).

Bolting is avoided by not growing in low temperatures, using plastic row covers (Daly and Tomkins 1997), or maintaining above 18°C the temperature at which seedlings are raised (Wiebe 1990). Gomasho is promoted by high nitrogen (N) application (especially ammonium nitrate) in the field and may be reduced by harvesting in warm weather when N turnover is highest (Mathiassen 1986). It is also exacerbated by a pH of 8 or above, high levels of phosphorus (Phillips and McKay 1989) and high tissue copper and low tissue boron levels (Phillips 1990). However, Phillips and Gersbach (1988) found that cultivar selection may have a bigger effect, as some cultivars, e.g. 'Kasumi 11', 'Hong Kong', and 'Orient Express', were very

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sensitive to this disorder, while others, e.g. 'China Pride' and 'Treasure Island', showed good tolerance at low temperatures. Proper storage conditions, as outlined below, are also important to retard the development of symptoms.

Tipburn is caused by poor translocation of calcium into the young, inner leaves and is associated with rapid growth and high transpiration through the outer leaves that reduces root pressure loading of calcium into the inner leaves (Daly and Tomkins 1997). It may also be caused by the developing floral parts after vernalisation competing for the available calcium (Pressman et al. 1993). Soluble calcium content was reduced in plants that were root growth restricted (Aloni 1986). Increased N fertilisation, regardless of type, reduced tipburn in one study (Vavrina et al. 1993), but Tao et al. (1986) found that ammonium toxicity may be responsible for tipburn when applied during head formation (Anon. 1984). Control of tipburn can be achieved also by increasing the humidity at night by spraying water or by using plastic covers (Guttormsen 1985); this reduced outer leaf transpiration and allowed increased calcium accumulation of the inner leaves. Foliar application of calcium did to some extent limit this disorder (Pressman et al. 1993), but this was not found in other studies (Borkowski et al. 1993, 1994). Repeated applications of calcium and naphthalene acetic acid (Wen et al. 1991) or daminozide (Aloni et al. 1986; Pressman and Aviram 1986) were other control methods that were found to be successful.

Water status is also an important quality-determining factor for Chinese cabbage. Chinese cabbage had a better yield and less tipburn with more frequent irrigation (Suh et al. 1987; McKay and Phillips 1990), so long as the irrigation water was not overly saline (McKay and Phillips 1990). Heat tolerance of Chinese cabbage was found to be related to better water uptake through a more vigorous root system and thicker leaves (Kuo et al. 1988). Water status at harvest may also play an important role, but no information is available as to what time of day it is best to harvest is. While turgid leaves at harvest are desirable (Daly and Tomkins 1997) and water loss should be reduced by harvesting on a cool day (Nguyen 1992) sugar levels in komatsuna, another *Brassica* crop, are higher in the afternoon. This increased sugar content may be important for prolonged storage as nutrient reserves in leaves are generally low and varieties of lower storage quality contained lower soluble solids than better storing ones (Wang 1993).

After harvest, a storage temperature of  $-1$  to  $0.5^{\circ}\text{C}$  is generally recommended for Chinese cabbage (Mathiassen 1986; Peters et al. 1986). However, Apeland (1985) found a form of chilling injury, brown midribs, after 45 days storage at  $0^{\circ}\text{C}$ . Midrib browning was reported to be associated with increases in levels of ACC, an ethylene precursor (Wang and Ji 1988). Some varieties, for example 'WR Green 60' and 'Tip Top', were seriously to moderately affected, whereas Treasure Island was unaffected. Kramer (1989) found that 12 weeks storage at  $0^{\circ}\text{C}$  was possible for Chinese cabbage, and that the hybrid Kingdom 65 best for storage at  $0$ – $1^{\circ}\text{C}$  for 14 weeks. However, a maximum of 6 weeks storage in low temperatures without controlled atmospheres was recommended by Mertens (1985). Varietal differences are the most likely cause of the observed differences in behaviour.

Chinese cabbage should be stored in 98–100% relative humidity (Hansen and Bohling 1981; Mathiassen 1986), for example in perforated polyethylene bags (Yong et al. 1993; Edmond et al. 1995).

We therefore examined the effect of pre- and post-harvest factors that had not been sufficiently researched: water stress during growth; time of day of harvest; delays in cooling; senescence processes during storage; and injury during handling.

## Materials and Methods

### Water stress during growth

Transient water stresses, mimicking insufficient irrigation, were applied to Chinese cabbages during growth and heading stages. Chinese cabbages cv. 'Yuki' were grown at the Ovens Research Centre, Victoria, Australia on three adjacent raised beds, representing replicates, each with three separate water stress plots with equal numbers of cabbages. After seedling establishment, soil moisture levels were monitored using tensiometers and cabbages were irrigated when readings were  $-35$  to  $-40$  kPa for 'no stress',  $-55$  to  $-60$  kPa for 'medium stress', or  $-75$  to  $-80$  kPa for 'high stress'. All treatments were fully irrigated 24 hours before harvest. Cabbage heads were then harvested on 5 May 1999 in early to mid morning, placed in lined, waxed cardboard cartons in the field and taken immediately to a coolroom. One head per treatment per replicate was sampled for relative water content, and the remaining 12 stored in the coolroom at  $0^{\circ}\text{C}$  overnight before transport, within 2 days, to the Adelaide University Waite Campus, South Australia,

at 2°–8°C. They were stored at 0°C for up to 9 weeks, and assessed at regular intervals as outlined below.

### Time of day of harvest and cooling delay

Chinese cabbage cv. 'Yuki' was grown at the Ovens Research Centre, Victoria, Australia on three adjacent raised beds, representing replicates, containing two rows of approximately 120 plants each that were divided into 10 plots. The crop was harvested on 4 May 1999, with each of the 10 plots allocated to a randomised complete block design of five harvest times — dawn, mid-morning, midday, mid-afternoon and dusk — by two holding periods — cool immediately and hold in-field for 30 minutes. Harvested heads were packed into waxed cardboard cartons fitted with polyethylene liners in the field and then transported at the designated time to a coolroom set at 0°C for cooling and overnight storage.

One head from each treatment was sampled to determine the relative water content. The remaining 12 heads were then transported to Adelaide where, on arrival, they were placed in separate perforated polyethylene bags and stored in cartons at 0°C. Three cabbages per replicate from each of the 10 harvest treatments were removed from storage for postharvest evaluation at intervals of 0, 3, 6, and 9 weeks.

Head temperatures in the field at various points inside and outside mature Chinese cabbage heads were measured using temperature data loggers. Three Chinese cabbage plants cv. 'Yuki' of uniform size and maturity, and situated adjacent to each other, were selected in a crop grown at Virginia, South Australia. Each cabbage plant was fitted with five temperature data loggers (Tinytalk Temperature Datalogger, Gemini Data Loggers, UK), with stab probes attached. Two probes were placed inside the cabbage head, one at the base and one in the centre. A third probe was placed under the leaves at the top of the head, while another was placed inside the midrib of a wrapper leaf, and one was suspended above the ground in the shade of the Chinese cabbage plant. Measurements were taken from 11 to 16 May 2000.

### Senescence processes

A crop of 'Yuki' was grown at Virginia, South Australia under commercial practices and 60 heads harvested on 29 and 31 May and 2 June 2000 as three replicates. Harvested heads were placed into unlined, waxed cardboard cartons in the field and transported to Adelaide University Waite Campus within 2 hours. There, heads were placed in separate, perforated

plastic bags, randomly allocated to a storage temperature treatment, 0, 2 or 20°C, and storage period, 0, 1, 2, 3, 6 or 9 weeks, and stored in cartons in coolrooms with 5 heads per treatment unit. Assessment during storage included respiration rate, ethylene production, weight loss, trimming loss and quality score (appearance, disorders). The incidence (percentage of heads affected) and severity score (1 = none; 4 = severe) of patchy papery necrosis (PPN) also was recorded. The zero time assessment was carried out 24 to 72 hrs after heads were placed into coolrooms to allow them to cool before taking temperature-sensitive measurements of respiration and ethylene production.

### Injury during handling

A crop similar to that used to assess senescence processes was harvested on 19, 23, and 26 June 2000, as three replicates, and all heads stored at 2°C. In the laboratory, sound heads were subjected to wound stresses before storage. These included, for each storage period (0, 3, 6 or 9 weeks) dropping the heads inside plastic bags twice from a height of 50 cm, compression of heads (in plastic bags) between a wooden board and the concrete floor with the equivalent of 3 kg per cabbage for 42–48 hours, or trimming of the 2–3 outermost leaves as close to base as possible. The wounding was designed not to cause physical failure, but to measure physiological changes induced by stress. The control was not stressed before storage. Postharvest assessments were as for the experiment above, with respiration and ethylene assessments done before and after wound treatments were applied, as well as at the end of each storage period.

### Postharvest evaluation

Relative water content was determined on three leaves from each head by weighing them before (fresh weight) and after (dry weight) drying in a fan-forced oven set at 60°C; the relative water content was calculated by dividing the difference between the weights by the fresh weight and expressing the result as a percentage.

Respiration and ethylene production rates were measured using flame-ionisation gas chromatography. Heads were weighed and placed into sealed 15 L plastic buckets for 1 hour (20°C) or 24 hours (0° and 2°C), a 1 mL gas sample was analysed, and headspace volume determined according to a weight-to-volume curve.

Upon removal from cool storage, cabbages were weighed, trimmed of senescing or damaged leaves to achieve a marketable standard, and then reweighed.

Trimming loss was calculated by subtracting the trimmed weight from the pre-trimming weight and recorded as a percentage of the pre-trimming weight.

The location and severity of visual symptoms of senescence (yellowing, browning), rotting, and of pre- and postharvest disorders (tipburn, gomasho, pest damage, PPN) were recorded. Also, an overall quality score of the Chinese cabbages was recorded according to their symptoms, ranging from 0 (good) to 3 (acceptable) for marketable quality, to 4 (below acceptable) for unmarketable quality.

Levels of sucrose, glucose and fructose in Chinese cabbage samples were determined using an enzymatic assay technique. Four samples, an outer, middle and inner leaf, and the core, were frozen to  $-80^{\circ}\text{C}$ , freeze-dried and then ground into a homogeneous powder. Samples were deproteinised by adding 640  $\mu\text{L}$  0.6 M  $\text{HClO}_4$  to 5 mg of sample, mixing and then adding 360  $\mu\text{L}$  2 M KOH. The mixture was centrifuged for 15 minutes at 17,000 g and 750  $\mu\text{L}$  of the resulting supernatant was adjusted to pH 8.0 using 0.5 M KOH and then diluted with an equal volume of milliQ water. The extract (50  $\mu\text{L}$ ) was used in an assay technique based on the Boehringer Mannheim Sucrose/D-Glucose/D-Fructose Enzymatic BioAnalysis kit (Catalogue No. 716260). The levels of sucrose, glucose, and fructose (mg/g dry weight) were estimated from the absorbency of NADPH at 340 nm measured using a Varian Cary 1 UV-Visible Spectrophotometer (Varian Australia, Mulgrave, Victoria).

## Data analysis

All numerical data were analysed for variance using Genstat 5, 4<sup>th</sup> Edition for Windows (Lawes Agricultural Trust, IACR, Rothamsted). Differences between treatments were determined using least-significant difference (LSD) at the 5% level.

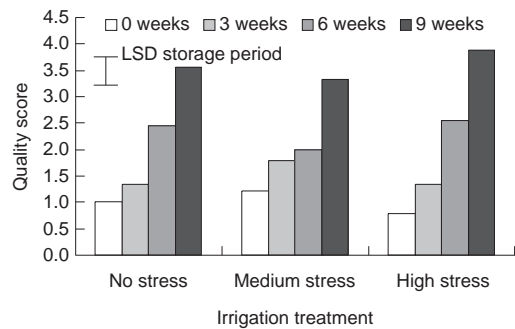
## Results and Discussion

### Water stress during growth

The water stress treatments during growth did not affect the postharvest physiological responses, harvested yield, or quality (Figure 1) of the Chinese cabbages. No differences in weight loss, trimming loss, or energy substrate levels were found, and water status was very similar, with the relative water content at harvest ranging from 94.4–94.9%.

This indicates that Chinese cabbage heads recovered from the transient water stresses when they were rewa-

tered. The identical yield and energy substrate levels of the harvested heads suggest that Chinese cabbages were still able to photosynthesise effectively. In addition, weight loss after harvest was comparable, indicating that water stress did not induce any permanent water stress responses such as cuticle thickening or modified stomatal responses. It is not clear as yet whether the ability of Chinese cabbages to withstand temporary water stress is linked to the wrapper leaves being preferentially affected compared with the rest of the head, as documented below for the response to time of day of harvest. An alternative explanation is that Chinese cabbages grew a stronger root system in response to the water stress to allow more efficient water uptake (Kuo et al. 1988). As heads were rewatered before harvest, the water status did not vary at harvest.



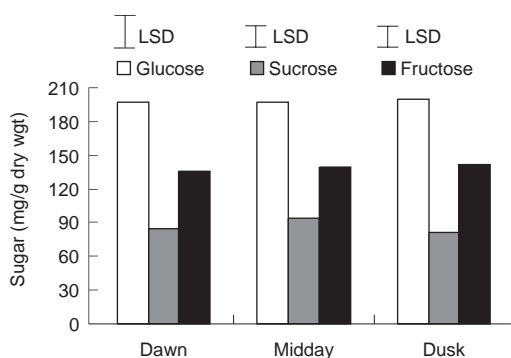
**Figure 1.** Quality score of Chinese cabbage cv. 'Yuki' transiently water stressed during growth after storage at  $0^{\circ}\text{C}$ . A score of 0 was the best quality and above 3 was considered unmarketable. Means of 12 heads each in three replicates are shown. Irrigation treatments did not influence quality ( $P > 0.05$ ), and the least significant difference (LSD) ( $P = 0.05$ ) for storage periods is shown.

### Time of day of harvest and cooling delay

The time of day of harvest (dawn, midday, dusk) did not influence quality (e.g. trimming loss) or storage life of Chinese cabbage (Table 1). No trend was found in water status or energy substrate levels (Figure 2) with harvest time. A delay in cooling harvested cabbages, left in the field for 0.5 hours at temperatures ranging from  $6.1^{\circ}\text{C}$  to  $20.3^{\circ}\text{C}$ , also had no influence on these parameters (Table 1).

This result was not expected, given that leaf turgor, generally highest in the morning, is desirable for good

storage of Chinese cabbage (Nguyen 1992; Daly and Tomkins 1997). On the other hand, sugar levels in komatsuna, another *Brassica* crop, are higher in the afternoon, and have been linked to improved storage (Wang 1993). However, we found no variation of water status or energy substrate levels throughout the day and subsequent storage was not affected. This can be explained by the observations of temperature effects on Chinese cabbages in the field.



**Figure 2.** Average sugar levels at harvest of Chinese cabbage heads cv. ‘Yuki’ harvested at different times of the day. Means of four locations in 12 heads in each of three replicates are shown. The least significant difference (LSD) ( $P = 0.05$ ) for each sugar is shown.

Temperature fluctuations at various points inside and at the surface of mature Chinese cabbage heads in the field (Figure 3) show that the inside of the head was protected or insulated, while the wrapper and outer leaves were most affected by temperature extremes. These therefore are also most likely to be affected by temperature-induced changes in water status and of the respiration/photosynthesis balance. Because the wrapper and some of the outer leaves are trimmed at

harvest, only that part of the head that had been protected was stored.

Temperatures in the field and metabolic rates were relatively low and heads were protected from water loss by packaging, ensuring that a minimal delay in cooling usually experienced in commercial practice had no impact on postharvest life. Also, owing to their bulk and packaging, heads took overnight to cool to  $0^{\circ}\text{C}$ , so that the 0.5 hour delay in the field did not affect their cooling to any great extent.

## Senescence processes

Chinese cabbage cv. ‘Yuki’ had low rates of respiration and ethylene production, especially at low temperatures, and weight and quality fell slowly but steadily during storage. This is the reason for its relatively long storage life. There were large differences in the rate of quality loss between  $20^{\circ}\text{C}$  and the low temperatures in all assessments, but no differences between  $0^{\circ}\text{C}$  and  $2^{\circ}\text{C}$ .

The first visible sign of senescence was the breakdown of chlorophyll, leading to yellowing of the edges of the outer leaves. This was first observed after 2 weeks at  $20^{\circ}\text{C}$ , but not until 6 weeks at the lower temperatures. This was not as serious an issue as for highly chlorophyllous leafy vegetables; the inner leaves of Chinese cabbage contained little chlorophyll. In any case, the outer leaves affected would have been trimmed off owing to the development of rots.

Rotting caused by microbial infection, mainly of outer leaves, the base, and other exposed wound sites, usually follows yellowing. Rotting is typically the main reason for reduction in quality and loss of saleable weight as a result of trimming.

The presence of postharvest disorders such as gomasho (we used a resistant cultivar) and PPN may also contribute to quality loss. PPN is a serious postharvest disorder and was described by Daly and

**Table 1.** Trimming loss and quality score after 9 weeks of storage at  $0^{\circ}\text{C}$  for Chinese cabbage cv. ‘Yuki’ harvested at different times of the day and held in-field for different periods before cooling.

	Harvest time			Holding period	
	Dawn	Midday	Dusk	0 hours	0.5 hours
Trimming loss (%)	22.6a	21.3a	21.8a	21.5a	22.1a
Quality score <sup>a</sup>	2.2a	1.8a	2.0a	1.9a	2.2a

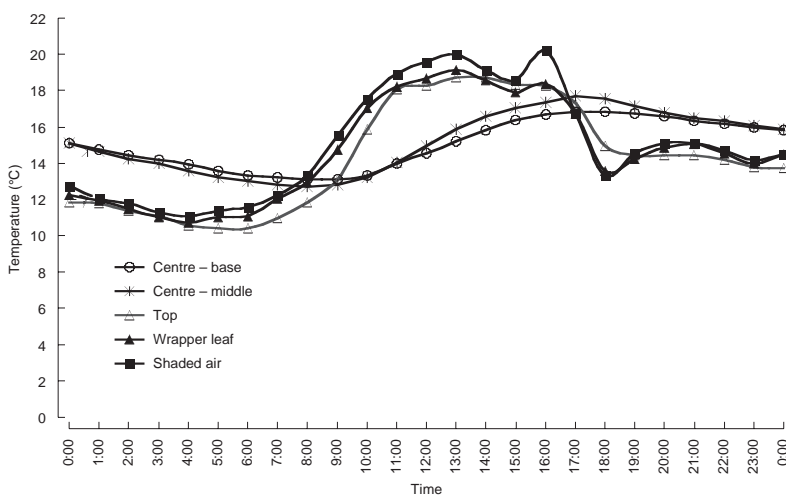
<sup>a</sup> Scores between 0 and 3 denote good (marketable) quality and scores  $>3$  denote poor (unmarketable) quality. Values are means of 12 heads in each of three replicates and different letters in rows for each factor denote significant difference using least significant differences ( $P = 0.05$ ).

Tomkins (1997); however, what causes it has previously not been elucidated. Our cultivar 'Yuki' was susceptible, and severity and incidence (Figure 4) were high after storage at 0°C, but much less occurred at 2°C, and none at 20°C. This suggests that PPN is a form of chilling injury. Previously, a temperature range of -1 to 0.5°C has been recommended for storing Chinese cabbage (Mathiassen 1986; Peters et al. 1986), but Apeland (1985) found a form of chilling injury termed 'brown midribs' after 45 days storage at 0°C. For chilling-injury-susceptible cultivars like

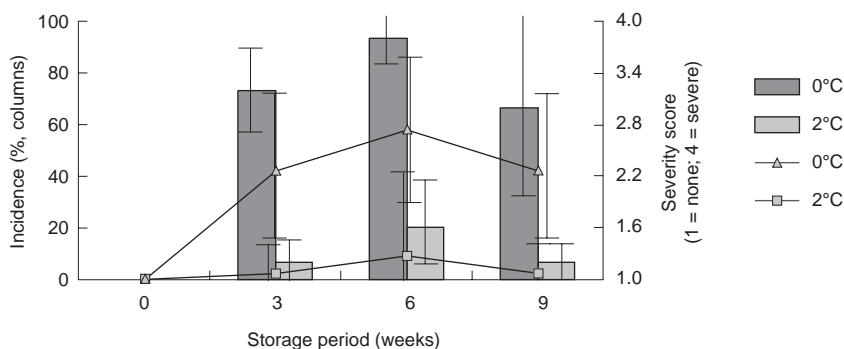
'Yuki', storage temperatures above 2°C are needed. Different cultivars of Chinese cabbage, if they are susceptible to chilling injury, seem to be susceptible to different forms of the phenomenon.

### Injury during handling

Chinese cabbage was not affected by any of the wounding treatments applied. The trimming, dropping, and compression treatments applied, were aimed at mimicking typical stresses experienced during Aus-



**Figure 3.** Temperature fluctuations over a 24-hour period at various positions inside and outside mature Chinese cabbages heads cv. 'Yuki' growing in the field. Minimum and maximum temperatures in the region for the same period, as recorded by the Bureau of Meteorology, were 13°C and 22°C, respectively. Values are means of data from three heads.



**Figure 4.** Incidence and severity of patchy paper necrosis (PPN) in Chinese cabbage cv. 'Yuki' during low temperature storage. Means  $\pm$  standard deviation of 12 heads each in 3 replicates.

tralian export conditions, and only in very few cases did they lead to product failure such as splitting of leaves. The stress induced by the treatments did not result in any obvious physiological change, quality differences, or final trimming losses.

The only difference found between treatments was that heads that were trimmed regularly had lower ethylene production at the end of storage. The trimmed heads consistently produced about 0.003  $\mu\text{L}$  of ethylene/kg/hour, while the other treatments increased to about 0.01  $\mu\text{L}$ /kg/hour after 6–9 weeks of storage. This shows that the outer leaves that were not trimmed produced more ethylene than the rest of the head, related to the earlier occurrence of senescence and disease on the outer leaves, as described above. The insides of the cabbage heads were not affected by this increase in ethylene production.

## Conclusion

Chinese cabbage cv. 'Yuki' is a relatively resilient crop in the field, as it manages to avoid problems linked to transient water stress, and is not affected by the time of day at which it is harvested. This is linked to the differential behaviour of the wrapper leaves that are trimmed off at harvest, compared with the protected rest of the head. Also, short cooling delays did not affect postharvest outcomes, as heads were protected from water loss and did not experience excessive temperatures.

After harvest Chinese cabbage cv. 'Yuki' enjoys a long storage life, because it has a low metabolic rate, but eventually some yellowing and, in particular, microbial rots lead to the degradation of the outer leaves. These can be trimmed off, so that after 9 weeks the inner head is still marketable. Nevertheless, this can lead to saleable weight losses of over 20% and trimming is an additional handling cost. Also, various forms of chilling injury of Chinese cabbage need to be considered for susceptible cultivars. 'Yuki', for example, should be stored above 2°C. Mechanical stresses below those that cause obvious product failure, e.g. splitting, as are experienced in handling systems like in Australia where heads are well packaged, did not affect postharvest outcomes.

## References

- Aloni, B. 1986. Enhancement of leaf tipburn by restricting root growth in Chinese cabbage plants. *Journal of Horticultural Science*, 61, 509–513.
- Aloni, B., Pashkar, T., and Libel, R. 1986. The possible involvement of gibberellins and calcium in tipburn of Chinese cabbage: study of intact plants and detached leaves. *Plant Growth Regulation*, 4, 3–11.
- Anon. 1984. Effect of time, form and concentration of nitrogen application on Chinese cabbage tipburn. Asian Vegetable Research and Development Center Progress Report 1984, 385–393.
- Apeland, J. 1985. Chilling injury in Chinese cabbage *Brassica campestris pekinensis* (Lour) Olsson. *Acta Horticulturae*, 157, 261–270.
- Borkowski, J. and Szwonek, E. 1993. Effect of temperature and spraying with calcium nitrate on health of Chinese cabbage, yield and nitrate content. *Biuletyn Warzywnicz*, 40, 15–24. (Abstract)
- Borkowski, J., Szwonek, E., Babik, I., and Rumpel, J. 1994. The effect of temperature on Chinese cabbage tipburn and its control by calcium nitrate or citric acid. *Acta Horticulturae*, 371, 363–369.
- Daly, P., and Tomkins, B. 1997. Production and postharvest handling of Chinese cabbage. Rural Industries Research and Development Corporation (RIRDC), Barton ACT, Australia. RIRDC Research Paper 97/1, 35p.
- Emond, J.P., Boily, S., and Mercier, F. 1995. Reduction of water loss and condensation using perforated film packages for fresh fruits and vegetables. In: Kushwaha, L., Serwatowski, R., and Brook, R., ed., *Proceedings of a conference held in Guanajuato, Mexico, 20–24 February 1995*. St Joseph, Mich., USA, American Society of Agricultural Engineers, 339–346.
- Guttormsen, G. 1985. Effects of air humidity and temperature on Chinese cabbage grown in greenhouses. *Forskning og Forsok I Landbruket*, 36(2), 81–89. (Abstract)
- Hansen, H. and Bohling, H. 1981. Long-term storage of Chinese cabbage. *Acta Horticulturae*, 116, 31–34.
- Kramer, T. 1989. Breeding activities on minor crops in the Netherlands. *Acta Horticulturae*, 242, 101–105.
- Kuo, C.G., Shen, B.J., Chen, H.M., Chen, H.C., and Opena, R.T. 1988. Associations between heat tolerance, water consumption, and morphological characters in Chinese cabbage. *Euphytica*, 39, 65–73.
- McKay, A. and Phillips, D. 1990. Chinese cabbage. Department of Agriculture, Western Australia, Bulletin No. 4197, 13p.
- Mathiassen, H.P. 1986. Discolored vascular bundles in Chinese cabbage after storage. *Gartner Tidende*, 102(48), 1614–1615.
- Mertens, H. 1985. Bewaarcondities belangrijk bij Chinese kool. *Groenten en Fruit*, 41(17), 62–63.
- Nguyen, V.Q. 1992. Growing Asian vegetables. NSW Agriculture Agfact H8.1.37, 16p.

- Pelleboer, H. and Schouten, S.P. 1984. Nieuwe methode voor bewaren Chinese kool succes. *Groenten en Fruit*, 40(16), 51.
- Peters, P., Jeglorz, J., and Kastner, B. 1986. Mehrjährige Untersuchungen zur Normal- und Kühlagerung von Chinasalat. *Gartenbau*, 33(10), 298–301.
- Phillips, D. 1990. Chinese cabbage research pays off. *Good Fruit and Vegetables*, September 1990, 26.
- Phillips, D. and McKay, A. 1989. Chinese cabbage — a crop at the crossroads. *W.A. Grower*, 26(11), 20–21.
- Phillips, D.R. and Gersbach, N.B. 1988. Factors influencing petiole spotting (gomasho) in Chinese cabbage. *Acta Horticulturae*, 247, 117–121.
- Pressman, E. and Aviram, H. 1986. Inhibition of flowering in Chinese cabbage by applying heat and growth retardants to transplants. *Plant Growth Regulation*, 4(1), 87–94.
- Pressman, E., Shaked, R., and Acran, L. 1993. The effect of flower inducing factors on leaf tipburn formation in Chinese cabbage. *Journal of Plant Physiology*, 141, 210–214.
- Schouten, S.P. 1985. Nieuw licht op het bewaren van Chinese kool. *Groenten en Fruit*, 40(33), 60–61.
- Suh, H.D., Park, S.K., and Kwon, Y.S. 1987. Effects of amounts and intervals of irrigation on the yield of hot pepper, radish and Chinese cabbage. *Research Reports of the Rural Development Administration*, 29(1), 24–29. (Abstract)
- Tao, X.Q., Zhao, H., Cheng, Q.F., and Hu, H. 1986. The effect of cultivars, fertiliser and harvest date on the storability of spring cabbage. *Acta Horticulturae Sinica*, 13(1), 42–48. (Abstract)
- Vavrina, C.S., Obreza, T.A., and Cornell, J. 1993. Response of Chinese cabbage to nitrogen rate and source in sequential plantings. *HortScience*, 28, 1164–1165.
- Wang, C.Y. 1985. Effect of low O<sub>2</sub> atmospheres on postharvest quality of Chinese cabbage, cucumbers, and eggplants. In: Blankenship, S.M., ed., *Controlled atmospheres for storage and transport of perishable agricultural commodities*. North Carolina State University Department of Horticultural Science, 142–149.
- Wang, C.Y. and Ji, Z.L. 1988. Abscisic acid and ACC content of Chinese cabbage during low-oxygen storage. *Journal of the American Society for Horticultural Science*, 113, 881–883.
- Wang, Y. 1993. Preliminary study on physiological mechanisms of storability differences among headed varieties of Chinese cabbage. *Journal of Shandong Agricultural University*, 24(1), 37–41. (abstract).
- Wen, F.Y., Sun, D.L., Ju, P.H., Su, Y.M., and An, Z.X. 1991. The effect of NAA on calcium absorption and translocation and the prevention of tipburn in Chinese cabbage. *Acta Horticulturae Sinica*, 18(2), 148–152. (Abstract)
- Wiebe, H.J. 1990. Estimation of the raising temperature at the time of bolting of Chinese cabbage. *Acta Horticulturae*, 267, 297–303.
- Yong, J.Y., Jin, C.J., Tag, J.C., Si, Y.L., and Un, H.P. 1993. Marketability affected by cultivars and packaging methods during the long-term storage of Chinese cabbage grown in autumn. *Journal of the Korean Society for Horticultural Sciences*, 34(3), 184–190.
- Zong, R.J. and Morris, L.L. 1986. Responses to exogenous ethylene treatment and ethylene evolution of Chinese cabbage during storage. *Acta Horticulturae Sinica*, 13(2), 113–118.

# Sanitary Washing of Vegetables

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## *Abstract*

The postharvest quality of many types of vegetables can be improved by washing during preparation for market. The primary purposes of washing are to remove soil, grit, and other debris from the vegetables, eliminate undesirable microbial contaminants, and clean/sanitise wounds incurred during the harvesting process. However, these aims are not achieved when the source water is not clean or when used wash-water is recycled without appropriate treatment. Vegetable surfaces, and at times the internal tissues, can also be contaminated by human pathogens (bacteria, viruses, nematodes, and protozoans). These may derive from the use of uncomposted animal manures or contaminated irrigation and wash-water. While postharvest washing is an important control point for microbial and chemical contamination it can itself present a risk. Wash-water rapidly accumulates soft rot organisms and possibly human pathogens if it is recirculated without sufficient treatment. To minimise contamination, farmers may either use a continuous clean water source, which may be very costly, or employ an effective water treatment system using one of several classes of sanitising chemicals, heat, or UV irradiation.

The power of sanitising agents is influenced by concentration, temperature, and water pH, hardness, and organic matter content. However, the influence of these parameters on the control of specific plant pathogens and human pathogens in wash-water is poorly understood. Similarly, there is little information on the ability of sanitisers to disinfect vegetable surfaces and contact surfaces such as harvesting and handling equipment.

This paper reports experiments that demonstrate the influence of sanitation conditions on the effectiveness of sanitisers, especially hypochlorites, in water and on surfaces.

THE postharvest quality of many types of vegetables can be improved by washing during preparation for market. The primary purposes of washing are to:

- remove soil, grit and other debris from the vegetables;
- eliminate undesirable microbial contaminants; and
- clean/sanitise wounds incurred during the harvesting process.

These aims are not achieved when the source water is not clean or when used wash-water is recycled without appropriate treatment.

Soil and grit left adhering to vegetables is not appreciated by consumers. Washing can therefore enhance saleability. The soil and organic debris also harbour microorganisms including fungi and bacteria that can invade damaged tissues and cause severe rot during postharvest transport and storage (Table 1). The surface of vegetables and at times the internal tissues can also be contaminated by human pathogens (bacteria, viruses, nematodes, and protozoans; Table 2). These may derive from the use of sewage, uncomposted animal manures, or contaminated irrigation and wash water. There have been many outbreaks of disease in humans attributed to microbial contamination of fresh fruits and vegetables (Beuchat and Ryu 1997; Little et al. 1997; Tauxe et al. 1997).

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While postharvest washing is an important control point for microbial and chemical contamination, it can itself present a risk. Wash-water rapidly accumulates soft rot organisms and possibly human pathogens if it is recirculated without sufficient treatment. To minimise contamination, farmers either use a continuous clean water source, which may be very costly, or employ an effective water treatment system using one of several classes of sanitising chemicals, heat, or UV irradiation. The discharge of water used for washing also has the potential to spread plant disease or contaminate the environment with human pathogens and pesticides. Treatment of used wash-water before disposal may therefore be desirable.

**Table 1.** Major postharvest pathogens of vegetables.

Fungi and protists	Bacteria
<i>Alternaria</i> spp.	<i>Erwinia</i> spp.
<i>Botrytis cinerea</i>	<i>Xanthomonas campestris</i>
<i>Colletotrichum</i> spp.	<i>Pseudomonas</i> spp.
<i>Fusarium</i> spp.	
<i>Geotrichum candidum</i>	
<i>Mucor</i> spp.	
<i>Penicillium</i> spp.	
<i>Rhizopus</i> spp.	
<i>Sclerotinia</i> spp.	
<i>Stemphylium</i> spp.	
<i>Phytophthora</i> spp.	

**Table 2.** Human pathogens isolated from fresh vegetables (J. Behrsing and R. Premier, unpublished data).

Bacteria	Protozoans and viruses
<i>Bacillus cereus</i>	<i>Cryptosporidium</i>
<i>Clostridium botulinum</i>	<i>Giardia</i>
<i>Listeria monocytogenes</i>	<i>Cyclospora</i>
<i>Salmonella</i> spp.	
<i>Escherichia coli</i>	Hepatitis A
<i>Yersinia enterocolitica</i>	Enteroviruses
<i>Camphylobacter jejuni</i>	Norwalk virus
<i>Shigella</i> spp.	Rotavirus
<i>Staphylococcus aureus</i>	

Hygienic postharvest practice is an effective strategy to minimise postharvest diseases of vegetables and this is usually achieved by sanitising produce and equipment (Coates and Johnson 1996). There are many sanitisers available, but there are few objective guidelines to help determine which are the most appropriate for a particular purpose. In Australia, chlorine-

based products are the most popular for vegetable washing, and several other types of sanitisers are used for cleaning plant and equipment. The power of sanitising agents is influenced by concentration, temperature, and water pH, hardness, and organic matter content. However, the influence of these factors on the control of specific plant pathogens and human pathogens in wash-water is poorly understood. Similarly, there is a scarcity of information on the ability of sanitisers to disinfest vegetable surfaces and contact surfaces such as harvesting and handling equipment.

This paper reports experiments which demonstrate the influence of sanitation conditions on the effectiveness of sanitisers, especially hypochlorites, in water and on surfaces. It also presents data on the quality of vegetable wash-water and discusses the implications for wash-water re-use and safe discharge

## Materials and Methods

### Selected sanitisers

The registration and use of sanitisers in Australia is regulated by the National Registration Authority (NRA), but there are also certain sanitisers that are exempt from registration (e.g. chlorine dioxide, when generated on site). In addition, the Australia and New Zealand Food Authority (ANZFA) regulates chemical residues in foods and approves food additives and processing aids, some of which are antimicrobial compounds. Sanitisers selected for this study are either approved by ANZFA or the NRA, or have been given an exemption by the NRA.

The selected sanitisers contain the active ingredients benzalkonium chloride (QAC), bromo-chlorodimethyl hydantoin (BCDMH), calcium hypochlorite (Ca(OCl)<sub>2</sub>), chlorine dioxide (ClO<sub>2</sub>), and peroxyacetic acid (PAA). Other permitted sanitisers include ozone, iodine, and peroxygens. Concentrations of active ingredients in solutions of BCDMH, calcium hypochlorite, and chlorine dioxide were determined by spectrophotometry. Sanitiser concentrations are expressed as parts per million (ppm) of the active species. For hypochlorite, this is ppm of free chlorine (fac); for BCDMH, this is ppm of free chlorine equivalents (fce).

### Pathogens

The following plant pathogenic fungi and bacteria were used as test organisms: *Mucor* sp., *Penicillium* spp., *Geotrichum candidum*, *Xanthomonas campestris*

pv. *campestris*, *Pseudomonas syringae* pv. *syringae*, and *Clavibacter michiganensis* subsp. *michiganensis*. *Escherichia coli*, a common indicator of faecal contamination, was selected to represent human pathogenic bacteria.

### Preparation of inocula

Bacteria were maintained at 21°C on nutrient agar (NA). Cell suspensions were prepared from 3–5-day-old cultures, enumerated by absorbance (Hach 2010 spectrophotometer), and adjusted to achieve approximately  $1 \times 10^6$  cells/mL. Fungi were maintained at 21°C on potato dextrose agar (PDA). Stock inoculum was prepared by washing 5–10-day-old cultures with sterile purified water, counted using a haemocytometer and adjusted to approximately  $1 \times 10^6$  spores/mL.

### Cell suspension tests

Sanitiser efficacy tests were adapted from the published methods of the Association of Official Analytical Chemists (AOAC 1984) and the Australian Therapeutic Goods Administration (Graham 1978). Inoculum (1 mL of cell/spore suspension) was added to 99 mL of sanitiser solutions at various concentrations. After 30, 60, 90, 120, and 240 seconds, 0.1 mL of this solution was extracted and added to a microcentrifuge tube containing 0.9 mL of deactivator solution (0.1N sodium thiosulfate and 10% v/v Ecoteric T80). The control was sterile deionised water (SDW) in place of the sanitiser and was extracted at 240 seconds only. Except where otherwise mentioned, tests were conducted at pH 6.5–7 and at  $21 \pm 2^\circ\text{C}$ . A sample of the reacted product (0.1 mL) was spread-plated onto NA for bacteria or PDA for fungi. The procedure was repeated 3 times for each sanitiser. Plates were incubated and colonies counted after 72 hours, except for *M. piriformis*, which was counted after 24 hours, and *C. michiganensis*, which was counted after 5 days.

Sanitisers were trialed at half, single, and double 'label' rates. All treatments were duplicated in 'dirty water' of a standard water hardness and containing 5% inactivated baker's yeast (Graham 1978). The pH was buffered at 5.5, 7.0, and 8.5 with 0.2M  $\text{NaH}_2\text{PO}_4$  and 0.2M  $\text{Na}_2\text{HPO}_4$ . All reactions were conducted at 4, 21, and 30°C.

### Surface tests

Two substrates were used: aluminium and wood (smooth-planed *Pinus radiata* and rough-sawn *Eucalyptus camaldulensis*). Both materials were cut into 25

$\text{cm}^2$  coupons. Wood was autoclaved, whereas metal was surface sterilised with 70% ethanol. Metal coupons were inoculated with 100  $\mu\text{L}$  of  $1 \times 10^4$  cells/mL spread with a glass rod. Three coupons were placed in stainless steel trays containing 150 mL sanitiser and removed after 1, 5, and 20 minutes. The metal was direct plated onto NA or PDA plates that were flooded with 1 mL of the deactivator. Plates were air dried for 30 minutes and then incubated at 21°C. Wood coupons were inoculated with 200  $\mu\text{L}$  of  $1 \times 10^4$  cells/mL and pressed onto plates flooded with 2 mL of the deactivator.

Resulting colonies were counted after approximately 72 hours. Differences in the efficacy of the sanitisers were analysed by GENSTAT analysis of variance.

### Vegetable wash-water quality

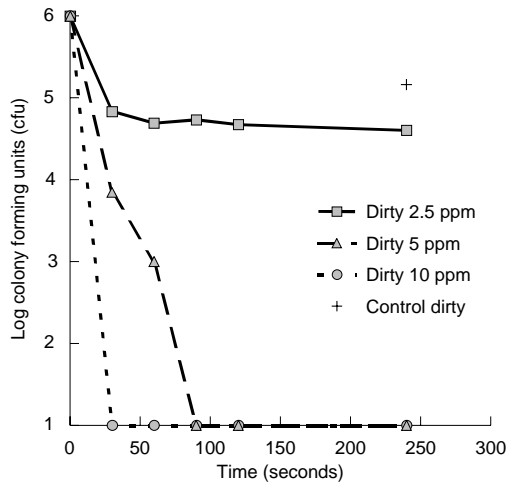
Source and waste-water samples were taken from a total of 17 different carrot washing facilities: 10 in Victoria, 4 in Tasmania, 2 in South Australia, and 1 in Queensland. Some properties were sampled more than once: 25 source-water and 25 waste-water samples were collected in total. All samples were tested for turbidity, biochemical oxygen demand (an indicator of organic matter), nitrates, nitrites, soluble reactive phosphorus, total coliforms, *E. coli*, and total yeasts and moulds. Aliquots were also dilution plated on PDA, MEA, and WA to isolate fungi. All fungi isolated were identified to at least genus level. Fungi that were considered potentially pathogenic were identified to species level. Selected isolates were then wound inoculated onto carrots to confirm pathogenicity.

## Results

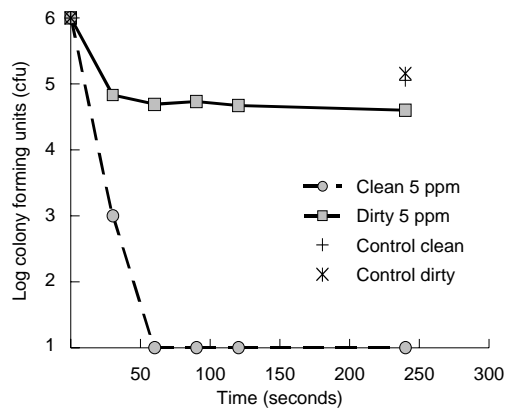
### Sanitiser effectiveness in water

In clean water, reductions of 4–6- $\log_{10}$  were achieved in less than 30 seconds at 20°C in most pathogen sanitiser combinations. *Mucor* was the most resistant organism (data not shown). In dirty water (TGA test), where kill rates were slower, increasing the concentration of sanitiser was required to achieve better than 4  $\log_{10}$  reductions (Figure 1, *Geotrichum* and BCDMH data shown). Dirt reduced the rate of pathogen reduction at the lower concentrations of BCDMH, calcium hypochlorite, and peroxyacetic acid (Figure 2, *C. m. michiganensis* and BCDMH data shown). The performance of chlorine dioxide (2.5 ppm) was unaffected by the TGA condi-

tions. In dirty water, 6- $\log_{10}$  reductions were achieved within 4 minutes for all organisms (except *Mucor*) at 60 ppm of hypochlorite, 2.5 ppm of chlorine dioxide, 1000 ppm peroxyacetic acid, and 10 ppm of BCDMH. Only peroxyacetic acid (1000 ppm) and chlorine dioxide (2.5 ppm) achieved greater than 4- $\log_{10}$  reductions of *Mucor* in dirty water.



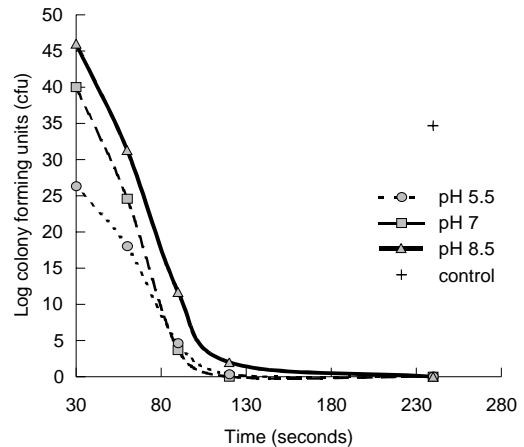
**Figure 1.** Effect of exposure time and sanitiser concentration on the efficacy of BCDMH (fce) against *Geotrichum candidum* in dirty water.



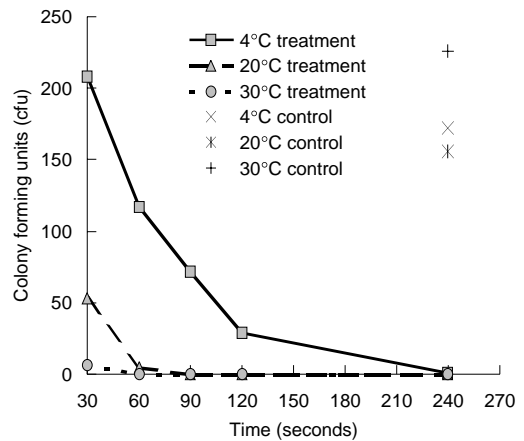
**Figure 2.** Effect of dirty water on the efficacy of BCDMH (2.5 ppm fce) against *Clavibacter michiganensis* subsp. *michiganensis*.

An increase in pH (from 5.5 to 8.5) decreased the performance of hypochlorites. Against *Mucor*, for example, calcium hypochlorite was almost twice as

effective at pH 5.5 than at 8.5 after 30 seconds (Figure 3). Chlorine dioxide was effective over a wider pH range and peroxyacetic acid was not significantly affected by pH over the range 5.5 to 8.5.



**Figure 3.** Effect of pH on the efficacy of calcium hypochlorite (30 ppm) against *Mucor* sp.



**Figure 4.** Effect of temperature on efficacy of BCDMH (5 ppm) against *Mucor* sp.

The efficacy of all sanitisers was reduced at low temperature (4°C). For example, the time required for BCDMH to completely kill *Mucor* was 60, 90, and 240 seconds at 30, 20, and 4°C, respectively (Figure 4).

### Sanitiser effectiveness on surfaces

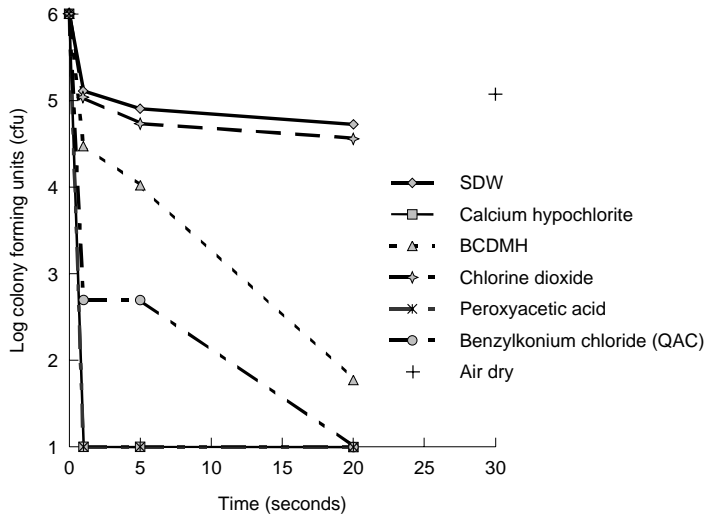
Peroxyacetic acid and calcium hypochlorite were the best performing sanitisers against *E. coli* on an aluminium surface, and chlorine dioxide was the poorest

(at their recommended label rates). There was no significant difference between water and chlorine dioxide (Figure 5).

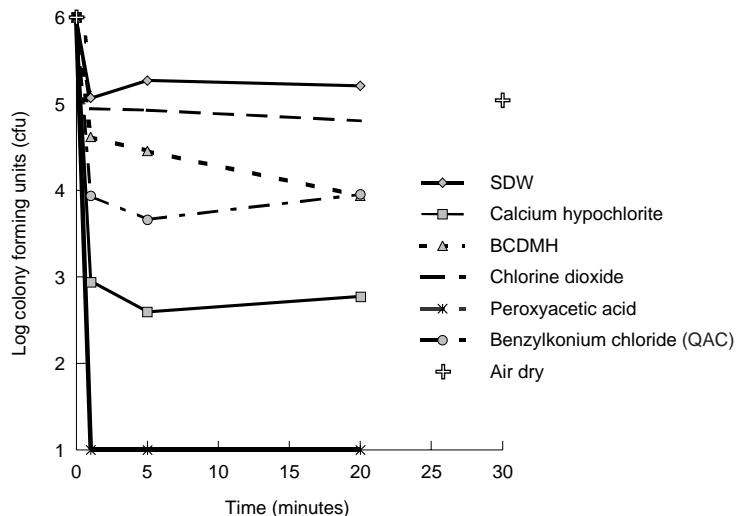
Peroxyacetic acid was the only sanitiser to achieve better than a 5 log<sub>10</sub> reduction against *E. coli* on smooth *P. radiata*. There was no significant difference between chlorine dioxide and water, whereas

BCDMH, calcium hypochlorite, and benzylkonium chloride displayed similar sanitising effectiveness at 'label' rates (Figure 6).

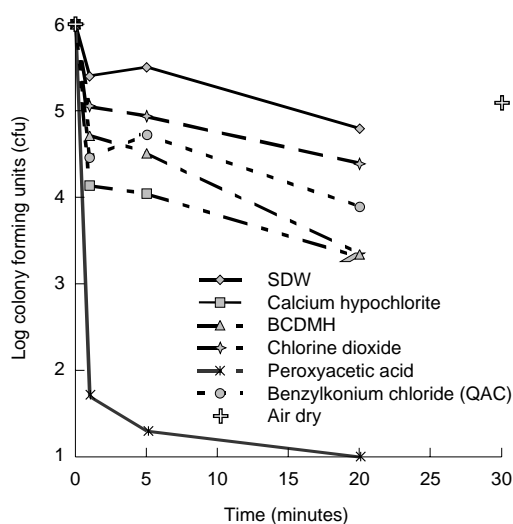
Peroxyacetic acid was the best sanitiser against *C. michiganensis* on rough-sawn *E. camaldulensis*. Other sanitisers gave similar kill rates, with chlorine dioxide showing the lowest efficacy (Figure 7).



**Figure 5.** Efficacy of selected sanitisers against *Escherichia coli* on an aluminium surface. Sanitiser concentrations were 30 ppm fac, 5 ppm fce, 5 ppm ClO<sub>2</sub>, 500 ppm PAA, 1000 ppm QAC.



**Figure 6.** The efficacy of selected sanitisers against *Escherichia coli* on a smooth wood surface. Sanitiser concentrations were 30 ppm fac, 5 ppm fce, 5 ppm ClO<sub>2</sub>, 500 ppm PAA, 1000 ppm QAC.



**Figure 7.** The efficacy of selected sanitisers against *Clavibacter michiganensis* subsp. *michiganensis* on a rough-sawn wood surface. Sanitiser concentrations were 30 ppm fac, 5 ppm fce, 5 ppm ClO<sub>2</sub>, 500 ppm PAA, 1000 ppm QAC.

### Vegetable wash-water quality

All water quality indicators deteriorated with the throughput of carrots. Concentrations of *E. coli*, yeasts, and moulds increased by an average of log<sub>10</sub>, and the frequency of detection of plant pathogens also increased markedly (Table 3).

## Discussion

### Sanitiser effectiveness in water

In both clean and dirty water, sanitiser efficacy was proportionate to sanitiser concentration. While many sanitisers reduced pathogen counts more rapidly at double the label rate, most performed adequately at the label rate. The sanitisers that did not achieve better than 2 log<sub>10</sub> reductions in dirty water within 4 minutes contact time were calcium hypochlorite against *Mucor* and *G. candidum*, BCDMH against *Mucor*, and peroxyacetic acid against *Mucor*. As increasing contact time beyond 4 minutes would be impractical, increased amounts of sanitiser would need to be added to overcome the demand of the water hardness and organic load. Dirty water contains substances that interfere with chlorination and bromochlorination, for

example ammonia, amino acids, and calcium carbonate (Bessemis 1998; White 1999). These substances create a 'chlorine demand' and only once this initial demand is met does free available chlorine or bromine (the main biocidal compound) occur. Chlorinating until the chlorine demand is satisfied is known as 'breakpoint chlorination' (Dychdala 1977). Sanitation systems that automatically deliver hypochlorites (including BCDMH) would be expected to maintain effective levels of the sanitiser above the chlorine demand of the water. Alternatively, water can be treated to reduce impurities before the sanitiser is added, or a sanitiser which is more effective in dirty water could be used. Increasing concentrations without prior water purification can prove costly and lead to increased corrosion, pollution, or worker discomfort.

**Table 3.** The effect of washing carrots on the quality and pathogen concentration of wash-water (Hamilton and Mebalds 2000).

Parameter	Source water	Waste-water
Turbidity (NTU)	62.5	195.2
Biochemical oxygen demand (mg/L)	7.7	29.6
Total reactive phosphorus-P (mg/L)	1.79	32.7
<i>E. coli</i> (cfu/100 mL)	44	555
Yeasts and moulds (cfu/100 mL)	41,591	418,409
<i>Alternaria alternata</i> (% of samples)	20%	52%
<i>Fusarium oxysporum</i> (% of samples)	12%	64%
<i>Mucor</i> sp. (% of samples)	16%	48%
<i>Pythium</i> sp. (% of samples)	0%	8%

Current data from researchers, manufacturers, and regulators indicate approximately 40–80 ppm of free available chlorine (from calcium hypochlorite), 5 ppm of chlorine dioxide, 80–500 ppm peroxyacetic acid, and 5–10 ppm free available chlorine equivalents (from BCDMH) were effective rates in clean wash-water.

When hypochlorites are dissolved in water they dissociate into two main compounds, hypochlorous acid (HOCl) and the hypochlorite ion (OCl<sup>-</sup>). The relative

abundance of each compound depends on the pH of the water. At low pH, hypochlorous acid, the more biocidal product, predominates (White 1999). In this study, as expected (Segall 1968), hypochlorite-based sanitisers were more effective at low pH. This indicates that in some instances, acidification of alkaline wash-water (e.g. using citric acid) could improve the efficiency of chlorination. At the concentrations used, chlorine dioxide and peroxyacetic acid performed well over the 5.5 to 8.5 pH range, but both are known to perform best at low pH (White 1999).

The performance of sanitisers increased at the higher temperature, as expected (Sabaa-Srur et al. 1993). Kill rates at 20°C and 30°C were similar, but at 4°C kill rates were significantly lower. This demonstrates that, in cold water e.g. in hydrocoolers, contact time needs to be prolonged.

### Sanitiser effectiveness on surfaces

As expected (Gibson et al. 1996), surfaces were more difficult to sanitise than water. In some cases, compared with water, surfaces require ten times the concentration of disinfectant (van Klingeren et al. 1998). In general, sanitisers had similar performance on wood and aluminium. Peroxyacetic acid was the most effective on surfaces, whereas chlorine dioxide (which was the most effective in water tests) performed poorly. Wood was found to be the more reactive surface, and in some instances sanitisers become ineffective within 5 minutes of contact. We expect this could be overcome by increasing the sanitiser concentration, or the volume of sanitiser solution available to the surface. As with the suspension test, fungi were found to be more resistant than bacteria to sanitisers on surfaces.

The reductions of *E. coli* achieved on wood and metal surfaces (1–5 log<sub>10</sub>) are similar to the 1–4 log<sub>10</sub> reductions achieved by BCDMH on broccoli after 30 minutes (P. Harrup and R. Holmes, unpublished data). Smaller reductions (1.7–2.8 log<sub>10</sub>) were achieved by calcium hypochlorite on broccoli and lettuce when the contact time was 30 seconds (Behrsing et al. 2000).

The efficiency of disinfecting compounds is relative to the rate of diffusion of the active agent through the cell wall (White 1999). Therefore, the addition of suitable surfactants to reduce the surface tension on the cell wall could enhance surface sanitation (Kostenbauder 1977). This aspect deserves further study.

### Vegetable wash-water quality

Carrot wash-water quality deteriorates over time and other research (Morgan 2001) found higher than normal sanitiser concentrations were required to sanitise potato wash-water because of the accumulation of organic materials. While there are no specific standards for farm water supplies in Australia, levels of BOD and P measured in the waste-water exceed the Chinese standards for agricultural water (Anon. 1988). This is indicative that the used wash-water is unsuitable for discharge into waterways. Added to this, the presence of plant pathogens suggests a possible biological hazard if the water were reused without treatment for crop irrigation or carrot washing. Where various types of vegetables are washed in the same system, water treatment or replacement will be needed to prevent cross-contamination between heavily contaminated vegetables (which are usually cooked) and cleaner salad vegetables (which are usually eaten raw). Wash water contaminated with human pathogens has been shown to infiltrate fresh-cut lettuce and tomatoes through the stomata and wound sites (Zhuang et al. 1995; Seo and Frank 1999).

In Australia, there are numerous sanitising agents used throughout the horticultural industry, not only chlorine. Ongoing research is needed to optimise vegetable washing systems using different sanitisers, produce types, pathogens, surfaces, temperature, pH, water hardness, organic matter load, surfactants, flocculants, and filters. Further research is also needed on by-products from the breakdown of sanitisers (which may be toxic) and disposal methods for used wash-water. This would improve the performance of washing systems and potentially decrease waste production, water consumption, energy consumption, pathogen dispersal, environmental contamination, and residual health risks.

### Acknowledgments

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## References

- Anon. 1988. National standards of the People's Republic of China, environmental quality standards for surface water UDC614.7, GB3838-88 <<http://svr1-pek.unep.net/soechina/water/standard.htm>>.
- AOAC (Association of Official Analytical Chemists) 1984. Official methods of analysis, 14th ed. USA, Association of Official Analytical Chemists.
- Behrsing, J., Winkler, S., Franz, P., and Premier, R. 2000. Efficacy of chlorine for inactivation of *Escherichia coli*. *Postharvest Biology and Technology*, 19, 187–192.
- Bessems, E. 1998. The effect of practical conditions on the efficacy of disinfectants. *International Biodeterioration and Biodegradation*, 41, 177–183.
- Beuchat, L.R. and Ryu, J-H. 1997. Process handling and processing practices. *Emerging Infectious Diseases*, 3, 459–465.
- Coates, L. and Johnson, G. 1996. Postharvest diseases of fruits and vegetables. In: Brown, J.F. and Ogle, H.J., ed., *Plant pathogens and plant diseases*. Australia, Rockvale Publications.
- Dychdala, G.R. 1977. Chlorine and chlorine compounds. In: Block, S., ed., *Disinfection, sterilization and preservation*. London, Lea and Febier, 167–195.
- Gibson, H., Elton, R., Peters, W., and Holah, J.T. 1995. Surface and suspension testing: conflict or complementary. *International Biodeterioration and Biodegradation*, 36, 375–384.
- Graham, B.M. 1978. The development of Australian legislation for disinfectants. *Australian Journal of Hospital Pharmacology*, 8, 149–155.
- Hamilton, A. and Mebalds, M. 2000. In: *In the wash* newsletter, volume 1. Melbourne, Department of Natural Resources and Environment.
- Kostenbaurer, H.B. 1977. Physical factors influencing the activity of antimicrobial agents. In: Block, S., ed., *Disinfection, sterilization and preservation*. London, Lea and Febier, 912–932.
- Little, C.L., Monsey, H.A., Nichols, G.L., and de Louvois, J. 1997. The microbiological quality of refrigerated salads and crudites. *PHLS Microbiology Digest*, 14, 142–146.
- Morgan, B. 2001. Exposing *Erwinia* newsletter, Issue 3 (March 2001). Adelaide, South Australian Research and Development Institute.
- Sabaa-Srur, A.U.O., Brecht, J.K., Sargeant, S.A., and Bartz, J.A. 1993. Recommended chlorine levels for treatment of float-tank water in tomato packinghouses. *Acta Horticulturae*, 343, 337–343.
- Segall, R.H. 1968. Fungicidal effectiveness of chlorine as influenced by concentration, temperature, pH and spore exposure time. *Plant Pathology*, 58, 1412–1414.
- Seo, K.H. and Frank, J.F. 1999. Attachment of *Escherichia coli* 0157:H7 to lettuce leaf surface and bacterial viability in response to chlorine treatment as demonstrated by using confocal scanning laser microscopy. *Journal of Food Protection*, 62, 3–9.
- Tauxe, R., Hedberg, C., Potter, M., Madden, J., and Wachsmuch, K. 1997. Microbial hazards and emerging issues associated with produce. A preliminary report to the National Advisory Committee on microbiological criteria for foods. *Journal of Food Protection*, 60, 1400–1408.
- van Klingeren, B., Koller, W., Bloomfield, S.F., Bohm, R., Cremieux, A., Holah, J., Reeybrouck, G., and Rodger, H.J. 1998. Assessment of efficacy of disinfectants on surfaces. *International Biodeterioration and Biodegradation*, 41, 289–296.
- White, G. 1999. *Handbook of chlorination and alternative disinfectants*. USA, Van Nostrand Reinhold.
- Zhuang, R-Y, Beuchat, L.R., and Angulo, F.J. 1995. Fate of *Salmonella montevideo* on and in raw tomatoes as affected by temperature and treatment with chlorine. *Applied Environmental Microbiology*, 61, 2127–2131.

# Storage of Oriental Bunching Onions

Wu Li\*

## Abstract

Weight loss, visual quality, leaf discoloration and growing point extension are the major storage quality parameters for oriental bunching onion. With oriental bunching onions stored in the open air (30 to 40% relative humidity, RH) during winter, weight loss can be very high, sometimes greater than 50%.

Temperature and relative humidity were the two most important limiting environmental factors affecting the storage life of oriental bunching onions. Weight loss, leaf discoloration and growing point extension were monitored over a range of storage temperatures and humidities. Deterioration was more serious at 5 and 15°C than at 0°C. Temperatures of -1.5°C and -2°C were satisfactory for long-term storage, with leaves maintaining a good appearance for a further 7 days after withdrawal to 2°C. Appearance was better after storage at 95–100% RH than at 70–80% or 40–50% RH. A combination of low temperature and high relative humidity is ideal for storage of oriental bunching onions. Control of temperature with refrigeration is preferred, if economically feasible. Similarly, maintaining humidity to reduce moisture loss will improve quality. Simple methods for this range from use of film wraps to plastic sheets placed over shoots in bulk storage.

Atmosphere modification (2–3% O<sub>2</sub>/1–2% CO<sub>2</sub>, and 5–6% O<sub>2</sub>/1–2% CO<sub>2</sub>) was found to be more effective than air storage in extending the shelf life of oriental bunching onions. Growing point extension was also slowed by modified atmosphere storage.

ORIENTAL bunching onions are one of the main vegetables in northern China, with 8.5 million tonnes produced every year. They are stored in the open air during the winter, during which time weight loss is very high. This study was conducted to investigate the effects of temperature, relative humidity and atmosphere modification on the visual quality of oriental bunching onions.

## Materials and Methods

Freshly harvested 'Zhangqiu' oriental bunching onions grown in Sanhe County of Hebei Province were used in all experiments. ('Zhangqiu' is the main variety currently grown in this production area.) Ideal oriental bunching onions were selected and randomly

placed in boxes and controlled atmosphere bags at 15, 5, 0, -1, -2, or -4°C. The following relative humidity (RH) and atmospheric conditions were trialed: 95–100%, 70–80%, and 40–50% RH; and air, 2–3% O<sub>2</sub>/1–2% CO<sub>2</sub>, and 5–6% O<sub>2</sub>/1–2% CO<sub>2</sub>. Samples were removed from storage after 0, 2, 4, 6, 8, 12, 16, 20, or 24 weeks. Three replicates were used per treatment.

A TC-8800 colour and colour difference meter was used for colour measurements. Visual quality was divided into 9 scores, where: 9 = fresh with green leaves; 5 = fresh with mostly green leaves; and 1 = wilting with yellow leaves.

## Results and Discussion

### Effects of temperature and relative humidity on shelf life

Temperature and relative humidity were the two most important limiting environmental factors affecting the

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storage life of oriental bunching onions. Weight loss (Figure 1), leaf discoloration and growing point extension were monitored over a range of storage temperatures and humidities. Deterioration was more serious at 5 and 15°C than at 0°C. Temperatures of -1.5°C and -2°C were satisfactory for long-term storage, with leaves maintaining a good appearance for a further 7 days after withdrawal to 2°C. Appearance was better after storage at 95–100% RH than at 70–80% or 40–50% RH.

A combination of low temperature and high relative humidity is ideal for storage of oriental bunching onions. Control of temperature with refrigeration is preferred, if economically feasible. Similarly, maintaining humidity to reduce moisture loss will improve quality. Simple methods to do this range from the use of film wraps to plastic sheets placed over shoots in bulk storage.

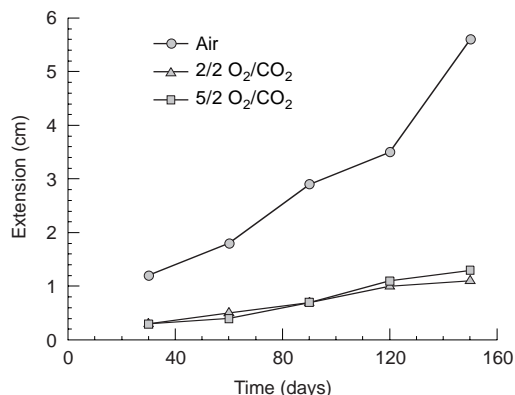
### Effect of atmosphere modification on shelf life

Atmosphere modification (2–3% O<sub>2</sub>/1–2% CO<sub>2</sub> or 5–6% O<sub>2</sub>/1–2% CO<sub>2</sub>) was found to be more effective than air storage in extending the shelf life of oriental bunching onions. Growing point extension was also slowed by modified atmosphere storage (Figure 2).

### Modified atmosphere packaging (MAP)

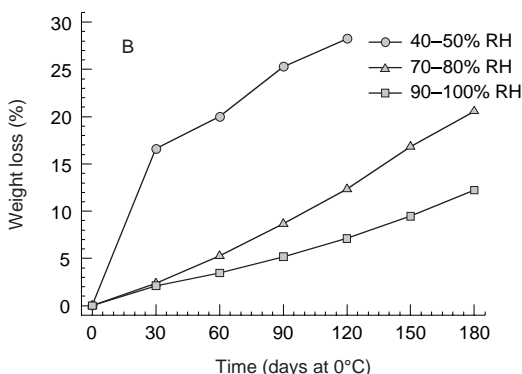
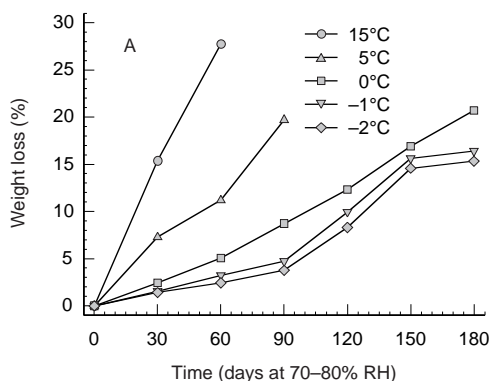
Package weight affected the atmospheric composition and visual quality of oriental bunching onions stored in MAP bags. Packages containing 1, 2, 4 or 5 kg of

onions reached steady state oxygen concentrations of approximately 14, 10, 6 and 3%, respectively, after a few days at 0°C (Figure 3A). Visual quality was best in packages with the lowest oxygen concentration (Figure 3B). The atmosphere within each package changed very little after it reached a steady state (Figure 3A).

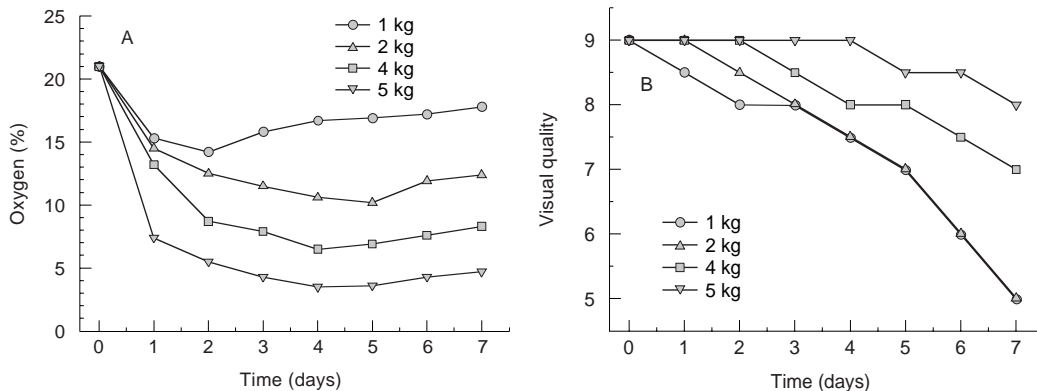


**Figure 2.** Reduction in growing point extension by modified atmosphere storage.

The practical introduction of MAP depends on cost and return. For MAP to generate stable atmospheres, refrigeration is needed, or at least an environment which guards against temperature abuse. MAP bags and refrigeration are currently used for garlic shoots, but these retail at four times the price of oriental bunching onions (and hence the additional cost can be justified).



**Figure 1.** Weight loss of oriental bunching onions during storage at various temperatures (A) and relative humidities (B).



**Figure 3.** Package weight of oriental bunching onions stored in modified atmosphere packaging (MAP) bags affects both the (A) oxygen concentration, and (B) the visual quality (see text) over time.

Traditional storage methods of oriental bunching onions are widely used in northern China. Liu Yehe (1956) and Lu Renqing (1981) point out that these methods do not inhibit leaf discoloration and growing point extension. The results of our study are similar to those of Li Xihong and Chen Li (2000) who found that 0°C, 95–100% RH and 1% O<sub>2</sub>/5% CO<sub>2</sub> are suitable storage conditions for young oriental bunching onions.

### Acknowledgment

This research work was supported in part by Australian Centre for International Agricultural Research Project PHT/1994/01616.

### References

- Liu Yehe 1956. Vegetable storage in Beijing suburbs. Publishing House of Economics, 72–85.
- Lu Renqing 1981. The handbook of vegetable production. Publishing House of Beijing, 346–379.
- Li Xihong and Chen Li 2000. Practical storage technology of fruits and vegetables. Scientific and Technical Documents Publishing House, 426–427.

# Storage of Chinese Cabbage

Lipu Gao, Shufang Zheng, Wu Li, and Ping Wu\*

## *Abstract*

Chinese cabbage is a popular vegetable in China and is cultivated in most areas. The total production area is about 700,000 ha. Chinese cabbage is stored for provision to markets during winter. Seed is planted in early autumn and the crop harvested at the beginning of winter (in Beijing, seed is planted in early August and harvesting takes place in early November). Much more attention is paid to the storage capacity when selecting cultivars and in growing Chinese cabbage for storage. Chinese cabbage makes up almost half the autumn vegetable production in northern China.

THE methods of storing Chinese cabbage have evolved over a long period. In some years up to 30 Mt may be stored. The storage methods include stacked storage, covered storage, and pit storage. In the 1970s, cold rooms were built, and Chinese cabbage was stored in them; in the 1980s, the Beijing Vegetable Research Center and Tsinghua University cooperated to develop a forced-air ventilation system; in the 1990s the system was adopted in Beijing, Tianjin, and inner Mongolia for Chinese cabbage. In Beijing, traditional storage methods have almost passed out of use.

## **Stacked Storage**

This form of storage is used in mild climatic areas or for short-term storage after harvest. In the field or a shaded place, the heads are stacked head inward and tail outward in either parallel-sided or cone-shaped stacks. Enough space is left between the heads to allow air circulation. Depending upon the surrounding temperature, the top of the stack may be covered when it is very hot or cold, otherwise cold air passing through the stack carries heat away.

## **Covered Storage**

This is also called ditch storage. In the Beijing area, the depth is 5–10 cm more than the length of Chinese

cabbage; the width is 1 m, with west–east orientation. The ditch length is determined by the amount to be stored. The key point for ditch storage is ground temperature: the closer it is to 0°C the better. Some assistance can be given to cooling the ditch such as a shading hedge or ventilation hole. So long as the surrounding temperature causes no damage to Chinese cabbage, they are left in the field. In the ditch, the heads of Chinese cabbage are packed closely together and the top is covered with leaves. When the surrounding temperature falls, the top is covered with soil. The temperature of the heads of cabbage must be held at 0°C. While exploiting low temperature and buffering effects of soil to get long storage life, there are disadvantages, such as difficulty of inspection and high losses.

## **Pit Storage**

This is the most common form of storage used for Chinese cabbage. Pits may be temporary—built with soil and wood, or permanent—built with bricks, cement, wood, or steel. All kinds permit good ventilation and temperature insulation.

Depending on the climate and level of groundwater, three kinds of pit can be built: above ground, half ground, and ground. With pit storage, Chinese cabbage is stored from November to March in the following year. After harvest, the cabbages are first trimmed and then arranged in parallel wall-type stacks with one head distance between the stacks. Ventilation is achieved by opening or shutting ventilation

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windows and shifting the heads of Chinese cabbage. Losses during pit storage are about 30–35%. Another disadvantage of pit storage is the labour cost for head shifting, which may be done up to 10 times during storage.

### **Cold Storage**

Chinese cabbage is cold stored on steel shelves, or in baskets or cartons. Attention needs to be paid to the high cost and water losses.

### **Ventilated Storage**

In order to reduce the need to turn the heads from time to time, semi-mechanical ventilated storage was developed by attaching ventilation systems to existing pit storages.

The ventilation system consists of an electric fan, ventilation channel, outlets for the channel, air mixing space, space between the Chinese cabbages, and

outlets from the pit. The fan pushes air into the ventilation channel and then through the outlets of the channel into the air mixing space, which is underneath the stacks of Chinese cabbage. Finally, the air is pushed through the spaces between the heads and then out through outlets from the pit.

In order to equilibrate the pressure in the ventilation channel, it was designed as a stair channel covered with cement slats. Spaces left between the slats form the outlets from the channel. The stacking format is ‘#’-like which guarantees that there will be spaces between the heads.

In ventilated storage, head shifting becomes unnecessary. It is no longer necessary to remove heads and reduce humidity and the natural source of cold air is well exploited. By using ventilated storage, 500 working days were saved and losses were reduced more than 10% when 100,000 kg Chinese cabbage was stored. The technique has been guaranteed a patent and granted an award by the Beijing Science Committee.

# Fresh-cut Asian Vegetables — Pak Choi as a Model Leafy Vegetable

T.J. O'Hare\*, A.J. Able†, L.S. Wong\*, A. Prasad\*, and R. McLauchlan\*

## Abstract

Pre-prepared fresh-cut salads are becoming increasingly common in the marketplace. Once dominated by lettuce, new vegetables are now being added to increase both flavour and visual appeal. A wide range of Asian brassicas is being sourced as constituents, but short shelf life because of yellowing is a problem to be contended with, and pak choi is a good example of this.

Yellowing in pak choi leaves is associated with a depletion of sugars (the main energy substrate). Increasing the initial leaf sugar level, or slowing the rate of sugar depletion, will directly increase shelf life. Sugars tend to be highest in younger leaves growing close to the tip, and lowest in leaves towards the base of the stem, even though the leaves may look similar in size and appearance. Removal of older leaves will therefore increase the life of a salad. Harvesting later in the day can also increase sugar levels, a result of photosynthesis during the day. Once harvested, leaves require sanitary washing and drying before packaging to avoid postharvest rots. Plastic packaging is vital to prevent wilting of leaves, but may also be used to provide an atmosphere conducive to slowing the rate of sugar depletion. Low oxygen (0.5–2% O<sub>2</sub>) and enhanced carbon dioxide (2–10% CO<sub>2</sub>) have been found to almost double shelf life in pak choi. However, for modified-atmosphere packaging to maintain an ideal atmosphere, stable temperature management is required, as high temperatures may lead to anaerobiosis and carbon dioxide toxicity of leaves. Common temperatures used for handling packaged salads range from 4° to 12°C. The above findings are for pak choi, but appear to apply also to many other Asian leafy brassicas used in fresh-cut salads.

ASIAN vegetables are a largely untapped resource for use in fresh-cut salads. Pre-prepared salads, both loose and pre-packed, are becoming increasingly common worldwide, catering to the consumer demand for convenience. A wide selection of Asian leafy vegetables can be utilised to add both visual appeal and flavour to salads. Many of these are members of the *Brassica* genus, which tend to have a common problem of leaf yellowing during postharvest handling.

The research literature on the practical use of Asian leafy brassicas is sparse, with much of the work having to be conducted from basic principles. In light of this,

our laboratory has conducted extensive trials investigating the use of Asian brassicas in fresh-cut salads (Prasad et al. 1997; Wong et al. 1997; O'Hare et al. 1998, 1999, 2000a,b; Able, Wong et al. 1999, 2000; Able, O'Hare et al. 2000). Because of the wide range of vegetables that can be used as salad constituents, our studies have focused on pak choi (*Brassica rapa* var. *chinensis*) as a model for other Asian leafy vegetables.

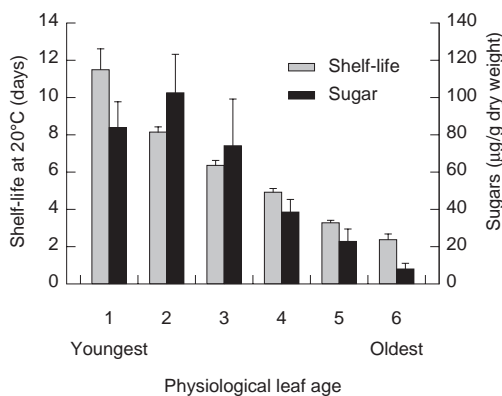
## Effect of Physiological Leaf Age

Brassica plants grow in a rosette, with older leaves toward the periphery and younger leaves towards the central growing point. Harvest of leaves for fresh-cut salads normally involves the cutting of leaves from the base of the plant, without actually removing the plant from the ground. This can be done either manually or by machine, but in both cases the harvest will consist of leaves of different physiological ages.

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In pak choi (and in many Asian brassicas) it is not uncommon for older and younger leaves to be similar in appearance, colour, and perhaps even size. Initially, this is of no consequence in a salad mix, but in time the older leaves start to yellow and become more susceptible to bacterial rots. This appears to be a result of the lower initial sugar levels in older leaves. Yellowing is linked to the availability of energy substrates, and since older leaves at harvest tend to have a lower initial supply of sugars, they have a shorter shelf life, yellowing significantly earlier (Figure 1). Consequently, avoiding the inclusion of older leaves in a salad mix increases salad shelf life. While there are several possible approaches to achieving this, it is an area in which more research is needed.



**Figure 1.** Shelf-life and initial sugar level of pak choi leaves of differing physiological age.

## Moisture Loss of Leaves

One of the most obvious problems with pak choi leaves is their propensity to wilt. This becomes exceedingly obvious when leafy salads are dispensed into supermarket display cabinets without the benefit of plastic packaging. Most, if not all, Asian leafy vegetables react no differently from lettuce and other Western leafy salad constituents, and will lose moisture quickly.

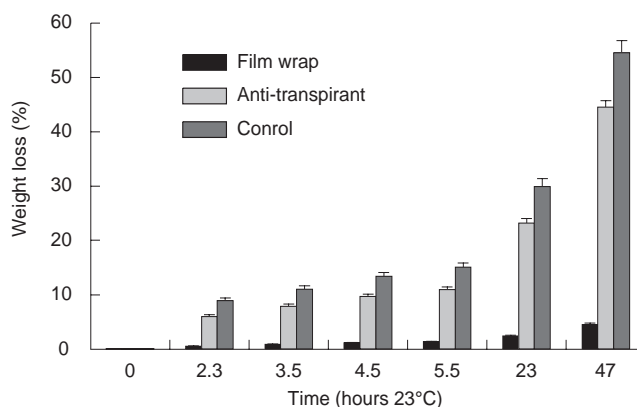
Packaged salads tend to retail at higher prices, which may reflect the added cost in manufacture, but they do reduce moisture loss very effectively, and are considerably more efficient than manually misting loose leaves, or treating leaves with an anti-transpirant (Figure 2).

One issue that should be emphasised is that plastic packaging does maintain a very high relative humidity, and hence sanitary washing before packing is essential to avoid bacterial rots. Again, pak choi is no different to conventional pre-prepared salad vegetables in this regard.

## Modified Atmosphere Packaging

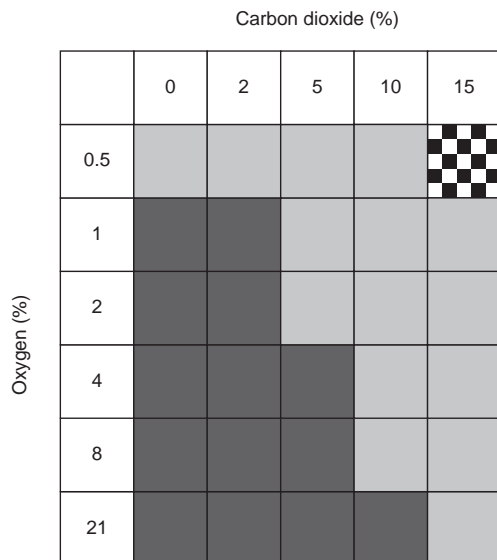
An additional advantage of plastic packaging is the ability to modify the package atmosphere to extend the life of the salad. With pak choi, yellowing can be retarded by reducing the oxygen concentration to approximately 0.5–2% and increasing carbon dioxide concentration to between 2 and 15% (Figure 3).

This reduces the rate at which sugars are used and can almost double the shelf life of leaves. Exposure to oxygen levels lower than 0.5% and carbon dioxide



**Figure 2.** Retardation of moisture loss in pak choi leaves using plastic film and anti-transpirants. Of the two alternatives, film wraps were considerably more effective.

levels higher than 15% for an extended length of time should be avoided, as the former will result in anaerobiosis and the latter will result in carbon dioxide toxicity, both of which will cause off-odours, and eventually tissue breakdown.



**Figure 3.** Combinations of oxygen and carbon dioxide capable of delaying leaf yellowing in pak choy (dark grey = no effect; light grey = increase; chequered = toxic to leaves)

Conventional modified atmosphere packaging requires strict temperature management of the handling system, as increases in temperature will lead to a change in the package atmosphere. The change can either shift the atmosphere away from the ideal (and shorten shelf life), or shift the atmosphere into oxygen and carbon dioxide concentrations that are toxic to the product. Packages are normally designed to operate within a narrow temperature range, and are usually marketed between 4°C and 12°C.

## Conclusions

Asian leafy vegetables appear to be amenable to use as salad constituents. They should be treated similarly to other leafy vegetables in that they require sanitary washing and will lose moisture if not packaged adequately. Unlike lettuce, the shelf life of many Asian brassicas is limited by leaf yellowing rather than browning. However, atmospheres for retarding yellowing are similar for that used to extend lettuce shelf life, and hence mixing of vegetables should not be restricted.

## Acknowledgments

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## References

- Able, A.J., O'Hare, T.J., Wong, L.S. and Prasad, A. 2000. Extending the shelf life of broccoli florets and pak choy leaves. In: Johnson, G.I., Le Van To, Nguyen Duy Doc, and Webb, M.C., ed., Quality assurance in agricultural produce. Proceedings of the 19<sup>th</sup> ASEAN/1<sup>st</sup> APEC Seminar on Postharvest Technology, 9–12 November 1999, Ho Chi Minh City, Vietnam. Canberra, ACIAR Proceedings No. 100, 444–450.
- Able, A.J., Wong, L.S., Prasad, A., and O'Hare, T.J. 1999. Postharvest physiology of pak choy (*Brassica rapa* var. *chinensis*). Australasian Postharvest Horticulture Conference Proceedings, 3–8 October 1999, Waitangi, New Zealand, 33.
- Able, A.J., Wong, L.S., Prasad, A., and O'Hare, T.J. 2000. Physiological leaf age and senescence of pak choy leaves. 'Combio 2000', 11–14 December 2000, Auckland, New Zealand.
- O'Hare, T.J., Able, A.J., Wong, L.S., and Prasad, A. 1999. Retardation of yellowing in broccoli florets and pak choy leaves by 1-methylcyclopropene. Australasian Postharvest Horticulture Conference Proceedings, 3–8 October 1999, Waitangi, New Zealand, 34.
- O'Hare, T.J., Wong, L.S., and Prasad, A. 1998. Extension of postharvest shelflife of fresh-cut pak choy, tatsoi, mizuna and choy sum by atmosphere optimisation. 4<sup>th</sup> Australian Horticulture Conference, 14–17 October, Melbourne, 36.
- O'Hare, T.J., Wong, L.S., Prasad, A., and Able, A.J. 2000a. Impact of exogenous and endogenous factors in the shelflife of fresh-cut leafy Asian vegetables. 4<sup>th</sup> International Conference on Postharvest Science, 26–31 March 2000, Jerusalem, Israel (in press).
- (2000b). Atmosphere modification extends the postharvest shelflife of fresh-cut leafy Asian brassicas. Proceedings of the 3<sup>rd</sup> ISHS International Symposium on Brassicas, 5–9<sup>th</sup> September 2000, Wellesbourne UK. Acta Horticulturae, 539, 103–107.
- Prasad, A., Wong, L.S., and O'Hare, T.J. 1997. Temperature storage of minimally processed Asian leafy vegetables. Australasian Postharvest Conference, 1997, Hawkesbury, New South Wales, 322–325.
- Wong, L.S., Prasad, A., and O'Hare, T.J. 1997. Shelf-life extension of minimally-processed Asian vegetables using controlled atmospheres. Australasian Postharvest Conference, 1997, Hawkesbury, New South Wales, 211–214.

# Forced-air Pre-cooling of Vegetables

Lipu Gao, Shufang Zheng, and Wu Li\*

FORCED-air pre-cooling is a technique for rapidly removing the heat from vegetables. The cost of forced-air pre-cooling is almost same as that for cold room pre-cooling, but forced-air pre-cooling is faster.

In China, research on, and application of, forced-air pre-cooling began only recently. Since the 1980s the production and transportation of vegetables has increased sharply, and almost all pre-cooling has been cold room pre-cooling. The forced-air pre-cooling system was introduced from Japan and research on the technique undertaken in Beijing Vegetable Research Center. Since the 1990s, exports of vegetables have been increasing annually, and the cold room pre-cooling capacity is no longer sufficient. Beijing Vegetable Research Center and Tsinghua University cooperated to design and develop a forced-air pre-cooling system, in order to meet market demand and increase pre-cooling efficiency.

Three models of portable equipment for forced-air pre-cooling have been developed and cold-room

tested during three years of research: CYYLJ-16 (0.5–1 t capacity); CYYLJ-32(1–2 t); and CYYLJ-80 (3–4 t). Also, a pre-cooling cold room with 12 t capacity was constructed at a vegetable production demonstration in Chaoyang District.

After an evaluation of the system, it is considered to be efficient in pre-cooling vegetables. The internal temperature of Chinese cabbage was still 6–8°C after 20 hours in a cold room, but it had fallen to 4°C after 5 hours of forced-air pre-cooling. Using forced-air pre-cooling, the temperature of tomatoes could be reduced from 27° to 10°C in 5 hours; of sweet pepper from 34° to 13°C in 3.5 hours; and of cucumber from 28° to 13°C in 3.5 hours.

In order to promote application of the equipment, operational guides to pre-cooling ten kinds of vegetables (tomato, cucumber, sweet pepper, eggplant, snow pea, broccoli, Chinese cabbage, lettuce, celery, and pak choy) were developed. The forced-air pre-cooling technique is now in use in the Beijing area.

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# Effect of Hot Water Treatment on Postharvest Shelf Life and Quality of Broccoli

Ping Wu and Wu Li\*

## Abstract

Broccoli was stored at 0, 10, or 20°C after immersion in hot water (38–52°C) for 10 or 30 minutes. Yellowing of broccoli was significantly slowed and shelf life significantly increased when broccoli was treated at 42–46°C and then stored at 10 or 20°C. Heat injury occurred when treatment was higher than 46°C. Broccoli shelf life was 2–3 days longer when stored at 10°C and 1–2 days longer when stored at 20°C after hot water treatment at 46°C. There was no significant effect of treatment on shelf life after long-term storage at 0°C. Weight loss was reduced by hot water treatment and the respiratory behaviour of the broccoli also changed.

BROCCOLI is a highly perishable fresh vegetable. After harvesting, it turns yellow and becomes unmarketable within 1–3 days at room temperature (Wang and Hruschka 1977). Storage at low temperature can reduce the rate of senescence. Storage in a controlled atmosphere (CA) or modified atmosphere (MA) can also extend the storage life of broccoli (Barth et al. 1993). Zong et al. (1985) reported that the shelf life of broccoli was more than 4 weeks when held at 0°C using MA packaging.

Heat treatments can also alter senescence of broccoli (Paull 1990). Forney (1995) and Kazami et al. (1991a, 1991b) reported that dipping broccoli in hot water delayed yellowing. Kazami et al. (1991a,b) reported the effect of hot treatments on loss of soluble protein, respiration, and ethylene production.

In the experiments detailed in this paper, the optimal hot water treatment to maximise storage life of broccoli cultivars common to China was identified. The effects of treatments on weight loss and decay were also investigated.

## Materials and Methods

### Hot water treatment

Three cultivars of broccoli were used in the experiments: 'Lilu', 'Luling', and 'B-53'.

The broccoli was immersed in hot water at selected temperatures between 38 and 52°C for 10 or 30 minutes and then dried by shaking gently and leaving at room temperature for 30 minutes. The treated broccoli was then stored at the desired temperature (0, 10, or 20°C).

### Packaging

The broccoli for grading and colour assay was placed into 0.03 µm polyethylene bags with folded openings. The broccoli used for respiration measurements was put into a container with a known volume when required.

### Colour assay

The colour was determined using a chromameter (CR-200). Five broccoli heads from each treatment were assayed. A position approximately 3 cm from the flower centre was selected as the assay site. Three sites were assayed for each broccoli head.

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## Respiration assay

The storage container was sealed before assay. The CO<sub>2</sub> concentration was determined by near infrared (NIR) analysis (RLR-2000) after several hours.

## Results

### Quality changes and general observations

The most significant effect on the quality of broccoli following treatment with hot water in the range 38–50°C was the retardation of yellowing. If treated with hot water higher than 48°C, heat injury occurred and off-odours were produced such that its edibility was lost. The ideal hot water treatment was 46°C for 10 minutes. After storage at 10 or 20°C for several days, the quality of the hot water dipped broccoli changed less than that of untreated samples. No obvious heat injury on the surface of the broccoli head was found.

### Postharvest colour change

The most significant effect of hot water treatment on broccoli is the retardation of yellowing, even in those broccoli heads treated with higher temperature water such that heat injury occurred. In the range 42–48°C, the higher the hot water temperature was, the higher the hue angle of the broccoli after storage at 10°C (Figure 1) or 20°C (Figure 2).

### Respiration rates of broccoli after harvest

The respiration rate of broccoli after harvest was determined for a combination of different hot water treatments and storage temperatures (Figures 3–5). The respiration rate of broccoli was significantly altered by the hot water treatments. At 10°C, the broccoli treated at 42, 44, and 46°C all reached the highest respiration rate on the sixth day after harvest (Figure 4). However, the control reached its respiration peak on the fourth day after harvest. Changes in the respiration rate of broccoli stored at 0 and 20°C were difficult to determine.

### Weight loss of broccoli during storage

The weight loss during storage of broccoli treated with hot water was significantly less than that of untreated samples (Table 1).

### Shelf life of broccoli

As the yellowing of broccoli was delayed by hot water treatment, the shelf life of broccoli was therefore

extended (Figure 6). After hot water treatment, the shelf life of broccoli was extended by 2–3 days when stored at 10°C and 1–2 days when stored at 20°C. The visual quality, smell, and flavour of treated broccoli did not show the deterioration that untreated broccoli did after storage at 10° or 20°C. There was no obvious effect of hot water treatment on storage life when the broccoli was stored at 0°C for 6 weeks.

**Table 1.** The weight loss (%) of broccoli after 14 days storage at 10°C.

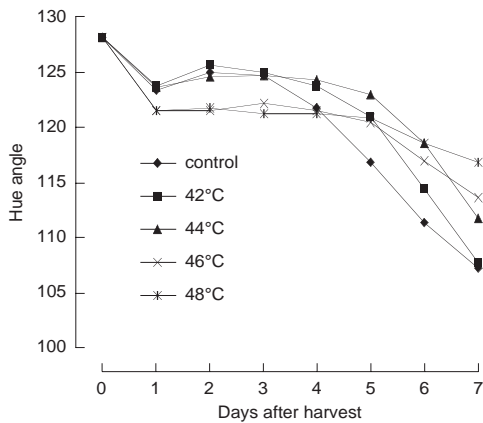
Treatment temperature (°C)	Treatment time (minutes)	
	10	30
38	5.3	6.1
42	4.3	4.6
46	4.2	4.3
50	10.3	19.8
Control	5.7	

## Discussion

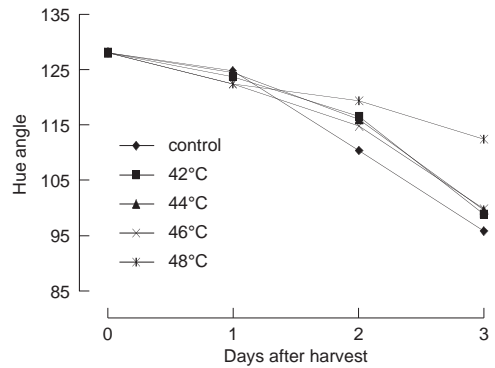
From the results of our three experiments, treatment with hot water in the temperature range 38–48°C had the most obvious effect on slowing the otherwise rapid postharvest yellowing of broccoli. Generally, the effect was best when the broccoli was treated at 46°C for 10 minutes. Hot water treatment can also delay the yellowing of broccoli if the water temperature is lower than 46°C. Hot water treatment appeared to have a greater effect when maintained for a longer time; that is, in general the 30-minute treatment was more effective than the 10-minute treatment. At higher temperatures, heat injury was observed and was detrimental to broccoli storage.

Cultivar 'B-53' was able to endure the 48°C treatment for 10 minutes in our experiments. The treated broccoli had no obvious heat injury or off-odours after storage, and the yellowing was delayed significantly. Higher treatment temperature tolerance varied between cultivars. The optimal treatment temperature was also dependent upon the time of harvest. The ideal treatment therefore has to be determined for each season and each cultivar.

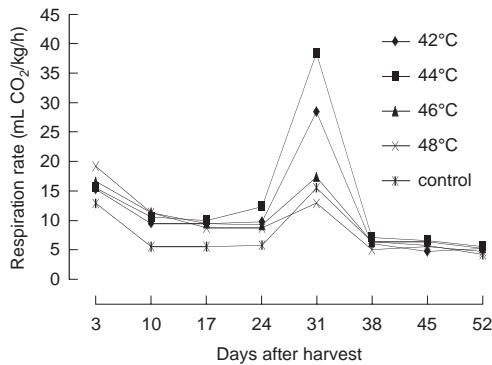
The growth conditions of broccoli can also influence the effect of postharvest heat treatment. In one of our experiments, many fungi infected the treated broccoli but there was no relationship between the extent of infection and the temperature of the hot water treatment. The control, on the other hand, suffered less



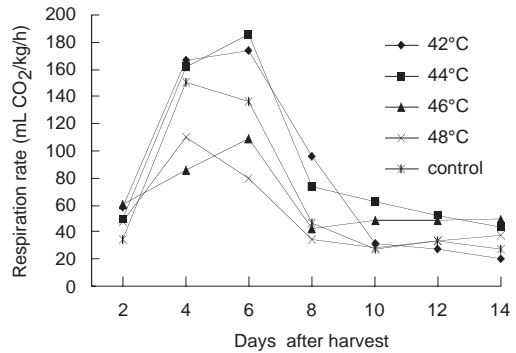
**Figure 1.** Postharvest colour changes in broccoli stored at 10°C following treatment with hot water at various temperatures.



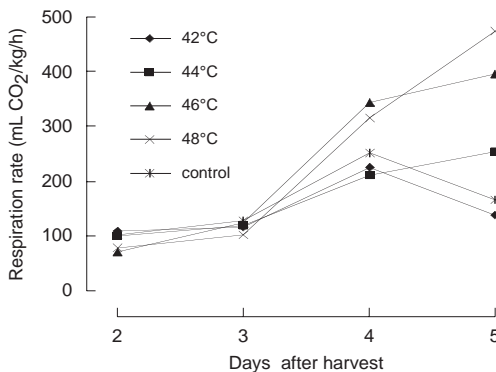
**Figure 2.** Postharvest colour changes in broccoli stored at 20°C following treatment with hot water at various temperatures.



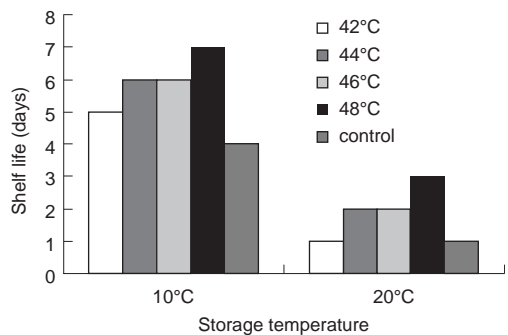
**Figure 3.** Postharvest respiration rate of broccoli stored at 0°C following treatment with hot water at various temperatures.



**Figure 4.** Postharvest respiration rate of broccoli stored at 10°C following treatment with hot water at various temperatures.



**Figure 5.** Postharvest respiration rate of broccoli stored at 20°C following treatment with hot water at various temperatures.



**Figure 6.** Effect of treatment with hot water at various temperatures on shelf life of broccoli stored at 10 and 20°C.

infection. Hot water treatment in this circumstance was not beneficial.

Three storage temperatures were selected in our experiments (0, 10, or 20°C). The results showed that hot water treatment can efficiently delay the yellowing and prolong the shelf life of broccoli when it is stored at 10 and 20°C. When the broccoli was stored at 0°C, heat treatment had no obvious effect. After 6 weeks of storage at 0°C, the untreated broccoli began to yellow, lose surface moisture, and show signs of fungal infection. The treated broccoli also started to lose moisture from the surface and become infected by fungi. Thus, we conclude that heat treatment before storage at 0°C will provide no benefits. Broccoli can be stored well at 0°C by using appropriate packaging and other methods.

Heat treatment changed the respiratory behaviour of broccoli so that the respiration peak of treated broccoli was delayed. However, owing to difficulties with our method for measuring respiration rates, we could not determine the exact respiration rate of the heat-treated broccoli. In the experiments, 3 to 4 broccoli heads were placed in one container to assay. Differences between the individual broccoli heads in respiratory rate and differing fungal infections on each head will influence not only the precision with which the respiratory rate can be measured but also the postharvest physiological state of other broccoli in same container. Hence, the experimental error will increase. This will be corrected in future experiments.

Based on theory and the results of our experiments, this treatment has potential for application in China. At present, the time from harvesting to marketing of broccoli in China is usually at least 1 to 2 days. In developed countries, there is a complete cold-chain system to ensure the postharvest quality of broccoli. However, methods widely used in developed countries such as pre-cooling have not been applied broadly in China, so the selling quality of broccoli cannot be ensured. Because of the limited mass production of broccoli by

individual farmers, especially in spring, the farmers cannot afford to purchase large amounts of pre-cooling equipment and refrigerated transport. The problem of lower selling quality of broccoli could be solved to some extent if the shelf life is increased by 1 to 3 days by heat treatment.

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## References

- Barth, M.M., Kerbel, E.L., Broussard, S., and S. J. Schmidt, S.J. 1993. Modified atmosphere packaging protects market quality in broccoli spears under ambient temperature storage. *Journal of Food Science*, 58, 1070–1072.
- Forney, C.F. 1995. Hot-water dips extend the shelf life of fresh broccoli. *HortScience*, 30, 1054–1057.
- Kazami, D., Sato, T., Nakagawa, H., and Ogura, N. 1991a. Effect of pre-storage hot water dipping of broccoli heads on shelf life and quality during storage. *Nippon Nogeikagaku Kaishi*, 65(1), 19–26. (in Japanese with English summary)
- 1991b. Effect of pre-storage hot water dipping of broccoli heads on soluble protein, free amino acid contents and protease activities during storage. *Nippon Nogeikagaku Kaishi*, 65(1), 27–33. (in Japanese with English summary)
- Paull, R.E. 1990. Postharvest heat treatments and fruit ripening. *Postharvest News & Information*, 1, 355–363.
- Wang, C.Y. and Hruschka, H.W. 1977. Quality maintenance in polyethylene-packaged broccoli. U.S. Department of Agriculture Marketing Report, 1085.
- Zong, R.J., Huang, B.Y., and Li, W. 1985. Studies on storage technique of broccoli. *Chinese Vegetables*, 15. (in Chinese)

# Effect of Salicylic Acid on Shelf Life of Broccoli

Ping Wu and Wu Li\*

## Abstract

Salicylic acid (SA) solution was tested as an ethylene inhibitor in broccoli. Broccoli was immersed in 0 to 2 g/L SA solutions for 10 minutes, stored at 10°C and changes in colour, and in content of soluble protein and sugar were determined. It was found that low-concentration SA dips (0–0.5 g/L) delayed yellowing of broccoli, but immersion at high concentrations (2 g/L) had no benefit on increasing shelf life. However, the effect of SA in low concentration was not statistically significant.

SALICYLIC acid (SA) is a simple phenolic compound occurring extensively in higher plants. It plays a role in regulating many physiological and biochemical reactions in plants (Li and Pan 1995). Raskin (1992) proposed that SA could be regarded as a new kind of endogenous phytohormone. Because it inhibits the biosynthesis of ethylene, it has been used to extend the shelf lives of fruit and vegetables. Research results have shown that SA inhibits some postharvest physiological changes in apples and has some effectiveness in keeping the freshness of tomatoes, apples, and pears (Yan et al. 1998). Li and Han (1998) found that SA gave some control of postharvest rots in peaches.

Broccoli is a highly perishable vegetable. After harvesting, it turns to yellow and becomes unmarketable very quickly at room temperature (Wang and Hruschka 1977). Research has shown that ethylene is one of the main factors causing yellowing and senescence of postharvest broccoli (Wang 1977).

In the work reported here, a SA solution was tested as an ethylene inhibitor in broccoli. The effects of immersion in different concentrations of SA solution on colour changes, soluble protein content, and shelf life were investigated.

## Methods and Materials

Hue angle (used as a measure of yellowing) was measured using a Minolta chromameter (CR-200). Three sites were assayed on each floret and the average of 10 readings on florets was calculated.

Soluble protein was extracted using a sodium dodecyl sulfate (SDS)-based method (Pogson and Morris 1997) and was then assayed using a protein analysis kit (Bio-rad) based on the Bradford method (Bradford 1976).

General appearance (GA) was determined using a scale of 1 to 9, where 9 was the best condition and 1 was the worst. When florets reached a GA score of 5.5, they were considered to be at the end of their shelf life.

## Results and Discussion

### Postharvest colour change

From the results of colour changes in broccoli (Figure 1), it was found that the yellowing rate of the broccoli treated with a SA solution whose concentration was in the range 0.01–0.5 g/L was lower than that of control samples. Treatment with SA solutions of higher concentration gave no benefit in slowing down the yellowing of broccoli.

### Soluble protein content during storage

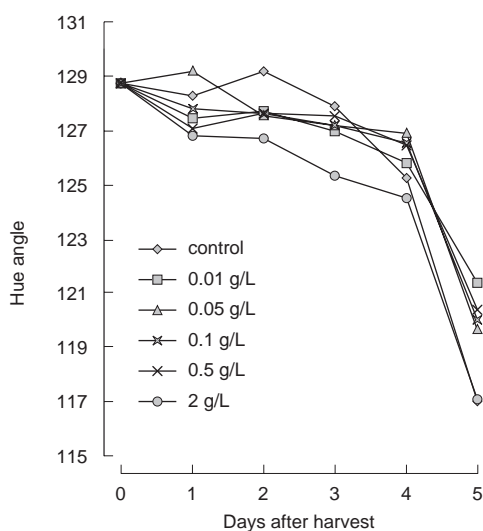
The results of soluble protein content determination (Table 1) showed that soluble protein content fell during storage at 20°C, but the rate of decrease varies. After 3 days storage at 20°C, the soluble protein

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content was higher in treated broccoli than that in the control.

### The postharvest shelf life of broccoli

As the yellowing of broccoli was delayed by SA treatment, the shelf life was therefore extended (Figure 2). When treated with a 0.01–0.5 g/L SA solution treatment, the shelf life was extended by 1 day when the broccoli was stored at 10°C. Within this range of SA concentrations, there was no difference between the effect of different concentrations on shelf life. Immersion at a higher concentration of 2 g/L had no benefit in increasing shelf life.



**Figure 1.** Postharvest colour change in broccoli following treatment with various concentrations of salicylic acid.

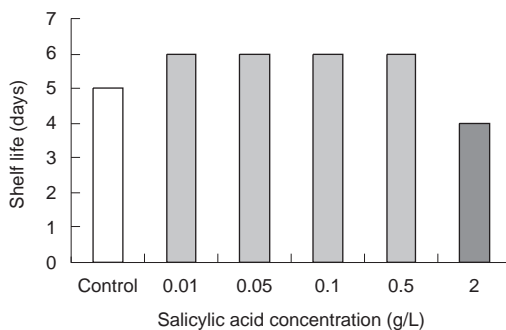
**Table 1.** Effect of salicylic acid (SA) treatment on soluble protein content of broccoli during storage at 20°C.

Days of storage	1	2	3
Control	11.16	5.79	5.56
0.1 g/L SA	12.09	7.90	7.30
0.5 g/L SA	10.83	8.71	8.78

Because there are no ethylene production data, the exact effect of SA on broccoli is not clear from this test. Compared with the effects of other ethylene

inhibitors on broccoli (Wang 1977), the effect of SA on broccoli shelf life is not significant.

Other researchers have found that low concentrations of SA similarly affect postharvest quality of other products: tomato (0.1 g/L; Yan et al. 1998), peach (0.1–0.3 g/L; Li and Han 1998), and pear (0.1 g/L; Yan et al. 1998). Our experiments reached a similar conclusion. However, further experimental work is needed to confirm the precise effect and mode of action of SA on shelf life of broccoli.



**Figure 2.** Effect of salicylic acid treatment on shelf life of broccoli stored at 10°C.

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### References

- Bradford, M.M. 1976. Quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry*, 72, 248–254.
- Li, D.H. and Pan, R.Z. 1995. Role of salicylic acid in plant. *Plant Physiology Communications*, 31(2), 144. (in Chinese)
- Li, L.P. and Han, T. 1998. Primary studies of salicylic acid on keeping freshness of peach. *Food Science*, 6, 61–63. (in Chinese)
- Pogson, B.J. and Morris, S.C. 1997. Consequences of cool storage of broccoli on physiological and biochemical changes and subsequent senescence at 20°C. *Journal of the American Society of Horticultural Science*, 122, 553–558.
- Raskin, I. 1992. Role of salicylic acid in plants. *Annual Review of Plant Physiology and Plant Molecular Biology*, 43, 439–463.

- Wang, C.Y. and Hruschka, H.W. 1977. Quality maintenance in polyethylene-packaged broccoli. US Department of Agriculture Marketing Report, 1085
- Wang, C.Y. 1977. Effect of aminoethoxy analog of rhizobitoxine and sodium benzoate on senescence of broccoli. *HortiScience*, 12, 54–56.
- Yan, T. et al. 1998. Effect of salicylic acid on fruit ripeness. *Acta Botanica Sinica*, 15(3), 61–64. (in Chinese)

# Using Benzothiadiazole and Biocontrol Microorganisms for Protection of Melon from Diseases

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## *Abstract*

Melon production is seriously damaged by powdery mildew and postharvest diseases in inner-Mongolia, China. Benzothiadiazole (BTH) and some biological control microorganisms showed significant activity in suppressing these diseases. Seed treatment of Hualaishi melon using biocontrol agents T4, B908, and TK7a resulted in more healthy seedlings compared with non-treated controls. Postharvest application of biocontrol agents on melon fruits also significantly reduced production losses caused by rot diseases. CPF-10, B908, and T4 were the most effective strains in the postharvest test. BTH, a compound that can stimulate systemic acquired resistance (SAR) in various plants, was sprayed on the melon plants during the flowering period. This procedure reduced the incidence of powdery mildew disease. Furthermore, melon fruits after BTH treatment ripened one week earlier, and resulted in a higher economic return in the market. Our results from both greenhouse experiments and field trials suggested that application of BTH and biocontrol microorganisms is a practicable approach for melon production in China.

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