Hort Innovation

Final Report

Identifying and sharing postharvest best practice on-farm and online

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Applied Horticultural Research

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VG13083

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Content

Summary

This project has compiled and communicated the latest in postharvest technology for vegetables. Information has been collated from the scientific literature, books and reports. In addition, trials were conducted where information was lacking or suspected to be outdated. These focused on measuring storage life of different vegetables at a range of temperatures, and measuring the rate of weight loss as affected by temperature and relative humidity.

Trials have demonstrated that it may not always be necessary to cool product to the 'optimum' temperature to achieve the quality and shelf life required for transport and retail. For example, although broccoli is 'optimally' stored at 0°C, storage at 2°C or even 4°C will keep it in excellent condition for at least 3 weeks, ample for normal domestic supply chains.

Another significant finding was that some chilling sensitive products, such as capsicums, eggplant and zucchini, can be stored for several days or even longer at low temperature before damage occurs. In the case of red and green capsicums, storage life was longest at 2°C and 4°C respectively; it took longer for the development of chilling injury to reduce quality than the rots which inevitably develop at higher – widely recommended – temperatures of 7°C or more.

Models were developed estimating daily potential moisture loss at a range of temperatures and humidity. This provides a tool for growers determining an appropriate rate of over pack for cartons or packages. The aim is to ensure packages are over the stated weight by the time they arrive at retail without giving away excess product.

This information has been compiled into a series of extension materials. These include a 150pp book "Postharvest management of vegetables; Australian supply chain handbook", numerous product fact sheets and a website which hosts all of the information compiled plus additional pictures, diagrams and reference material.

The materials have also been presented to growers in a National postharvest 'Roadshow". In total 12 workshops have been held in major vegetable production regions. Following an initial all-day pilot, this was refined into a 3-hour intensive workshop which included hands-on demonstrations, practical exercises, and region specific information. The workshops were very well received, with nearly all participants commenting how much they enjoyed the presentations and that they took home new ideas to use in their businesses. Encouragingly, additional requests for workshops were received which could not be accommodated within the project timeline.

The project has therefore demonstrated a strong demand within vegetable industry supply chains for information and training in postharvest management. This is an area which has had less attention in recent years, but is clearly critical in terms of reducing waste, avoiding unnecessary costs and meeting consumer demands. It is recommended that some postharvest training and extension activities should continue. These could take the form of short courses, an annual Masterclass, or even a training package developed for retailers.

Keywords

Postharvest, Vegetable, Cooling, Temperature, Humidity, Condensation, Storage, Packaging, Shelf life, Quality, Microbes, Modified atmosphere, Controlled atmosphere, Quarantine, Safety, Physiology.

Introduction

In the last few years the vegetable industry has invested significantly in research to increase productivity and find production efficiencies. More recently, several projects have focused on understanding consumers and creating new, value added products to increase consumption. Postharvest management, the vital link between the farm and the consumer, has generally had less attention.

Perhaps surprisingly, this is by no means a local phenomenon. There has been little basic research on postharvest management of vegetables for at least 20–30 years. Although there is a range of references that provide information on optimum storage temperature and expected shelf life, many are actually based on a single source of information; "*The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks, USDA Agricultural Handbook 66*". Although this book has been revised three times since it was first published in 1954, recommendations have generally changed little over the years.

Moreover, most references only cite shelf life at an optimum temperature. However, these conditions may not be achievable, or even desirable. For example, the USDA material recommends 0°C storage for 23 of 34 vegetable lines. However, 0°C storage increases energy and equipment costs and risks freezing product, often for little additional storage life compared to storage at 2°C or higher. If only a short storage life is needed to transport and distribute the product, these costs are not justified by returns.

At the same time, the way we grow vegetables, and the type of products produced, have changed radically. Hydroponic and greenhouse production, new varieties and entirely new categories (fresh cut, babyleaf) mean that the products now marketed bear scant resemblance to those used to conduct original research in the 1950's.

Despite this, temperature is a common cause of rejection of product by retailers. Product specifications, especially for chilling sensitive products, include delivery temperature limits based on old recommendations that may not be appropriate to new varieties. Chilling is a function of time, as well as temperature, so demonstrating that brief periods at potentially damaging temperatures do not impact product quality would appear to directly benefit producers.

This project has conducted new research into postharvest storage of vegetables, examining the effect of temperature on storage life for a range of important levy paying vegetables. We have also modelled rates of water loss according to temperature and humidity, and identified how much water some products can lose before becoming unacceptable.

This new data has been combined with information in peer reviewed literature, books and industry reports. The result is a range of resources to help growers determine appropriate cooling, packing, storage and transport methods for vegetables. These include a handbook, fact sheets, and website. Major extension activities have also occurred during the project, with workshops conducted in all Australian states in major vegetable production regions. The project has therefore successfully communicated the very latest in postharvest management of vegetables to the Australian vegetable industry.

Methodology

Storage life trials

A series of storage trials were conducted examining storage and shelf life of a range of levy paying vegetables at 2, 4, 7 and 12°C. These primarily focussed on vegetables for which there was either no information available, or for which information was inconsistent / outdated.

Table 1. Vegetables for which shelf life was tested at 2, 4, 7 and 12°C, list based on either a lack of existing information, or that available information was conflicting / inconsistent.

No information	Inconsistent information
Buk choy	Red capsicum
Choy sum	Green capsicum
Gai lan	Cucumber (field)
Bitter melon	Cucumber (greenhouse)
Baby spinach	Eggplant (greenhouse and field)
Rocket	Green beans
Kale	Baby squash
Spring onion	Zucchini

Vegetables that had been harvested within the previous 24 hours were either sourced locally direct from growers, or through Sydney Markets. In each case, samples (approx. two to three cartons) were divided equally among the four storage temperatures and placed in plastic trays loosely covered with plastic film to maintain high RH around the product.

Products were stored at each temperature for a defined period. Leafy vegetables were assessed for quality immediately on removal to 20°C, whereas chilling sensitive products were kept at 20°C for 2 days before assessment. This allowed any chilling injury to become apparent, as symptoms are often masked immediately after removal from low temperature storage.

One of the challenges with measuring storage life for vegetables is defining exactly when a product is no longer 'marketable' or 'acceptable'. Except for moisture loss, there are few objective measures that can be used to define senescence. Pictorial and descriptive grading scales were developed for each product to help ensure that grading was consistent.

Quality attributes were assessed using a five point scale, where 1 = excellent, fresh; 2 = good, marketable; 3 = OK, not marketable but still edible; 4 = poor and 5 = fully senescent. Data was graphed against storage time to allow estimation of the number of days until overall quality fell below grade 2. Examples of chilling sensitive and non-chilling sensitive product are shown in Figure 1. Each trial was replicated in time 2 or 3 times.

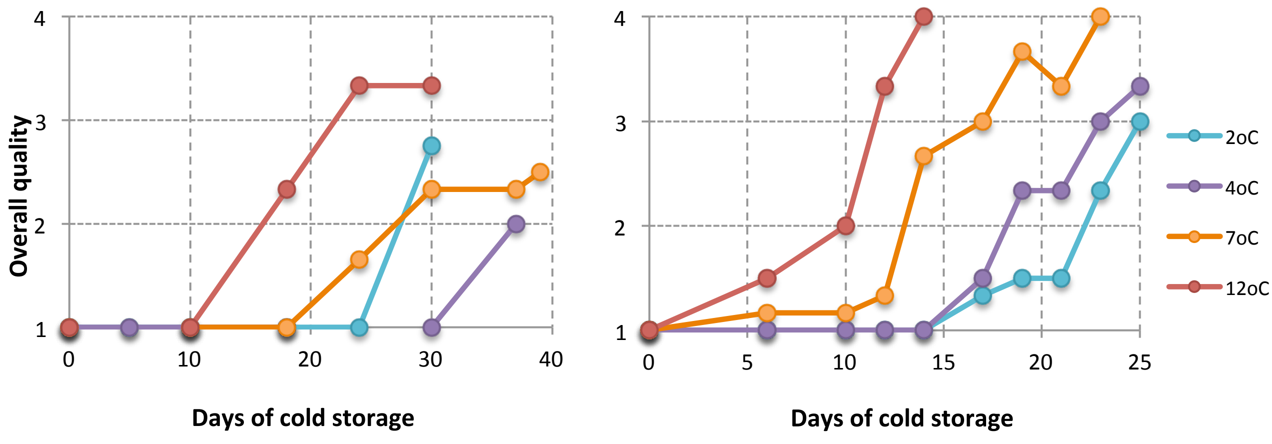


Figure 1.The effect of storage temperature and time on quality of green capsicum (left) and buk choy (right). Quality was assessed 2 days (capsicum) or immediately (buk choy) after removal from storage.

Moisture loss trials

These trials examined rates of moisture loss and the amount of weight that could be lost before product was no longer acceptable. Vegetables tested in this way included: beans, broccoli, Brussels sprouts, cabbage, carrot, cauliflower, celery, choy sum, cucumber (field and greenhouse), eggplant, lettuce (butter and iceberg), kale, pak choy, parsnip, pumpkin (butternut), shallots, silverbeet, sweetpotato and zucchini.

For each product nine bunches / items / groups of three were purchased. Three units were placed at 5°C, 20°C and either 2°C or 10°C. Temperature and relative humidity were monitored throughout. Samples were re-weighed at appropriate intervals ranging from 1–10 days and acceptability recorded.

Each trial was repeated three times using samples purchased from different suppliers (Sydney Markets and/or local retailers). To ensure estimates were conservative, it was assumed that weight loss at purchase was negligible. Moisture loss and quality were graphed over time to estimate the percentage weight loss where product remained marketable or consumable based on softening and texture loss (Figure 2).

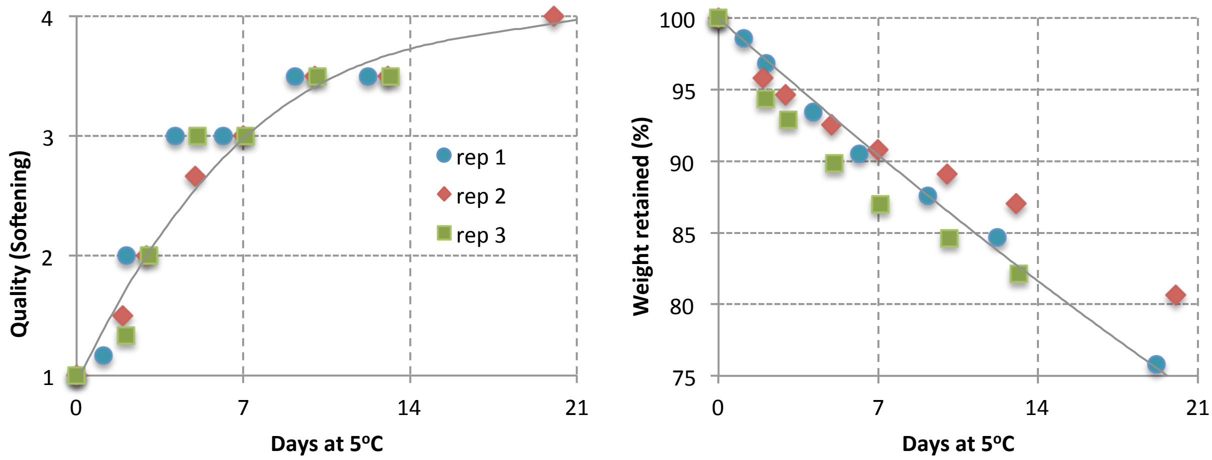


Figure 2.Relationship between quality changes and weight loss for broccoli stored at 5°C. The data suggests that 3–5% weight loss results in broccoli becoming unmarketable, while 7–10% weight loss renders it un-consumable due to softening.

A model was produced predicting weight loss at a range of temperatures and humidities based on vapour pressure deficit values. The model included a small offset for loss attributable to respiration (USDA values). Average values and variability were estimated using the values derived from experimental data (Table 2). These values can be used to estimate the amount of product that needs to be over-packed (e.g. +5%) to still exceed the package weight after storage and transport.

Table 2. Average percent weight loss per day for unprotected broccoli at different temperatures and humidities, ± values represent 95% of the predicted range.

Relative Humidity	Temperature				
	0°C	2°C	5°C	10°C	20°C
40%	3.0 ±1.4	3.5 ±1.4	4.3 ±1.5	5.5 ±1.5	10.2 ±1.6
60%	2.2 ±1.4	2.5 ±1.4	3.1 ±1.4	3.9 ±1.4	7.0 ±1.5
80%	1.4 ±1.4	1.5 ±1.4	1.8 ±1.4	2.2 ±1.4	3.8 ±1.4
90%	1.0 ±1.4	1.0 ±1.4	1.2 ±1.4	1.4 ±1.4	2.2 ±1.4
100%	0.0	0.1	0.2	0.5	1.4

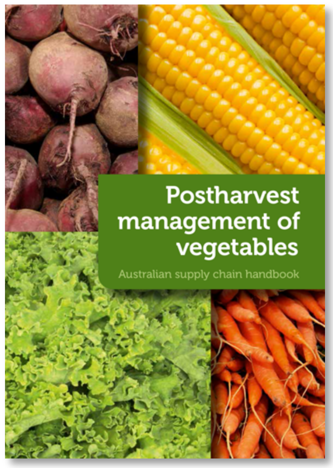
Extension materials

Having compiled new and existing information, the next step was to develop suitable extension materials for vegetable growers. The original proposal was for an 'app' and 'information packs'; essentially a series of fact sheets. However, after discussion with industry members, it was agreed that a handbook collating this information would be a more useful resource. This would make it a more long-lasting and usable resource than loose sheets or booklets.

It was also determined that the information would be better presented in a website than an app. Websites are more flexible in format and do not require regular updates to deal with new iOS etc. A website was designed with the inclusion of the information presented in the book plus additional detail, particularly crop specific information, pictures and diagrams.

In addition, a workshop was developed that was suitable for vegetable growers and packing facility staff. An initial pilot workshop was conducted at Melbourne Markets in November 2015. Attendees included representatives of all parts of the vegetable supply chain, from input supplier, to grower, to retailer. As a result of this workshop, a number of refinements were made to the material, as well as a significant number of additions. These included reducing some of the scientific detail, adding extra practical exercises, adding a section on food safety and reducing the duration from a full day to 3 hours. In addition, information was structured to allow examples to be tailored to regional needs.

Outputs



Postharvest management of vegetables – Australian supply chain handbook

- 150pp in colour, spiral bound, A5 size.

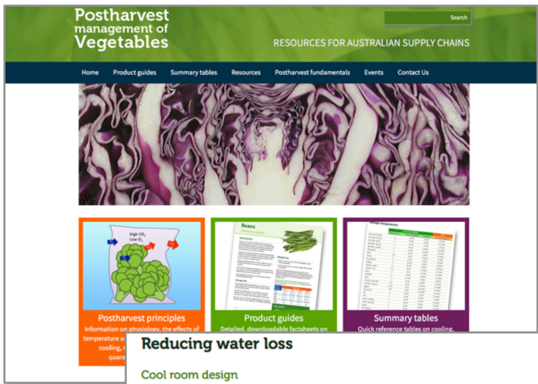
This publication aims to provide information on not only the BEST way of handling vegetables, but also the most cost effective. The guide is split into three main sections:

1. **Introduction to the principles of postharvest**
   This section outlines general postharvest principles as they apply to vegetable crops. These include physiology and biochemistry, the effects of temperature, moisture loss and humidity, the storage atmosphere and evaluation and management of quality.

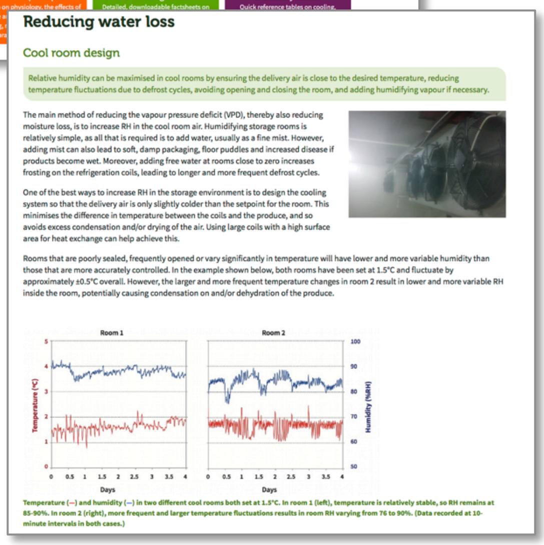
2. **Crop specific information**
   Crop specific information is presented on twenty-two important vegetable lines. This includes specific data on water loss, respiration rate, effect of temperature on storage life, respiration rates and ethylene sensitivity. Pictures of defects, diseases and disorders are included, along with best practice recommendations for each vegetable or category of vegetables.

3. **Reference tables and charts**
   A series of tables summarises information on both minor and major vegetable crops. This can be used as a quick reference guide by those just wanting to check storage recommendations, storage life or other details.

Postharvest management of vegetables – postharvest.net.au



The website includes all the information in the book, as well as additional pictures, diagrams and crop specific information. It is easily searchable with embedded connecting links and tabs for extra information. Front tabs lead to:



Postharvest principles: This information is also contained in the book, but here with additional pictures and diagrams and links to further reading.

Resources: Links to publications and websites with further information.

Events: Used to promote the postharvest roadshows. Could be used for other purposes in the future.

Product guides: Brief information on a range of vegetable crops plus a detailed downloadable fact sheet. The fact sheets build on the information in the book, adding pictures and information on common postharvest diseases and disorders. Where sufficient data is available, a graph is included showing shelf life at different storage temperatures, and a table with estimated daily moisture loss rates at 0–20°C and 40–100% RH. Some sheets also have grading information or pictures. Key information is contained within a front panel, with storage data summarized in an easy-to-read, colour-coded panel.

A total of 15 product guides have been developed so far. Although they are mainly designed for web access, some have also been printed as hard copies for targeted distribution at workshops, field days, conferences and other events attended by growers.

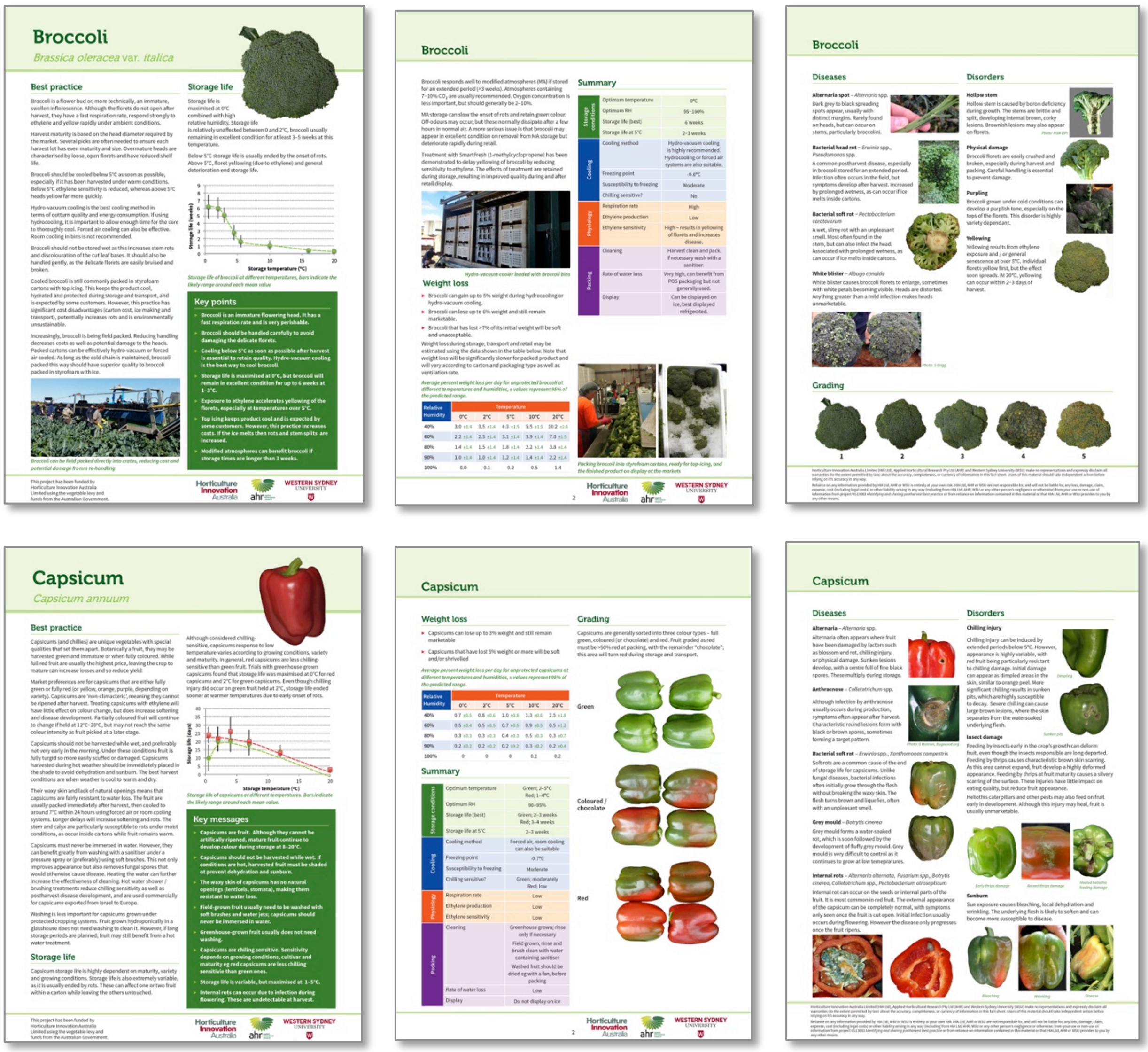


Figure 3. Examples of the fact sheets – broccoli and capsicums.

Postharvest management of vegetables – the Roadshow

The workshops were a major output from the project. They were developed as ½ day, professional development workshops. The aim was to help packing shed managers, QA officers, and vegetable supply chain business representatives to optimise their handling and storage of fresh vegetables, maximise quality and minimise losses. Topics included;

- Cooling methods and strategies
- Food safety and sanitisers
- Managing the storage environment
- Quality assessment
- Supply chain evaluation
- New postharvest technologies

Case studies, demonstrations and hands-on activities were developed to help explain the principles of postharvest management and discuss issues specific to vegetable businesses.

Participants received a free copy of the new 'Postharvest management of vegetables – Australian supply chain handbook', as well as a folder with copies of the slides as handouts.

Publications

Some of the experimental results from the project have been accepted for two oral presentations at the Postharvest Unlimited conference, to be held in Madrid in October 2017.

Two accompanying papers have also been prepared for publication in Acta Horticulturae and attached to this report.

Outcomes

Storage trials

The storage trials demonstrated that damage due to temperature, whether high or low, is a factor of time. If product is to be stored for a short time only, then storage temperature is less critical, as demonstrated in Table 3.

Table 3. Overall visual quality (based on a 1-5 rating scale) and estimated storage life of selected vegetables.

Vegetable	Days of cold storage	Overall visual quality (1-5)*			
		2°C	4°C	7°C	12°C
Buk choy (hydroponic)	0	1.0	1.0	1.0	1.0
	6	1.0	1.0	1.2	1.5
	10	1.0	1.0	1.2	2.0
	14	1.0	1.0	2.7	4.0
	19	1.5	2.3	3.7	5.0
	23	2.3	3.0	4.0	5.0
	Estimated* storage life (days)	22	18	13	10
Choy sum (hydroponic)	0	1.0	1.0	1.0	1.0
	6	1.0	1.0	1.2	1.3
	10	1.0	1.0	1.9	2.7
	14	1.0	1.2	2.5	4.2
	19	1.5	1.9	3.3	4.8
	23	2.5	3.0	4.0	4.9
	Estimated* storage life (days)	21	19	13	9
Capsicum – green (greenhouse-grown)	0	1.0	1.0	1.0	1.0
	7	1.4	1.5	1.9	1.8
	10	2.1	2.4	2.9	2.2
	17	3.0	3.2	3.4	2.7
	21	3.1	3.2	3.8	3.0
	Estimated* storage life (days)	20	19	15	14
Capsicum – red (greenhouse grown)	0	1.0	1.0	1.0	1.0
	10	1.7	1.9	1.8	1.0
	18	2.1	2.5	2.9	2.0
	24	2.7	3.1	3.7	3.0
	30	2.9	3.8	4.0	3.0
	Estimated* storage life (days)	22	18	15	13
Cucumber (Lebanese) (greenhouse-grown)	0	1.0	1.0	1.0	1.0
	5	1.5	1.0	1.0	1.0
	10	3.5	2.6	1.5	1.2
	12	4.8	3.1	2.7	1.2
	14	5.0	5.0	5.0	1.5
	17	5.0	5.0	5.0	4.0
	Estimated* storage life (days)	6	8	11	15
Eggplant (field-grown)	0	1.0	1.0	1.0	1.0
	7	2.1	2.0	1.5	1.0
	9	2.8	2.5	2.2	1.7
	11	4.0	4.0	3.5	1.8
	14	5.0	5.0	3.8	2.2
	Estimated* storage life (days)	6	6	10	14
Zucchini (field-grown)	0	1.1	1.1	1.1	1.1
	5	1.7	1.5	1.5	1.5
	9	2.2	1.5	1.5	1.8
	11	3.5	2.1	1.8	2.8
	13	3.7	2.2	2.0	2.9
	Estimated* storage life (days)	7	10	13	10

The results from the storage trials were combined with other data (where available in the literature or other reports) to develop a table of storage recommendations. This is included in section 3 of the handbook as well as on the website.

Table 4. Optimum storage conditions for different vegetables, and approximate storage life at 5°C (standard cold room)

	Storage temperature (°C)	Relative humidity (%)	Approximate storage-life	Storage life at 5°C
Asian leafy Buk Choy	0	95-100	3 weeks	2-3 weeks
Asian leafy Choy Sum	1-5	90-95	3 weeks	10-14 days
Asian leafy Gai Lan	0	95-100	10-14 days	7-10 days
Asian leafy Pak Choy	0	95-100	2 weeks	10-14 days
Asian leafy Wombok	0	95-100	2-3 months	3-6 weeks
Baby leaf lettuce	1	90-95	8-12 days	7-10 days
Baby leaf rocket	0	95-100	7-10 days	5-10 days
Baby leaf spinach	0	95-100	10-14 days	7-10 days
Beans	4-7	95	7-10 days	6-8 days
Broccoli	0	95-100	3-4 weeks	2-3 weeks
Brussels sprouts	0	95-100	3-5 weeks	1-3 weeks
Cabbage	0	98-100	3-6 weeks	3-4 weeks
Capsicum	2-7	95-98	2-3 weeks	2-3 weeks
Carrot	0	98-100	4-6 weeks	2-3 weeks
Cauliflower	0	95-98	3-4 weeks	2-3 weeks
Celery	0	98-100	4-6 weeks	2-4 weeks
Cucumber	10-12	85-90	10-14 days	1-2 weeks
Eggplant	10-12	90-95	1-2 weeks	1-2 weeks
Green onions	0	95-100	2-4 weeks	2-3 weeks
Kale	0	95-100	10-14 days	7-10 days
Lettuce (Loose leaf)	0	90-95	2-3 weeks	1-2 weeks
Lettuce iceberg	0	98-100	2-3 weeks	1-2 weeks
Parsnip	0	95-100	4-6 weeks	2-3 weeks
Pea, edible pod	0	90-98	1-2 weeks	1-2 weeks
Pumpkin	10-15	50-80	2-3 months	1-2 weeks
Silverbeet	0	95-100	10-14 days	7-10 days
Sweet corn	0	95-98	5-8 days	3-5 days
Sweetpotato	16-18	85-95	1-2 months	7-10 days
Zucchini	7-10	95	1-2 weeks	7-10 days

In addition, the relationship between storage temperature and storage life was graphed for a range of products. These have only been presented where data appeared replicable and robust, and/or was consistent with other data. These graphs are included in the handbook and on the product factsheets. Many contain both original data collated through the project and data sourced elsewhere – adding certainty to the relationship presented (Figure 4). This allows growers to make an informed decision about how much they need to cool their product, and likely effects of higher or lower temperatures on product quality.

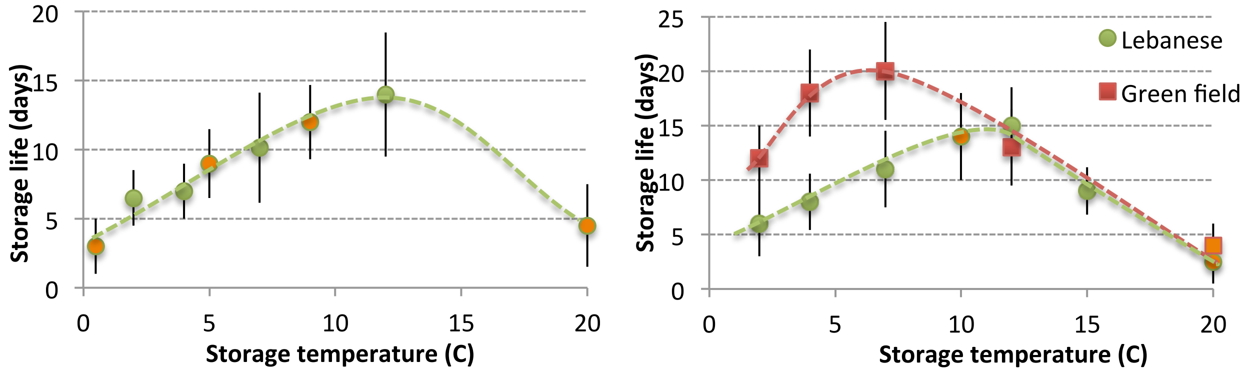


Figure 4.Relationship between temperature and storage life for eggplant (left) and cucumbers (right). Orange points based on other sources (e.g. UC Davis), all other data original from this project.

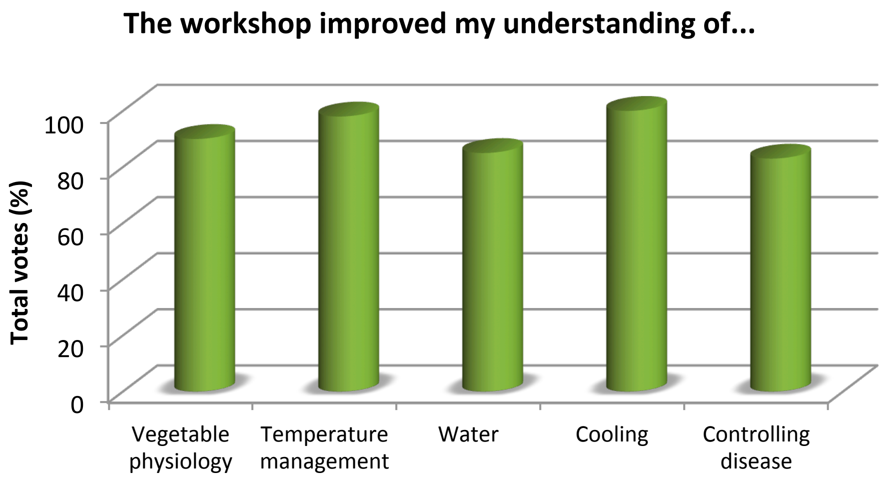
Roadshows and extension

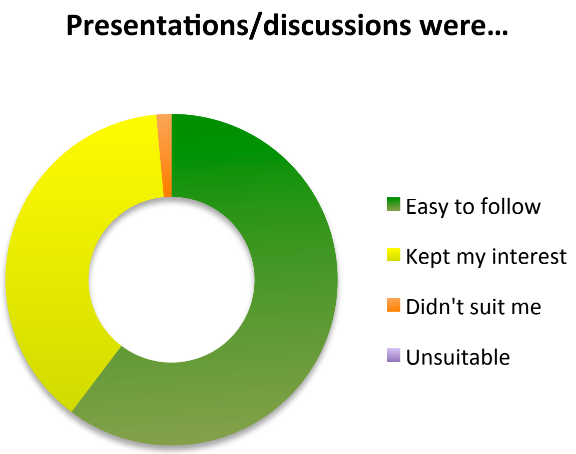
In total, 12 workshops have been run, in addition to the original pilot workshop at Melbourne Markets, and 150 growers have participated. Feedback from the events has been almost universally positive (Figure 5) with many comments about how much they enjoyed and learned from these events, particularly the practical demonstrations.

Table 5. Postharvest workshops conducted and number of participants

Date	Location	No. of participants
1st September, 2016	Sydney Markets, NSW	15
6th September, 2016	East Gippsland, Victoria	10
7th September, 2016	Somerville, Victoria	10
8th September, 2016	Devonport, Tasmania	13
9th September, 2016	Richmond, Tasmania	26
9th November, 2016	Manjimup, WA	8
10th November, 2016	Wanneroo, WA	9
21st February, 2017	Ayr, Qld	9
22nd February, 2017	Bowen, Qld	12
1st August, 2017	Adelaide Hills, SA	7
2nd August, 2017	Adelaide Plains, SA	8
16th August, 2017	Bundaberg, Qld	23

		Total	150





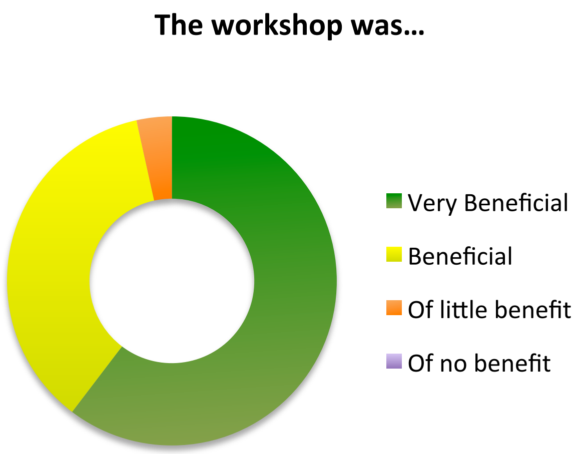


Figure 5. Feedback from the postharvest Roadshow workshops (n=150)

Some take home messages from participants:

- Importance of humidity in cool rooms and effectiveness of sanitisers
- Faster and more efficient crop handling from picking to cooling before dispatch
- How to improve packing and storage practices
- Will possibly implement forced air cooling systems to decrease temperature of product from farm quicker
- Given us a broader vision for our future business plans with our crop
- Will be more informed when asked by stakeholders on this subject
- Found out where to go for further information – i.e. book, factsheets and website
- Will think about using sanitiser in our hydro cooler
- Ideas for our new shed/cool room that will be developed in the next 6 months

- I now know how to test chlorine levels in water
- We will review our cooling strategies
- Found some new options for temperature monitoring

Evaluation and discussion

There is a common idea that basic postharvest research on issues like temperature, humidity, moisture loss and storage has all been done, and that we know all we need to know. This project has demonstrated that this is not the case; a quick search of research projects on postharvest management of vegetables brings up studies of gene expression, phytochemical changes, metabolomics, microbial safety, modelling and so on. There is very little research on what happens within supply chains or under commercial conditions. Applied research is less prestigious than 'higher level' work, so it can be difficult to publish in well-regarded, peer-reviewed journals.

It is clear from these results that many of the existing recommendations are no longer accurate or simply do not exist for specific products. However, they are still widely applied within industry, and may be used by retailers to reject products delivered outside specified temperatures.

This project has both generated new data on vegetable storage and communicated the latest in postharvest advances for vegetables to growers around the country. More than 1,400 copies of the postharvest handbook have been distributed to members of the vegetable supply chain, the fact sheets have been well received at field days and meetings, and much positive feedback has been received regarding the workshops, with 150 participating directly in the roadshow series. Additional requests have been received for workshops, demonstrating the strong demand within industry for clear information on postharvest management.

One of the common comments among growers who participated was that, in retrospect, they would have liked some of their packing staff to attend. While some felt elements of the material were unnecessarily "sciencey" for this purpose, they recognised that if staff understand why they need to do something, they are more likely to do it. Some of the food safety material was felt to be particularly useful from this point of view.

The retailers have also commented that a targeted, cut-down version of this training would be ideal for their retail staff. It is recognised that many of those involved in handling fresh produce have little or no understanding of the importance of the cold chain, moisture management, or even that fresh vegetables are still alive and interacting with the environment. Understanding how to handle products could help reduce damage and wastage, and provide consumers with a more consistent product.

Conversely, other participants commented that they would have liked more technical information. These tended to be those running larger businesses, who were already well aware of postharvest principles. It is possible that a 2-day Postharvest Masterclass may have been more suitable. This type of event has been proven extremely effective in the Soil Wealth (VG13076) and Soil Borne Disease (VG15010) projects. Such a Masterclass could feature a range of speakers, complex practical demonstrations and activities and even packhouse visits. The international leader in this area is UC Davis, which runs an annual week-long postharvest course followed by a week of visits to packing facilities around the Central Valley and Salinas.

In summary, the project has successfully promoted the importance of postharvest management within vegetable supply chains. It has raised awareness of issues with cooling (particularly the use of ice) and promoted discussion on finding more efficient methods to store and transport product. New ideas such as using GPS loggers to track consignments, applying SmartFresh to extend storage life and adopting energy efficient cooling methods have created interest. Other topics covered, such as the influence of pH on sanitisers, have come as new information to people who likely thought they were familiar with such issues. It is clear that ongoing extension in this field would be valued by many.

Recommendations

- Investigate potential sources of funding to continue postharvest training activities for the vegetable industry (e.g. VegPro). Basic food safety training for packing staff would also be of value. This training could be similar to that already developed, or be further refined and shortened.
- Investigate opportunities for a Postharvest Masterclass for vegetable growers. This could be an annual event involving speakers from a range of organisations. The Masterclass could be conducted over 2 days or more and provide in-depth knowledge for those involved in postharvest supply chains.
- Develop a short training module suitable for retail staff. This would include basic information on storing and displaying vegetables. The objective is to avoid damage at retail – particularly chilling injury, dehydration and rots, all of which may be observed on retail shelves and which are a major disincentive to purchase by consumers.
- Continue to investigate the relationship between temperature and storage life for a range of vegetables. This activity was not originally budgeted or scheduled within the current project. However, it was added once it became clear that the required information was not otherwise available or that existing information was likely to be outdated / inaccurate. The trials performed within this project were therefore limited in scope and replication. Although they have generated useful and important information, repeating these storage trials to include seasonal effects, production methods and other factors would add value and robustness to this information.

Scientific refereed publications

Journal articles

Ekman J.H., Goldwater A., Winley, E., Marques J.R., Holford, P. 2017. A snapshot of updated storage guidelines for vegetables: when the best is not the best. Acta Horticulturae, *submitted.*

Ekman J.H., Goldwater A., Winley, E., Marques J.R., Holford, P. James, H., Vedeniapine, P., Ipsen, B. 2017. Preserving broccoli quality from harvest to retail: use of 1-MCP and MAP. Acta Horticulturae, *submitted.*

Whole book

Ekman J.H., Goldwater, A., Winley E. 2016. Postharvest Management of Vegetables. Australian supply chain handbook. Horticulture Innovation Australia.

Intellectual property/commercialisation

No commercial IP generated

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Appendices

Appendix 1.

Acta Horticulturae paper “A snapshot of updated storage guidelines for vegetables: when the best is not the best”. To be presented at Postharvest Unlimited, Madrid.

Appendix 2.

Acta Horticulturae paper “Preserving broccoli quality from harvest to retail: use of 1-MCP and MAP”. To be presented at Postharvest Unlimited, Madrid.

A snapshot of updated storage guidelines for vegetables: when the best is not the best

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Abstract

For most vegetables, guidelines are available regarding optimum storage and handling. However, much of the basic research linking shelf life to temperature was conducted decades ago, and may be based on different varieties, growing conditions and marketing chains. Furthermore, recommendations do not always consider commercial issues or the costs and returns on investment in improved product management. To verify, and potentially revise, storage temperature recommendations, we conducted trials examining storage and shelf life of selected vegetables grown in south-east Australia. Vegetables were stored at 2, 4, 7 or 12°C for up to 39 days, removed at intervals of 2–5 days, and visually assessed for external quality. The estimated storage life of buk choy and choy sum generally reduced with higher storage temperatures, whereas the inverse occurred for chilling sensitive vegetables including green capsicum, Lebanese cucumber, eggplant and zucchini. A key finding, however, was that chilling sensitive vegetables could be stored for several days or even longer at nominally damaging temperatures (i.e. 2–4°C) before damage occurred. Also, short term storage temperature appeared to be less critical than previously thought. These results demonstrate it is not always be necessary to cool product to the 'optimum' temperature to achieve the quality and shelf life required for transport and retail. That may have considerable logistical benefits, e.g. when produce needs to be held at less than optimal temperatures due to transport within mixed loads. Raising the storage temperature by even a few degrees can reduce cooling costs as well as wear on plant and equipment. In most cases vegetables are stored for only short periods of time. This type of information can help members of the supply chain decide what is the most cost-effective temperature for cold rooms and trucks, providing acceptable quality and storage life without adding unnecessary cost.

Keywords: postharvest, supply chain, storage, temperature, quality, vegetables, recommendations

INTRODUCTION

Many fresh vegetables are highly perishable commodities. Effective marketing often requires some storage to balance daily fluctuations in the supply chain and allow distribution to distant markets. Cold storage typically fulfils various key objectives, including slowing down biological activity (without causing chilling injury), reducing moisture loss and susceptibility to damage from ethylene, and slowing the development of microorganisms (Kader, 2011).

There has been little basic applied research on postharvest management of vegetables, especially in the last 20 years. Although a number of references provide information on optimum storage temperature and expected shelf life, many are actually based on a single source of information: "*The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks, USDA Agricultural Handbook 66*" (Gross et al., 2004). This book has been revised three times since it was first published in 1954, but recommendations have generally changed little over the years. Most references also only cite shelf life at an optimum temperature. However, these conditions may not be commercially achievable or, at times, desirable.

For example, the USDA material recommends 0°C storage for 23 of 34 vegetable lines. However, 0°C storage increases energy and equipment costs and risks freezing product, often for little additional storage life compared to storage at 2°C or even higher. If only a short storage life is needed for transport and distribution, these costs are not justified by returns.

Also, the way we grow vegetables, and the type of products produced, have changed considerably in the last 60 years. Hydroponic and greenhouse production, new varieties and entirely new categories (fresh cut, babyleaf) mean that the products now marketed bear scant resemblance to those used to conduct original research in the 1950's. As a result, some of the existing recommendations simply do not exist for specific products or may no longer be accurate.

Overall, there is little information on the impact on quality or storage life of increasing temperature to more easily managed levels, such as 2°C or 5°C, both of which are commonly used commercially. To narrow that knowledge gap, a recent project in Australia has developed a handbook with information on postharvest management of vegetables, including temperature guidelines on a range of vegetables (Ekman et al., 2016).

Despite limited information on its effects, 'out of specification' temperatures are a common cause of rejection of product by retailers. However, damage is a function of time, as well as temperature. Demonstrating that brief periods at potentially injurious temperatures do not impact product quality would appear to have direct benefits for producers. Aiming to update and potentially revise storage temperature recommendations, we conducted a series of trials examining storage and shelf life of selected vegetables grown in south-east Australia (New South Wales). We focussed on vegetables commercially relevant to the Australian market for which there was either no information available, or for which information appeared inconsistent or outdated.

MATERIALS AND METHODS

Storage and shelf life of the Asian leafy vegetables buk choy and choy sum (both hydroponically-grown), green and red capsicum (greenhouse-grown), an of field-grown Lebanese cucumber, eggplant and zucchini were examined.

Vegetables that had been harvested within the previous 24 hours were either sourced direct from local growers or through Sydney Markets. In each case the samples (approx. two to three cartons) were divided equally among four storage temperatures (2, 4, 7 and 12°C) and placed in plastic trays loosely covered with plastic film to maintain high RH around the product. Products were stored at each temperature for a defined period of up to 39 days and removed from storage at intervals of 2–5-days (depending on the commodity). Leafy vegetables were assessed immediately on removal to 20°C, whereas chilling sensitive products were kept at 20°C for 2 days before quality was assessed. This allowed any chilling injury to become apparent, as symptoms are often masked immediately after removal from low temperature storage. Each trial was repeated twice using samples purchased from different suppliers.

Quality attributes were assessed using a five-point scale, where 1 = excellent, fresh; 2 = good, marketable; 3 = OK, not marketable but still edible; 4 = poor and 5 = fully senescent. Pictorial and descriptive grading scales were developed for each product to help ensure consistent quality assessments. Data was graphed against storage time. This allowed estimation of the number of days until overall quality fell below grade 2.

RESULTS AND DISCUSSION

The storage trials showed that damage due to temperature, whether high or low, is a factor of time. Figure 1 provides examples of how quality of buk choy, green capsicum and eggplant varied over time at each storage temperature.

Unsurprisingly, the estimated storage life of the leafy Asian vegetables buk choy and choy sum reduced with higher storage temperatures. These products remained marketable for 2.5–3 weeks when stored at 2–4°C compared to 13 days at 7°C and 9–10 days at 12°C (Table 1). In contrast, estimated storage life generally increased with higher storage temperatures for the chilling sensitive vegetables Lebanese cucumber, eggplant and zucchini. For these vegetables, optimum temperatures were consistent with those usually recommended. A significant finding was that even the most chilling sensitive products investigated in this study could be stored for several days or even longer at low temperature (i.e. 2–4°C) before damage occurred.

This was not the case for greenhouse grown capsicums. Only minor effects of chilling were observed for green capsicum after prolonged storage at 2°C. No chilling injury was observed for red capsicum stored at 2°C. An earlier trial where greenhouse grown capsicum were stored at 0.5°C also failed to produce symptoms of chilling injury in red fruit, although in this case there was significant injury to green fruit (data not shown). For both red and green capsicums, storage life was maximised at 2–4°C. In effect, it took longer for the development of chilling injury to reduce quality than the rots which inevitably develop at higher – widely recommended (Cantwell, 1996) – temperatures of 7°C or more. It should be noted that capsicum storage life is often ended by rots and can be extremely variable, even within an apparently homogenous, greenhouse-grown batch of fruit.

These results demonstrate that if a product is to be stored for a short time only, then non-optimal storage temperatures can still provide an acceptable outcome. This could have considerable logistical benefits through the supply chain. In many cases there may be no option but to store product at less than optimal temperatures, such as where only a single cool store is available for a mixture of products, or during transport where product is shipped in mixed loads. The impact of temperatures either below or above optimal levels is generally not well defined. For example, determination of how long products such as cucumber, eggplant, and zucchini can be kept at a chilling temperatures before permanent damage occurs could help streamline supply chains. It would also help avoid unnecessary rejection of products on arrival at markets or distribution centres. Conversely, raising the storage temperature by even a few degrees could significantly reduce cooling costs as well as wear on plant and equipment. This type of information can help members of the supply chain decide what is the most cost-effective temperature for cold rooms and trucks, providing acceptable quality and storage life without adding unnecessary cost.

CONCLUSIONS

Damage due to temperature, whether high or low, is a factor of time. Unsurprisingly, estimated storage life of buk choy and choy sum reduced with higher storage temperatures, whereas the inverse occurred for chilling sensitive vegetables. Greenhouse grown green capsicums were less chilling sensitive than previously reported and red capsicums displayed no chilling injury symptoms.

Overall, the study highlights the importance of updated applied research based on local and current cultivars, growing conditions and harvest/postharvest management. The above trials investigating the relationship between temperature and storage life for a group of vegetables were limited in scope and replication. More extensive trials are warranted, especially as storage characteristics are likely to be affected by seasonal effects, production methods and varieties. Moreover, some newer products have had little attention in this regard. Understanding where the critical limits are for different vegetables can help supply chains function flexibly and efficiently, with positive outcomes for all.

ACKNOWLEDGEMENTS

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Table 1. Overall visual quality (based on a 1–5 rating scale) and estimated storage life of selected vegetables as affected by storage temperature and duration. Quality was assessed on removal (buk choy and choy sum) or two days after storage (other vegetables).

Vegetable	Days of cold storage	Overall visual quality (1-5)*			
		2°C	4°C	7°C	12°C
Buk choy (hydroponic)	0	1.0	1.0	1.0	1.0
	6	1.0	1.0	1.2	1.5
	10	1.0	1.0	1.2	2.0
	14	1.0	1.0	2.7	4.0
	19	1.5	2.3	3.7	5.0
	23	2.3	3.0	4.0	5.0
	Estimated* storage life (days)	22	18	13	10
Choy sum (hydroponic)	0	1.0	1.0	1.0	1.0
	6	1.0	1.0	1.2	1.3
	10	1.0	1.0	1.9	2.7
	14	1.0	1.2	2.5	4.2
	19	1.5	1.9	3.3	4.8
	23	2.5	3.0	4.0	4.9
	Estimated* storage life (days)	21	19	13	9
Capsicum – green (greenhouse-grown)	0	1.0	1.0	1.0	1.0
	7	1.4	1.5	1.9	1.8
	10	2.1	2.4	2.9	2.2
	17	3.0	3.2	3.4	2.7
	21	3.1	3.2	3.8	3.0
	Estimated* storage life (days)	20	19	15	14
Capsicum – red (greenhouse grown)	0	1.0	1.0	1.0	1.0
	10	1.7	1.9	1.8	1.0
	18	2.1	2.5	2.9	2.0
	24	2.7	3.1	3.7	3.0
	30	2.9	3.8	4.0	3.0
	Estimated* storage life (days)	22	18	15	13
Cucumber (Lebanese) (greenhouse-grown)	0	1.0	1.0	1.0	1.0
	5	1.5	1.0	1.0	1.0
	10	3.5	2.6	1.5	1.2
	12	4.8	3.1	2.7	1.2
	14	5.0	5.0	5.0	1.5
	17	5.0	5.0	5.0	4.0
	Estimated* storage life (days)	6	8	11	15
Eggplant (field-grown)	0	1.0	1.0	1.0	1.0
	7	2.1	2.0	1.5	1.0
	9	2.8	2.5	2.2	1.7
	11	4.0	4.0	3.5	1.8
	14	5.0	5.0	3.8	2.2
	Estimated* storage life (days)	6	6	10	14
Zucchini (field-grown)	0	1.1	1.1	1.1	1.1
	5	1.7	1.5	1.5	1.5
	9	2.2	1.5	1.5	1.8
	11	3.5	2.1	1.8	2.8
	13	3.7	2.2	2.0	2.9
	Estimated* storage life (days)	7	10	13	10

* Rating scale: 1=excellent and 5=fully senescent, with rating 1 and 2 considered acceptable. Colours represent: green=fresh/top quality; yellow=intermediate but still acceptable; red=not marketable.
* Storage life may vary considerably according to cultivar, growing conditions, harvest and postharvest management. Values are guides only representing the average time produce is likely to remain commercially acceptable.

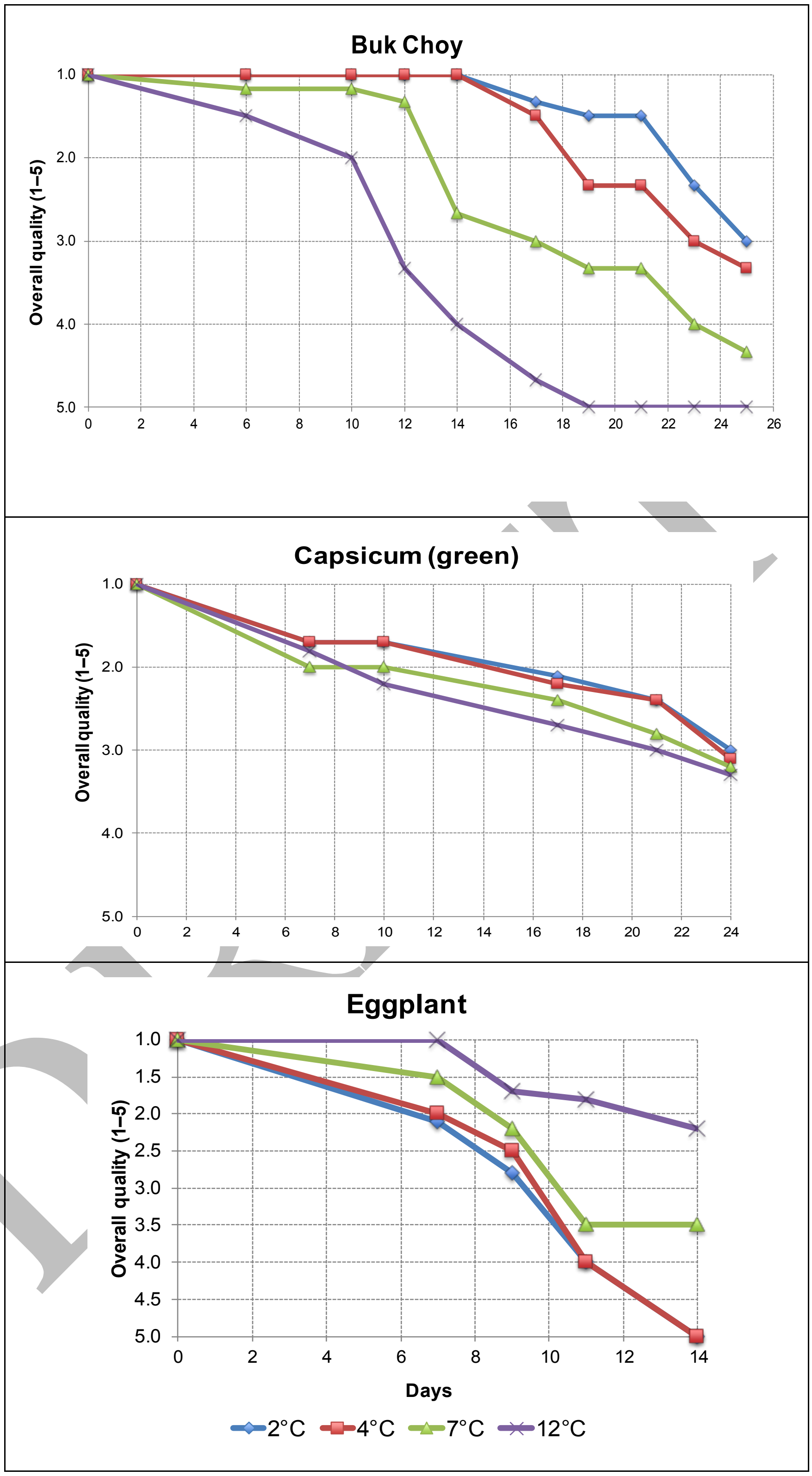

Figure 1 Overall quality (1–5) of buk choy (top), green capsicum (middle) and eggplant (bottom) as affected by storage temperature and duration. Quality was visually assessed on removal (buk choy) or two days after storage (capsicum and eggplant) based on a 5-point rating scale (1=excellent and 5=fully senescent).

Preserving broccoli quality from harvest to retail: use of 1-MCP and MAP

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Abstract

Despite broccoli's image as a healthy, nutritious and flavoursome vegetable, sales in the Australian market have been constrained by poor quality at retail and disappointing shelf life. In a series of four experiments across three broccoli growing regions over two seasons, we tested the potential of SmartFresh® In-Box, a new delivery system for the ethylene inhibitor 1-methylcyclopropene (1-MCP), to enhance broccoli retail quality. We added 2, 4, or 8 'In-Box' sachets to broccoli packed in either standard perforated low-density polyethylene (LDPE) or 'Ripelock' liners, the latter a newly designed option less permeable to 1-MCP which provides modified atmosphere packaging conditions. Compared to untreated controls (i.e. liners alone), applying the 'In-Box' system with 2–4 sachets, especially when combined with the RipeLock liner, improved the retention of green colour and overall visual quality of broccoli, thus increasing marketability by 5-7 days when heads were transported and held at 5–7°C for 2–3 weeks. In addition, the percentage of marketable heads increased from 0% to 72–100% during simulated retail display at 7°C for up to 2 weeks. There were more modest treatment differences in rots development and no differences on broccoli weight loss. Delaying application of 1-MCP by 24 hours after harvest had little impact on its effectiveness. 1-MCP concentrations peaked from 0.3–2.3 ppm at 5 hours after packing, then fell to levels below 0.1 ppm after 24 hours. The In-Box/RipeLock system generally provided broccoli with equal or better protection from fluctuating cold chain temperatures than the standard industry practice of top icing in styrofoam. Results suggest the In-Box/RipeLock system can potentially replace top-icing, especially in situations of long transport/storage and/or under temperatures higher than optimal. In addition, the effects of In-Box were retained once broccoli was transferred to warmer temperatures, a condition typically found during the supply chain, including retail and consumer's handling.

Keywords: postharvest, 1-methylcyclopropene, SmartFresh®, In-Box, modified atmosphere packaging, storage, hydrocooling

INTRODUCTION

Broccoli is regarded worldwide as a healthy and tasty vegetable, which can add variety to many meals. According to recent consumer research in Australia, although consumers like and want to purchase broccoli, poor and inconsistent quality is a major barrier to increased consumption (Hamblin, 2013). Quality issues include not just appearance at the retail display, but also lack of storage life after purchase. Another study showed that broccoli freshness at retail was highly variable, suggesting that Australia consumers were likely to be disappointed with broccoli quality as much as one shopping trip in four, which could be impacting sales (Ekman, 2014).

Broccoli is typically harvested at the immature stage and its florets rapidly loose green colour (due to chlorophyll degradation) and senesce after harvest, especially at ambient temperatures. As a rapidly developing inflorescence, it has little protection against moisture loss, few storage reserves, and it is very sensitive to external ethylene. Low temperature is critical to preserving broccoli in desirable conditions postharvest. In Australia, top icing is typically used with broccoli packed in 8 kg Styrofoam cartons to extend shelf life. Despite some advantages, such as ensuring that heads stay fully hydrated and typically buffered from temperature fluctuations during transport/storage, it also has significant disadvantages. These include industry environmental footprint, potential product damage and cost.

The ethylene inhibitor 1-methylcyclopropene (1-MCP), which is active at very low concentrations, has a non-toxic mode of action and negligible residue, is an additional tool to reduce the negative effects of ethylene and improve postharvest quality of many horticultural crops (Watkins, 2006). Applied 1-MCP, traded as SmartFresh®, has been reported to delay yellowing/senescence, and thus extend shelf life of broccoli held at temperatures of 5–20°C in various studies (Ku and Wills, 1999; Fan and Mattheis, 2000; Yuan et al., 2010; Xu et al., 2016). 1-MCP effects in broccoli are reported to be further enhanced when combined with modified atmosphere packaging (Kasim et al., 2007; Sabir, 2012). The effects of 1-MCP may also be retained during longer periods of cold storage, with the result that broccoli yellows more slowly when placed on retail display (Ekman and Pristijono, 2010). Although SmartFresh® appears to offer an alternative to ice in terms of maintaining freshness of broccoli, and is registered for that purpose, it has found little commercial application to date in Australia. This is in part due to the logistical difficulties of treatment. As 1-MCP is applied as a gas, broccoli must be placed in a sealed chamber for treatment. Although products can be treated as low as 1°C if exposure times are increased (Fernandez-Leon et al., 2013), treatment at >10°C is recommended, as it is fast and effective. This is not consistent with the usual handling methods for broccoli, which is harvested into bins, precooled, then packed into either lined cartons or styrofoam with ice and held in the coldroom until dispatch.

The new SmartFresh® In-Box system could make this technology easier to use and thus more attractive. The In-Box sachets are added to the product packed inside a liner, allowing 1-MCP to be generated inside the carton, so it could be more easily adopted within existing systems. They are recommended to be used with a 'RipeLock' liner (AgroFresh Inc., Philadelphia, USA), which has been designed with specific permeabilities to 1-MCP, O_2 and CO_2 than a standard LDPE liner, thus producing some MAP conditions once the bag is sealed. Testing of In-Box sachets in South Africa reduced broccoli yellowing during storage at 7.5°C for 22 days and retail display conditions, but results were not as effective at 12°C (due to off-odours) or when compared to previous reports on broccoli fumigated with 1-MCP (de Beer and Crouch, 2015). However, as only a single In-Box sachet was added to each carton in that study (volume not stated), it is possible that adding more than one sachet could further enhance results.

In this study, we tested the potential of the new SmartFresh® In-Box system to reduce reliance on ice and styrofoam packaging and potentially increase the retail freshness and quality of broccoli in Australian commercial and/or simulated supply chains. We conducted four experiments across three broccoli growing regions over two seasons. We added 2-8 in-Box sachets to broccoli packed in either conventional perforated low-density polyethylene

(LDPE) liner or in sealed RipeLock liner, either immediately after pre-cooling or following standard overnight storage. We particularly examined whether In-Box would be comparable to standard ice packs regarding protection against temperature fluctuations.

MATERIALS AND METHODS

Four experiments were conducted as described below. Experiments 1 and 2 aimed to test how the SmartFresh® In-Box system could be applied commercially. Experiments 3 and 4 were conducted to test the effect of different SmartFresh® concentrations on broccoli quality following transport and storage.

Experiment 1

Broccoli (cv 'Marathon') was hand-harvested at a commercial farm in Werribee (Victoria) on 14 December, 2015. The heads were immediately taken to the packing shed and divided into 21 approximately equal units. Within each unit, six heads were randomly selected, tagged and weighed (average of 417 g). Data-loggers were inserted into selected stems and marked with flagging tape. All samples were loaded into plastic crates and hydro-vacuum cooled. On removal from the hydro-vacuum, nine units (3 treatments x 3 replicates) were set up immediately. The remaining 12 units (4 treatments x 3 replicates) were stored overnight, as per normal commercial practice, and set up the following morning. The seven treatments were applied as described in Table 1. The perforated LDPE and the RipeLock liners (without or with 4 In-Box sachets) were closed by pushing as much air as possible out of the bag, twisting the top and securing it with a rubber band and knotting to form, in the case or the RipeLock liner, an airtight seal as per manufacturer's specifications. Except for the number of treatments or otherwise stated, a similar procedure was adopted in all four experiments.

Table 1. Description and ID numbers of packing treatments applied to broccoli heads in the four experiments conducted in the study.

Packing treatment (1-MCP-treated in bold)	Experiment 1	Experiment 2	Experiment 3	Experiment 4
	Treatment ID			
Applied immediately after harvest				
* Perforated low density polyethylene (LDPE) liner	1-1		3-1	
* RipeLock liner			3-2	
*** LDPE liner plus 4 x In-Box sachets**	1-2			
*** RipeLock liner plus 2 x In-Box sachets**			3-3	
*** RipeLock liner plus 4 x In-Box sachets**	1-3	2-1	3-4	
*** RipeLock liner plus 8 x In-Box sachets**			3-5	
Applied 24 hours after harvest				
* Perforated LDPE liner		2-2		4-1
* RipeLock liner	1-4	2-3		4-2
*** Perforated LDPE liner plus 4 x In-Box sachets**	1-5	2-4		
*** RipeLock liner plus 2 x In-Box sachets**				4-3
*** RipeLock liner plus 4 x In-Box sachets**	1-6	2-5	3-6	4-4

*** RipeLock liner plus 8 x In-Box sachets**				4-5
* Styrofoam + top icing (standard)	1-7	2-6	3-7	4-6

When all treatments were complete, the cartons were palletised and stored before overnight refrigerated transport via truck to Sydney Markets (approx. 880 km). The samples were then collected and transferred by car to the postharvest laboratory of the University of Western Sydney, Hawkesbury (approx. 49 km) for quality and shelf life assessments as described below in the 'Quality assessments' section.

Experiment 2

Broccoli (cv 'Aurora') was harvested on 7 March, 2016 from a commercial farm near Manjimup (Western Australia). Broccoli was returned to the pack house and cooled thoroughly within three hours of harvest using a hydro-vacuum cooler. Samples were then divided into 18 equal units. Three units (one treatment x 3 replicates) were set up immediately, the remainder 15 units (5 treatments x 3 replicates) were stored overnight and set up the following morning. The six treatments were applied as described in Table 1.

When all treatments were complete, the cartons were palletised and stored before refrigerated transport to Sydney, with transfers in Perth and Adelaide (approx. 4,350 km in total). The samples were collected six days later and transferred to the laboratory (as per experiment 1) for quality assessments as described below.

Experiment 3

Broccoli (cv 'Aurora') was harvested at the same commercial farm as experiment 2 on 14 February, 2017. Samples were transported to the packing shed and hydro-vacuum cooled. Samples were then divided into 21 equal units. Fifteen units (5 treatments x 3 replicates) were set up immediately, the remainder six units (2 treatments x 3 replicates) were stored overnight and set up the following morning. The seven treatments were applied as described in Table 1.

Temperature data loggers were included with at least one carton per treatment. The delayed addition of InBox and styrofoam icing both followed normal commercial procedure. In this case the broccoli had been stored overnight at approximately 3°C after hydro-vacuum cooling, then packed the following morning. All broccoli was stored overnight before being transported to Sydney and handled as per conditions described in experiment 2. Quality was assessed as described below.

Experiment 4

Broccoli (cv 'Ironman') was harvested at a commercial farm in Windsor (New South Wales) on 9 May, 2017. Samples were transported by car directly to the laboratory (approx. 9 km) and room cooled overnight. Samples were then divided into 18 equal units (6 treatments x 3 replicates). The six treatments were applied approx. 24 hours after harvest (rather than immediately after harvest), as described in Table 1, as this was considered a more realistic scenario by the farm management.

At this trial aimed to replicate the conditions that had been previously observed in commercial supply chains, samples were moved to an 8°C cool room for four days after packing. During this time, they were removed twice and left at ambient for 2 hours, simulating movements in and out of cool rooms/trucks. Quality was assessed as described below.

Quality assessments

On arrival at the postharvest laboratory, broccoli heads from all four experiments were weighed and visually assessed for quality using a 1-5 rating scale. Assessments included yellowing (by comparison with a photographic scale, where 1=fully green and 5=very yellow), florets/stem rots development (1=no rots and 5=severe, >10% florets rotten), and overall appearance/marketability (1=excellent and 5=very poor). Broccoli was considered marketable when rated 1, 2 or 3.

In experiment 1, broccoli heads were stored at 5°C and assessed on removal at 12, 19, 23, 27 and 30 days storage. In experiment 2, samples were stored at 7°C or 16°C to simulate average temperatures during refrigerated and non-refrigerated retail display. Samples stored at 7°C were evaluated twice weekly, whereas those held at 16°C were assessed daily. Assessments continued until the broccoli was no longer considered marketable.

In experiments 3 and 4, water from the ice-packed broccoli was drained and heads repacked into lined cartons before storage at 7°C. In experiment 3, samples were removed 2, 3 and 4 weeks after harvest and allowed to warm to 20°C before assessment. In experiment 4, samples were assessed on removal at 1, 2 and 3 weeks after harvest, then daily at 20°C until heads were no longer marketable.

Gas analyses

During experiment 4, gas samples were taken from the In-Box-treated broccoli boxes for later analysis by gas chromatography at the AgroFresh Melbourne laboratory. A specially designed sampling pump was placed inside the packed cartons. Samples were taken 5, 12 and 24 hours after the packages were sealed. In addition to 1-MCP, ethylene, O_2 and CO_2 concentrations inside the sealed RipeLock liners were also determined. Given these liners provide MAP conditions, as well as having specific permeability to 1-MCP, it was important to assess whether these liners were providing a desirable combination of O_2 and CO_2.

Statistical analysis

All data was analysed using CoStat statistical software to calculate least significant differences between mean values at $P \leq 0.05$. Letters separating the treatment means are used in tables.

RESULTS AND DISCUSSION

Experiment 1

Broccoli treated with SmartFresh® In-Box (4 sachets) and packed in a RipeLock bag remained marketable for approximately 23 days following harvest, 1-day transport and storage at 5°C (Figure 1). This was similar to broccoli that was top-iced and packed in Styrofoam. In contrast, broccoli packed in a cardboard carton with an LDPE liner remained marketable for around 18 days, regardless of whether In-Box sachets were added. In-Box-treated broccoli yellowed more slowly and retained quality at 5°C better than broccoli that was inside an LDPE bag. Delaying treatment for 24 hours did not reduce the effectiveness of the In-Box treatment. In-Box sachets placed inside an LDPE bag were less effective at retarding yellowing than when the RipeLock bag was used – consistent with a higher rate of permeation of 1-MCP through perforated LDPE film. There were not treatment differences for weight loss or rots development (data not shown).

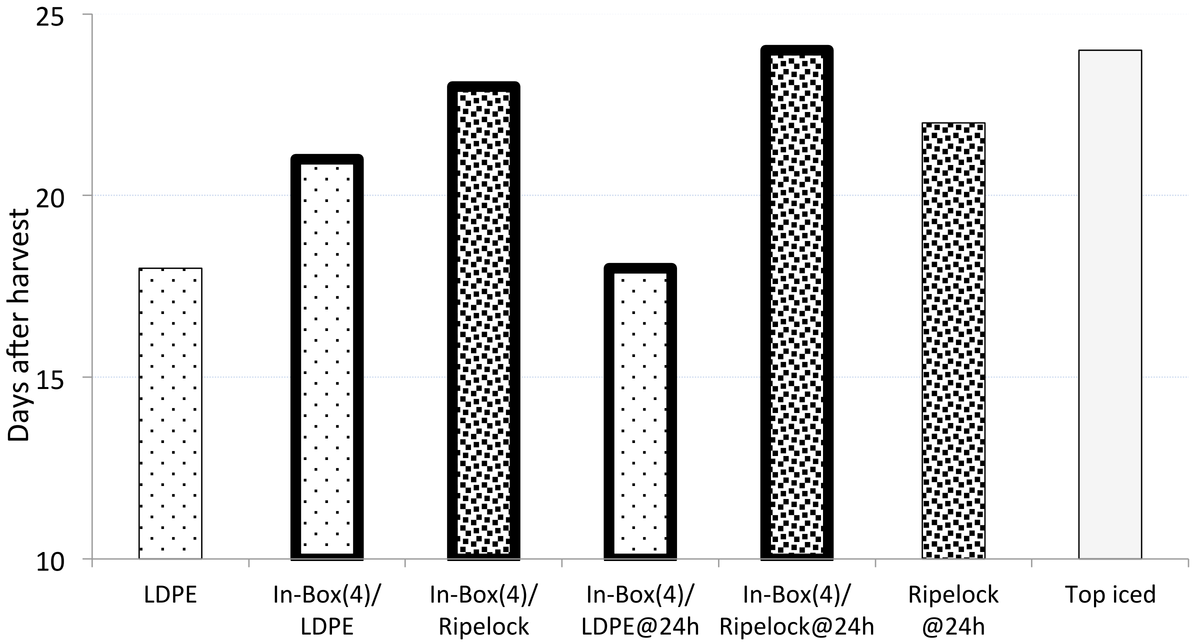

Figure 1 Days broccoli was still marketable on removal from storage at 5°C following packaging in LDPE film or RipeLock film with or without SmartFresh® (4 x In-Box sachets), applied immediately after cooling or with a 24 hour-delay, or packed in a styrofoam carton with top icing applied 24 hours after harvest (standard). Heads were visually assessed for overall marketability based on a 1-5 rating scale (1=excellent and 5=very poor, with ratings 1-3 considered marketable).

The percentage of marketable broccoli heads 25 days after harvest (including 1-day transport and storage at 5°C) was on average 97% for the In-Box/RipeLock treatments (1-3 and 1-6), compared to 89% for the top icing treatment (1-7), 72% for the In-Box/LDPE treatments (1-2 and 1-5), 72% for the RipeLock liner treatment, and 44% for the LPDE liner treatment (1-1).

Experiment 2

Broccoli treated with the In-Box system (4 sachets) combined with the RipeLock liner had generally similar visual quality compared to the standard top iced treatment during simulated retail display at 16°C for 2 days or 7°C for 4 days (Table 2). These results followed a 5-day transport in a refrigerated truck to Sydney, in which broccoli temperatures inside the cartons varied between 5–10°C for several days, rising to around 13°C during trans-shipment in Perth. As expected, the broccoli packed in styrofoam cartons with top icing was protected from these fluctuations in the cold chain and remained below 5°C until it reached Sydney. However, despite this reasonably severe temperature challenge, In-Box-treated broccoli performed equally well. Although results appear slightly better when the broccoli was treated as soon as possible after harvest and packed in RipeLock film, those differences were generally not significant during simulated retail. It is likely that this temperature abuse during transport contributed to the relatively poor results for broccoli packed in LDPE or RipeLock films, compared with the broccoli packed in styrofoam and ice. There were no treatment differences for weight loss (data not shown).

Table 2 Visual quality based on yellowing, rots development, and overall marketability of broccoli as affected by different packing treatments during simulated retail display at 16 or 7°C following a 5-day transport in a refrigerated truck. Broccoli heads were visually assessed based on a 1-5 rating scale for yellowing (1=fully green and 5=very yellow), rots development (1=no rots and 5=severe, >10% florets rotten), and overall appearance/marketability (1=excellent and 5=very poor). Means within columns followed by different letters are significantly different (P≤0.05).

Packaging treatment	Held at 16°C for 2 days			Held at 7°C for 4 days		
	Visual quality (1-5)			Visual quality (1-5)		
	Yellowing	Rots	Overall	Yellowing	Rots	Overall
2-1: In-Box(4)/RipeLock	2.0^{a}	2.0^{bc}	2.0^{a}	1.0^{a}	1.4^{a}	1.9^{a}
2-2: RipeLock @24h	3.0^{b}	2.3^{bc}	3.2^{b}	3.2^{b}	1.4^{a}	3.6^{c}
2-3: In-Box(4)/RipeLock @24h	2.0^{a}	1.2^{a}	2.1^{a}	1.5^{a}	1.3^{a}	2.3^{ab}
2-4: LDPE @24h	3.1^{b}	2.4^{c}	3.4^{b}	3.0^{b}	1.9^{a}	3.0^{bc}
2-5: In-Box(4)/LDPE @24h	2.1^{a}	2.4^{c}	2.4^{a}	1.1^{a}	1.9^{a}	2.0^{a}
2-6: Top iced @24h	2.0^{a}	1.9^{a}	2.2^{a}	1.3^{a}	1.1^{a}	2.1^{a}

As a result of delayed yellowing, broccoli heads treated with In-Box system and those packed in ice remained marketable for approximately 1 week after arrival in Sydney when placed under simulated retail display at 7°C. In comparison, other not treated with 1-MCP were marketable for only 2 days. When held at 7°C for 4 days, 85% of In-Box-treated heads were marketable (treatments 2-1, 2-3 and 2-5), which was similar to the top icing treatment (89%), whereas the other two treatments without 1-MCP application (2-2 and 2-4) resulted in nil marketable heads at that stage. When broccoli was placed at 16°C for 2 days, 100% of heads from the In-Box and top ice treatments were marketable, compared to 61% for the other two treatments.

The results from experiments 1 and 2 suggest that treatment with the In-Box system can potentially provide broccoli with similar protection from fluctuating cold chain temperatures to top icing. Results were best when the In-Box sachets were combined with the RipeLock liner.

Experiment 3

Treatment with the In-Box system generally better maintained green colour and improved overall appeal of broccoli two weeks after harvest (including a 5-day transport at 8°C followed by storage at 7°C) compared to packing in ice or a liner only (Table 3). Inclusion of 4 or 8 In-Box sachets was most effective, but even 2 In-Box sachets provided a significant improvement compared to packing in an LDPE liner. Treatment with the RipeLock liner alone was less effective than the In-Box treatments, but was still comparable to standard top icing. Rots were initially similar in all treatments except the LDPE liner, but differences emerged 3-4 weeks after harvest, with many of the heads packed in ice or liners alone developing severe decay (data not shown). However, by this time all broccoli was unacceptable due to yellowing. As in experiments 1 and 2, there were not treatment differences for weight loss (data not shown).

Delaying treatment by 24 hours after harvest had little impact on the effectiveness of In-Box treatment, especially yellowing and rots, confirming results from experiments 1 and 2. These results suggest that would be the easiest procedure to fit into existing practices and still provide useful efficacy.

Table 3 Visual quality based on yellowing, rots development, and overall marketability of broccoli as affected by different packing treatments 14 days after harvest. Broccoli heads were transported for 5 days at 8°C, held at 7°C for 8 days, then visually assessed based on a 1-5 rating scale for yellowing (1=fully green; 5=very yellow), rots development (1=no rots; 5=severe, >10% florets rotten), and overall marketability (1=excellent; 5=very poor). Means within columns followed by different letters are significantly different (P≤0.05).

Packaging treatment	Visual quality (1-5) 14 days after harvest		
	Yellowing	Rots	Overall
3-1: LDPE	4.0^{a}	2.6^{a}	5.0^{a}
3-2: RipeLock	2.9^{b}	1.6^{b}	2.9^{b}
3-3: In-Box(2)/RipeLock	2.0^{c}	1.4^{b}	2.3^{c}
3-4: In-Box(4)/RipeLock	2.0^{c}	1.4^{b}	2.0^{d}
3-5: In-Box(8)/RipeLock	2.0^{c}	1.6^{b}	2.0^{d}
3-6: In-Box(4)/RipeLock @24h	2.0^{c}	1.6^{b}	2.8^{b}
3-7: Standard (Top iced @24h)	3.0^{b}	1.2^{b}	3.0^{b}

The results for In-Box compared to top icing and packing in styrofoam are particularly promising given that these cartons were transported at an average of 8°C, whereas the top iced broccoli stayed close to optimal temperatures throughout the supply chain. Two weeks after harvest, the percentage of marketable heads was 100% for all In-Box treatments and the RipeLock liner treatment, 92% for the top icing treatment and 0% for the LDPE liner treatment. This confirms results from experiment 2 that treatment with In-Box can protect broccoli from the effects of temperature abuse during transport as well as packing in ice.

Experiment 4

After two weeks storage at 7°C, In-Box-treated broccoli heads combined with RipeLock liner were significantly greener and had better overall acceptability than the other treatments on removal, including broccoli packed in ice (Table 4). As a result, 72 of In-Box-treated broccoli remained marketable after 2 weeks storage, compared to 0% packed in ice or in LDPE. These differences were retained during 1 or 2 days at 20°C. Although broccoli samples appeared similar on removal after one-week storage, In-Box-treated heads remained green for two days at 20°C, whereas all other treatments yellowed within 1-2 days (data not shown). As in previous experiments, there were no treatment differences for weight loss (data not shown). It confirms another study showing that the Inbox system combined with the RipeLock liner was effective in preventing unwanted water loss in broccoli (de Beer and Crouch, 2015).

Table 4 Visual quality based on yellowing, rots development, and overall marketability of broccoli as affected by different packing treatments 14 days after harvest. Broccoli heads were held at 7°C for 14 days, then visually assessed on removal based on a 1-5 rating scale for yellowing (1=fully green; 5=very yellow), rots development (1=no rots; 5=severe, >10% florets rotten), and overall marketability (1=excellent; 5=very poor). Means within columns followed by different letters are significantly different (P≤0.05).

Packaging treatment	Quality (1-5) 14 days after harvest		
	Yellowing	Rots	Overall
4-1: LDPE	4.1^{a}	2.2^{abc}	4.0^{b}
4-2: RipeLock	3.3^{b}	1.8^{bc}	3.3^{c}
4-3: In-Box(2)/RipeLock	2.0^{c}	2.3^{ab}	3.3^{c}
4-4: In-Box(4)/RipeLock	2.1^{c}	1.9^{bc}	2.9^{c}
4-5: In-Box(8)/RipeLock	2.2^{c}	2.1^{bc}	3.1^{c}
4-6: Standard (Top iced)	3.3^{b}	2.7^{a}	4.0^{b}

All In-Box treatments provided similar effects, with only a slight (and mostly non-significant) increase in effects as the dosage increased from 2 to 8 In-Box sachets per box. Considering the results from the previous experiments, there appears to be a slight additional effect from increasing the number of In-Box sachets from 2 to 4, but no additional benefits from using 8 sachets. This suggests that the ethylene receptors within broccoli are saturated relatively easily, requiring 1ppm of 1-MCP or even less over several hours to achieve full effectiveness.

As in experiment 3, the RipeLock liner alone also provided some benefits compared to a simple, perforated LDPE liner, presumably due to modification of the internal atmosphere, as well as possibly due to high humidity inside the package.

All experiments

Overall results suggest that the adoption of the In-Box system combined with RipeLock liner could reduce reliance on ice and styrofoam packaging. Although many growers still pack broccoli in ice in order to protect it from temperature fluctuations in supply chains, ice adds significant cost in terms of power consumption, water use, labour and transport. The styrofoam packaging required is also expensive and not easily recyclable and, if the ice melts, it can increase stem splits and rots. While the cost of the In-Box treatment is likely to be significant, it could be offset by reductions in packaging, power and transport costs, as well as providing a more sustainable method of packing broccoli.

The above results also confirms previous work in South Africa, in which applied SmartFresh® In-Box system combined with the Ripelock liner significantly reduced the yellowing rate of broccoli stored at either 0°C or 7.5°C for 42 or 22 days, respectively, plus 3 days at 10°C, thus extending storability by a week compared to untreated or ethylene exposed produce (de Beer and Crouch, 2015). The results in that trial and this current study suggest that the detrimental higher yellowing rate of broccoli resulting from increased holding temperatures (e.g. during transport and/or storage) can potentially be alleviated with the application of the In-Box plus RipeLock system.

Interestingly, the beneficial effects of In-Box were retained once broccoli was transferred to warmer temperatures, a condition that would be typically expected during the supply chain (e.g. during storage at the back of stores, retail display, or once consumers take the product home). Similarly, applied 1-MCP was reported to extend shelf life of broccoli held at 20°C for 5 days, maintaining visual quality by retarding chlorophyll degradation, as well as reducing loss of health-promoting bioactive compounds, particularly glucosinolates (Yuan et al., 2010). The latter would be an additional quality benefit from a consumer point of view. In addition to its direct role in inhibiting ethylene action and thus retarding chlorophyll degradation and senescence, a more recent study suggests that 1-MCP may also delay senescence of broccoli florets by maintaining higher sugar content (which is typically associated with better flavor quality) through regulating sugar metabolism (Xu et al., 2016).

Gas analyses

The In-Box/RipeLock bags stabilised at approx. 16% O_2 and 4% CO_2 within about 12 hours after sealing, a level of CO_2 likely to have minor effect on broccoli quality. There were little differences in O_2 and CO_2 levels between the 2, 4 or 8 sachet treatments.

Ethylene accumulated in the range of 0.3–0.7ppm inside the In-Box/RipeLock bags, which would still normally be expected to increase deterioration of untreated broccoli. Although ethylene levels were not measured inside the RipeLock bag alone, it is likely that the In-Box system reduced broccoli sensitivity to ethylene, as demonstrated by significant reductions in yellowing during and after storage shown in the experiments above.

At 5 hours after packing, 1-MCP concentrations peaked at 0.7 ppm (2 sachets), 0.3 ppm (4 sachets) and 2.3 ppm (8 sachets). 1-MCP levels fell by 70–95% after 12 hours and were below 0.1 ppm in all treatments after 24 hours of packing. The lack of a direct correlation between 1-MCP concentration and number of applied sachets (especially between 2 and 4) could be due to variability in release rates, different rates of absorption into the broccoli, or a different diffusion rates through the RipeLock liner.

CONCLUSIONS

The results from the above experiments achieved at different times of year and using produce from a range of sources, show that the SmartFresh® 'In-Box' system can be a flexible and effective treatment for extending broccoli storage and shelf life. Compared to untreated controls, the application of the 'In-Box' system with 2–4 sachets, especially when combined with the RipeLock liner, improved the retention of green colour and overall visual quality of broccoli, thus increasing marketability by 5-7 days when heads were held at 5-7°C for 2-3 weeks. It also increased the percentage of marketable heads from 0% to 72–100% during simulated retail display at 7°C for up to 2 weeks before transfer to 20°C. In two of the experiments, these handling conditions included a 5-day transport by truck at 5-10°C before storage/retail simulations. Delaying application of 1-MCP by 24 hours after harvest had little impact on its effectiveness. Depending on the number of sachets, 1-MCP concentrations peaked from 0.3–2.3 ppm at 5 hours after packing, but fell to levels below 0.1 ppm after 24 hours. The In-Box/RipeLock system generally provided broccoli heads with equal or better protection from fluctuating cold chain temperatures than the standard industry practice of top icing in styrofoam.

Thus, results suggest the In-Box/RipeLock system has the potential to replace top-icing, especially in situations where broccoli may be transported long distances, stored for extended periods, or is likely to be subjected to temperatures higher than optimal during the supply chain. In addition, the effects of In-Box were retained once broccoli was transferred to warmer temperatures, a condition typically found during the supply chain, including product handling during retail and consumer's households.

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