Leafy Asian Vegetables

Extending Their Shelf Life

A report for the Rural Industries Research and Development Corporation

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Foreword

A potential means of extending the shelf life of leafy Asian vegetables is a technology widely known as modified atmosphere packaging (MAP), a technology that has been successfully used with other leafy greens such as lettuce, but had not been investigated for Asian vegetables.

Consequently, a project was instigated in July 1996 under the funding of the Asian Foods program of RIRDC to assess the potential application of this technology to Asian vegetables, especially those that are current constituents of leafy salad mixes. The project's aim was to identify potentially useful atmospheres for extending the shelf life of leafy Asian vegetables and to estimate plastic film parameters that would enable an atmosphere to be maintained within a package.

This report outlines the findings, and provides a basis for estimating appropriate films for a range of package sizes and constituents. These findings can be trialed by industry, but the researchers warn that they are untested at this stage. Testing of these recommendations is being carried out under a new RIRDC project (DAQ-239A) currently in progress.

This report, a new addition to RIRDC's diverse range of over 400 research publications, forms part of our Asian Foods program, which aims to foster the development of a viable Asian Foods industry in Australia.

Most of our publications are available for viewing, downloading or purchasing online through our website:

- downloads at www.rirdc.gov.au/reports/Index.htm
- purchases at www.rirdc.gov.au/pub/cat/contents.html

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Executive Summary

Leafy Asian vegetables constitute the largest proportion of the Australian Asian vegetable industry. A growing sector of this industry is the area of fresh-processing, in which leaves are used as constituents of pre-made salads and stirfrys. The shelf life of these leaves is inherently short and consequently produces a major restriction on market expansion. Presently, product shelf life varies from one day to one week, depending on the product type and if the packaging (if any) is suitable for the product and conditions it is marketed under. A reasonable period of domestic shelf life should be in the order of 10 days, while export markets such as Singapore require in the proximity of 16-20 days to allow for shipping time. These periods are seldom achieved without research into product design, usually requiring the development of modified atmosphere packaging (MAP) to extend shelf life.

Shelf life of packaged leaves can be limited by a number of factors, such as yellowing, browning and rots. Little if any literature relates to investigations on shelf life constraints to fresh-processed Asian vegetable leaves, however preliminary evidence (confirmed by our project) indicates that yellowing is the principle restraint to many brassica species, which constitute a large proportion of leaves that are used in mixes. The current project focuses on seven leafy Asian vegetables of importance to the Australian industry: pak choy, tatsoi, mizuna, mibuna, Chinese mustard, choy sum and garland chrysanthemum. All of these vegetables belong to the genus *Brassica*, with the exception of garland chrysanthemum (*Chrysanthemum coronarium*).

The key method through which this project aims to extend shelf life of these vegetables is the development of recommendations for the development of modified atmosphere packaging. This requires identifying appropriate atmospheres that will extend shelf life, identifying vegetable respiratory rates and plastic permeances which will affect the final development of atmospheres within a package, and identifying other factors that will have a strong influence on product shelf life.

The project was consequently broken down into the following areas:

- *identifying the effect of physiological leaf age on shelf life*
- *identifying the effect of temperature on shelf life of each vegetable*
- *identifying optimum oxygen and carbon dioxide concentrations for extending the shelf life of each vegetable*
- *identifying respiratory rates under optimum atmospheres to calculate plastic packaging specifications*
- *estimating plastic film parameters based on experimental data*
- *recording the temperature range of several existing cold-chains from farm to retail*

A primary factor that directly affects shelf life is temperature. Temperature was shown to have a strong influence on leaf shelf life, underlying the importance of cold-chain integrity to product durability. Trials also indicated that different vegetables had different inherent shelflives. Consequently, a package containing more than one vegetable could be limited by a specific vegetable type. The choice is then to increase the shelf life of the limiting vegetable, or to exclude it as a salad constituent.

Furthermore, although the shelf life of a salad or stir-fry mix may be limited by a specific vegetable, this effect is, firstly, more important at lower temperatures where the range of shelflives has a greater spread and, secondly, dependent on temperature, as the limiting vegetable can vary between storage temperature regimes. This information can be used as a guide for refrigerated storage of packages containing these commodities. It should be noted however, that where procedures such as modified atmosphere (MA) packaging are to be used, relative shelf life between vegetables may vary from that observed under normal air storage. Shelf life differences are also likely to become more important at higher temperatures with modified atmosphere packaging, as retardation in senescence processes will potentially provide a greater spread in shelf life between vegetables.

A factor which seems to have been neglected in past studies of shelf life, physiological leaf age can have a profound affect on shelf life. Many leafy Asian vegetables grow in the form of a rosette, with the inner leaves having the youngest physiological age. Consequently, when the leaves are harvested as a whole, a range of leaf ages exist, even though all leaves may be of the same colour and appearance. Leaf age has a strong mediating effect on yellowing, with physiologically younger leaves remaining green longer. With the knowledge that physiological leaf age has a strong influence on leaf yellowing, shelf life of a package of fresh-processed leaves will be limited by the oldest leaves present at the time of packing.

Atmosphere modification significantly increased the shelf life of all vegetables studied. Under the atmosphere recording the longest shelf life for each vegetable (at 10^oC), shelf life was increased by 130% for choy sum, 110% for tatsoi, 160% for pak choy, 140% for mibuna, 70% for mizuna, 225% for Chinese mustard and 160% for garland chrysanthemum. Taking into account that the optimum atmosphere may be difficult to maintain under a commercial situation (eg. oxygen concentration is low enough to be risking anaerobic conditions), 'safer' atmospheres gave shelf life increases of 110%, 110%, 140%, 50%, 60%, 190% and 85%, respectively. This equated to a final shelf life of 21 days for choy sum, 21 days for tatsoi, 19 days for pak choy, 27 days for mibuna, 24 days for mizuna, 23 days for Chinese mustard and 12 days for garland chrysanthemum.

Although a range of atmospheres existed for each vegetable that could attain the same increase in shelf life, a range of atmospheres was targeted which was considered both effective and relatively safe in relation to leaf integrity. These atmospheres included $1\%O_2$ or $2\%O_2$ in combination with either $2\%CO_2$ or $5\%CO_2$. Lower oxygen levels were considered difficult to maintain, while higher levels were less effective. Similarly, higher carbon dioxide levels would be more likely to result in carbon dioxide toxicity under adverse conditions (temperature abuse), while nil carbon dioxide was usually not as effective as slightly higher concentrations.

As mentioned above, temperature has a direct effect on the shelf life of leafy Asian vegetables. More importantly however, high temperatures can upset the atmosphere equilibrium of a modified atmosphere package. High temperatures will cause the vegetables to use up oxygen and to produce more carbon dioxide faster than the gas can permeate through the plastic film. If severe enough and for a long enough period, oxygen depletion will result in anaerobiosis (leaves ferment) and high carbon dioxide concentrations will result in carbon dioxide toxicity (resulting in the development of off-odours and tissue damage). Consequently, integrity of a commercial cold-chain is of maximum importance.

Assessment of several existing cold-chains showed generally good conditions for maintaining temperature control. Potential places of temperature abuse were observed in only two areas.

The first of these involved transport in a non-refrigerated vehicle, while the second was linked to storage of the product under non-refrigerated conditions while awaiting collection by the next part of the cold-chain. These assessments were easily performed and provided good information for improvement of cold-chains under commercial conditions.

In order to estimate packaging film parameters to develop modified atmospheres, respiration rates of each vegetable were measured under the atmospheres outlined above. This information provided all that was necessary to tailor an appropriate plastic film to a package of given weight and surface area. A range of potential film parameters have been estimated together with the formulae required to estimate new parameters for different package sizes. At this stage, the plastics are theoretical parameters only and require testing before a full recommendation can be made. It should be noted that these plastics will be tested under RIRDC project DAQ239A (starting date July 1998) with results to be published during this project.

Introduction

Growth of the Australian Asian vegetable industry is increasing as domestic consumption continues to become more cosmopolitan and the ethnic population increases in size. As Lee (1995) produced the first and only comprehensive audit of the industry in 1993/94, the past growth-rate of the industry can not be accurately quantified. However, both the quantity and variety of Asian vegetables available at mainstream supermarkets has significantly increased in the last five years.

Leafy Asian vegetables are sold in many forms, either as bunches, heads or as individual leaves. Individual leaves from different species may also be combined to form salad or stir-fry mixes, and it is upon these individual leaves that this project concentrates. Heading vegetables, which are largely dominated by Chinese cabbage, can also form part of a salad mix, but this is usually in a diced or grated form, which introduces its own set of limiting factors and has not been investigated here.

Individual leaves when sold together can be classified as a 'fresh-processed' product. Fresh processing is a value-adding procedure which converts whole vegetables into a convenient and prepared, but fresh form for the consumer. Demand for this type of product is increasing and is expected to continue to escalate into the next decade. Many leafy Asian vegetables appear suitable for minimal processing, although little or no information is available for these commodities. Potential products include individual leaves, prepared shoots, salad mixes and stir-frys. Demonstrated markets include restaurants and service industries, food institutions and supermarkets both domestically and overseas.

Market access is largely restricted by the shelf life of the product. Apart from wilting which will occur with most leaves if not packaged, limiting factors to shelf life include yellowing, browning and rots. In the case of Asian vegetable leaves, the primary limitation to shelf life tends to be yellowing. This seems to be especially so with brassicas, which comprise the greater majority of leafy Asian vegetable in the marketplace. Yellowing is an obvious sign that the product has reached the end of its shelf life.

An increase of shelf life potentially allows access both to areas requiring longer transport periods and to markets with extended handling procedures or longer turnover periods. Presently, product shelf life varies from one day to one week, depending on the product type and if the packaging (if any) is suitable for the product and conditions it is marketed under. A reasonable period of domestic shelf life should be in the order of 10 days, while export markets such as Singapore require in the proximity of 16-20 days to allow for shipping time. These periods are seldom achieved without research into product design, usually requiring the development of modified atmosphere packaging (MAP) to extend shelf life.

Little if any literature relates to investigations on shelf life constraints to fresh-processed Asian vegetable leaves. With this in mind, many factors had to be considered, including leaf age, handling temperatures and the practicalities of generating and maintaining an optimum atmosphere within a package. Furthermore, the large number of Asian vegetables available meant that not all vegetables could be studied, with the project concentrating on seven leafy vegetables currently used in domestic salad mixes.

The outcomes of this project provide a basis for the development of modified atmosphere packaging, although testing is still required to confirm these recommendations. This testing is currently being performed within a new project (RIRDC project DAQ239A) which follows on from the present project. This project will test recommendations and adjust film parameters where necessary.

These trials will be published jointly with additional studies commissioned by RIRDC in this area to provide the most comprehensive guide to date for postharvest handling of leafy Asian vegetables.

Objectives

The objective of this project is to extend the shelf life of fresh processed leafy Asian vegetables to enable domestic expansion and potential access to export markets. The project focuses on seven leafy Asian vegetables of importance to industry: pak choy, tatsoi, mizuna, mibuna, Chinese mustard, choy sum and garland chrysanthemum.

To achieve this objective, the project has identified and separated key factors affecting shelf life, and developed preliminary recommendations for the development of modified atmosphere packaging.

The project is broken down into the following areas:

- *identifying the effect of temperature on shelf life of each vegetable*
- *identifying the effect of physiological leaf age on shelf life*
- *identifying optimum oxygen and carbon dioxide concentrations for extending the shelf life of each vegetable*
- *identifying respiratory rates under optimum atmospheres to calculate plastic packaging specifications*
- *estimating plastic film parameters based on experimental data*
- *recording the temperature range of several existing cold-chains from farm to retail*

Methodology

The principal limitation to shelf life in many leafy Asian vegetables is chlorophyll degradation, resulting in leaf yellowing and an obvious signal that the product is no longer fresh. In many brassicas, chlorophyll loss can be greatly retarded by modifying the atmosphere (ie. oxygen, carbon dioxide) in which the product is packaged. This is accomplished by first establishing the optimum atmosphere for the product, followed by determining the respiration of the product under this atmosphere. As the product is actively respiring, an equilibrium atmosphere equivalent to the optimum atmosphere can be formed using plastic film with the appropriate permeability to oxygen and carbon dioxide.

The project focussed on the determination of optimal packaging atmospheres for leaves of pak choy (*Brassica rapa* var. *chinensis*), tatsoi (*B. rapa* var. *rosularis*), Chinese mustard (*B. juncea*), mizuna and mibuna (*B. rapa* var. *nipposinica*), choy sum (*B. rapa* var. *parachinensis*) and garland chrysanthemum (*Chrysanthemum coronarium*). Atmosphere optimisation of oxygen and carbon dioxide concentrations was conducted in a matrix of oxygen and carbon dioxide combinations under a continuous flow system maintained at 10^{o}C (this temperature is considered a practical estimate of a moderately well controlled cold-chain aiming at a temperature of 4^{o}C).

Shelf life parameters were based on colour changes, development of off-odours and rots. Physiological leaf age had an immediate effect on shelf life, and thus measurements were made on the youngest fully expanded leaf of a plant to standardise trials. Colour change was monitored as the change in hue angle and visual appearance.

Respiratory rates (oxygen and carbon dioxide) under optimum atmosphere were calculated using a static respiration technique and monitored by thermal conductivity gas chromatograph. The respiration rates were subsequently used in the design of plastic packaging of correct permeance to form an optimum equilibrium atmosphere.

The effect of temperature on leaf respiratory response and product shelf life was monitored under air (21% O_2, 0% CO_2) in order to calculate relative product responses to cold-chain fluctuations. Respiration was calculated using the same procedure as above.

Commercial cold-chains were monitored by placing temperature dataloggers within the packaged vegetables to estimate temperatures that were being experienced at any part of the cold-chain. Data was used to estimate potential trouble spots where temperature abuse could compromise the shelf life of the product.

Effect of temperature on shelf life

Temperature storage trials at 1-25^{o}C were performed with leaves of pak choy, tatsoi, Chinese mustard, mizuna, mibuna, choy sum and garland chrysanthemum to identify shelflives, the factors limiting shelf life, and respiration rates.

Yellowing has been previously implicated as limiting shelf life of pak choy (Wang and Herner, 1989), choy sum (Hirata et al., 1987), Chinese mustard (Lazan et al., 1987) and garland chrysanthemum (Yamauchi et al., 1980). Prior studies have also shown temperatures of 2-4^{o}C in Chinese mustard (Lazan et al., 1987), 1^{o}C in choy sum (Hirata et al., 1987) and 0-1^{o}C in garland chrysanthemum (Yang, 1992) to increase shelf life by delaying yellowing. The present trial provides information confirming what factors are limiting each vegetable, and the base shelf life each vegetable has without atmosphere modification under various temperature conditions that could be experienced in a cold chain. This information will give an idea of what shelflives to expect and which vegetables may be limiting if placed in a mixed salad or stirfry.

Individual varieties were harvested at the six leaf stage and brought to the laboratory on the same day. After washing and drying, leaves were excised from plants midway along the petiole, and placed in unsealed plastic bags. Five replicates per temperature treatment were stored at 1, 5, 10, 15 and 25°C. For each vegetable, a range of leaf ages were selected and rated as a group for general appearance (1, dislike extremely; 9, like extremely) at zero time and at subsequent removals. Plots were fitted to this data to estimate the shelf life of each replicate. Shelf life constituted the time taken to reach a score of 5.5. Respiratory rates were calculated for all replicates using a static respiration procedure. Replicates were sealed in airtight plastic containers and gas samples taken at 0 and 2 hours for gas analysis.

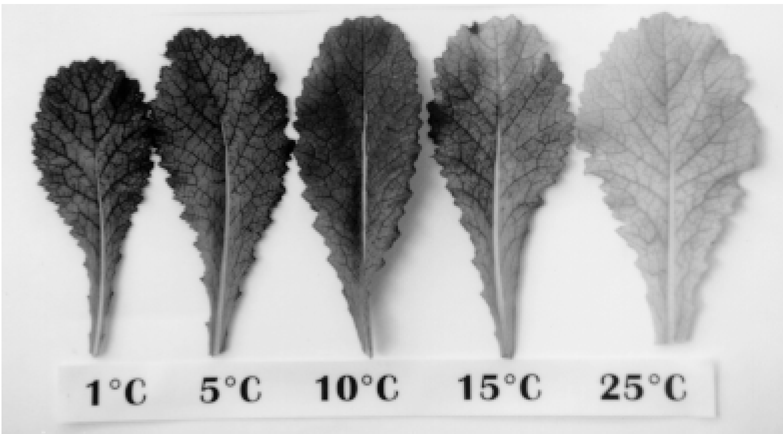

Figure 1. Shelf life of Chinese mustard was limited by leaf yellowing. After four days, shelf life had expired at 15^{o}C and 25^{o}C.

Shelf life of vegetables was limited by either leaf yellowing and/or rotting (Figure 1). Yellowing was the predominant limiting factor for all vegetables except in garland chrysanthemum where older leaves rotted at 15 and 25°C, which was possibly linked to wet weather during the week of harvest. All vegetables exhibited longest storage life at 1^{o}C (Figure 2), ranging from 12 days (Chinese mustard) to 19 days (mibuna), without any evidence of chilling injury. As temperature increased, both shelf life and the range between vegetable-shelflives became narrower, so that at 25°C all vegetables had a shelf life between 2 and 4 days. Vegetables limiting shelf life were not consistent across the temperature range studied. At 25°C, constituents did not significantly differ in their shelf life.

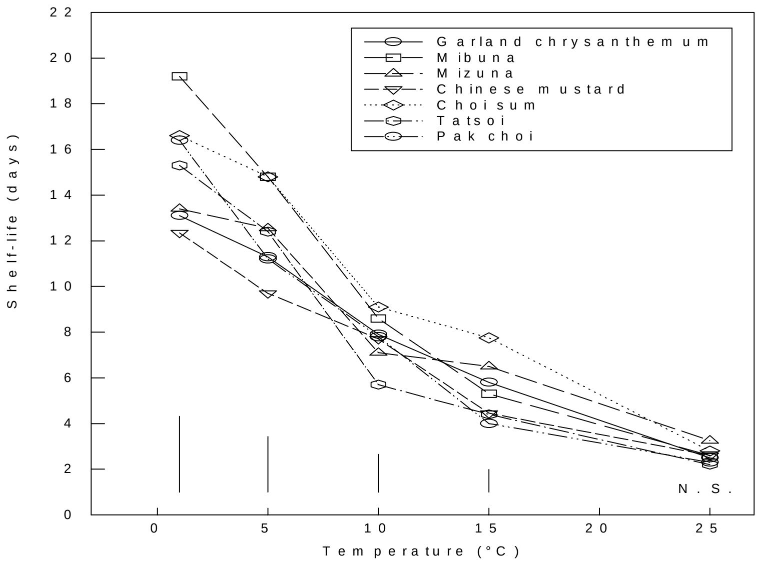

Figure 2. Vegetables limiting shelf life were not consistent across the temperature range studied. At 25°C, there was no significant difference in shelf life.

Respiration rates of all vegetables increased with temperature, concurrent with a decline in shelf life. Respiration of the different vegetables varied widely, but high respiration did not necessarily infer a shorter shelf life than a vegetable with lower respiration rate (Figure 3).

The present trial indicates that temperature has a strong influence on leaf shelf life, underlying the importance of cold-chain integrity to product durability. It also indicates that different vegetables have different inherent shelflives. Consequently, a package containing more than one vegetable may be limited by a specific vegetable type. The choice is then to increase the shelf life of the limiting vegetable, or to exclude it as a salad constituent.

Furthermore, although the shelf life of a salad or stir-fry mix may be limited by a specific vegetable, this effect is, firstly, more important at lower temperatures where the range of shelflives has a greater spread and, secondly, dependent on temperature, as the limiting vegetable can vary between storage temperature regimes. This information can be used as a guide for refrigerated storage of packages containing these commodities. It should be noted however, that where procedures such as modified atmosphere (MA) packaging are to be used, relative shelf life between vegetables may vary from that observed under normal air storage. Shelf life differences are also likely to become more important at higher temperatures with MA, as retardation in senescence processes will potentially provide a greater spread in shelf life between vegetables.

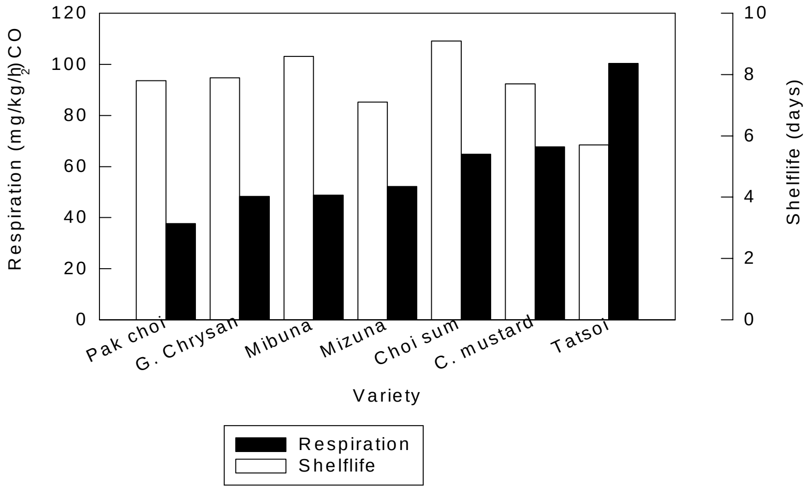

Figure 3. Respiration rates of vegetables differed but high respiration did not necessarily infer shorter shelf life at 10°C.

Effect of leaf age on shelf life

Many leafy Asian vegetables grow in the form of a rosette, with the inner leaves having the youngest physiological age. Consequently, when the leaves are harvested as a whole, a range of leaf ages exist, even though all leaves may be of the same colour and appearance. This can have a profound influence in response to atmosphere modification and shelf life, which needs to be considered by anyone handling this type of commodity.

The following trial with pak choy illustrates the effect of leaf age on the subsequent shelf life of each leaf when placed under a range of oxygen atmospheres. The parameter used to measure loss of shelf life was leaf yellowing, measured here using hue angle, an objective form of measurement that can detect small changes in colour.

Plants of pak choy were harvested at the six-leaf stage and equilibrated to 10°C overnight. Plants were separated into component leaves with the outermost leaf constituting the oldest leaf and the innermost leaf greater than 25 mm in length constituting the youngest leaf. Leaves were measured for initial hue angle before being stored for 17 days at 10°C (95% RH). At 17 days, leaves were removed from containers and remeasured for hue-angle.

Leaf senescence was characterised by a yellowing of leaves which was indicated quantitatively by a decline in hue angle. Leaf age had a direct effect on the degree of yellowing, with oldest leaves yellowing significantly more than younger leaves (Figure 1). In fact, the two youngest leaves did not change significantly in hue angle after a storage period of 17 days.

Figure 1. A range of leaf ages are present on a single plant (youngest to oldest leaves are shown from left to right). Younger leaves (towards left) were still green after 17 days at 10°C, while older leaves had yellowed.

Reducing the oxygen concentration had a mediating effect on the rate of leaf yellowing, slowing the rate of colour degradation of all leaves which had begun to yellow at 17 days storage (Figure 2). The effect of leaf age however could not be negated, with older leaves still displaying a shorter shelf life than younger leaves under the same atmosphere.

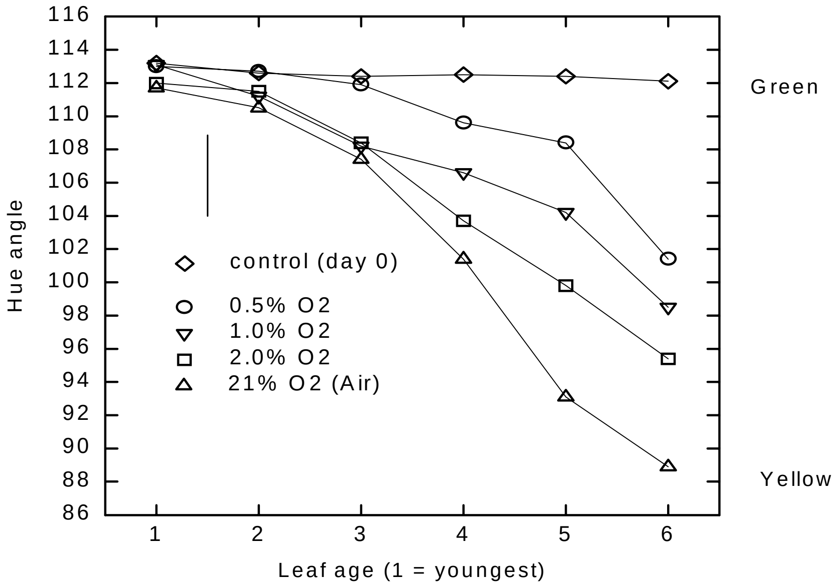

Figure 2. Leaf age has a direct effect on rate of yellowing. Reducing the oxygen concentration within a package is one means of reducing this rate.

Leaf age appears to have a strong mediating effect on chlorophyll loss, with physiologically younger leaves tending to maintain higher levels of chlorophyll, irrespective of oxygen concentration. A similar effect of leaf age on rate of chlorophyll loss has been observed in parsley (Apeland, 1971) and it is likely that this effect will apply to the other vegetables under study in the current project (all have a rosette structure). The reason for the observed variation in chlorophyll degradation between differently aged leaves can only be speculated, but may be related to differences in energy substrate (eg. sugar supply) and factors influencing ethylene sensitivity.

With the knowledge that physiological leaf age has a strong influence on leaf yellowing, shelf life of a package of minimally processed leaves will be limited by the oldest leaves present at the time of packing. From an experimental point of view, this makes an accurate assessment of shelf life difficult. With this in mind, assessments of shelf life under different atmospheres were made with the youngest fully expanded leaf. This leaf was considered mid-way between the youngest and oldest leaves present in a typical package.

Effect of atmosphere on shelf life

Although little study has been made, there is evidence that atmosphere modification can retard leaf yellowing of at least some leafy Asian vegetables, including pak choy (Wang and Herner, 1989), Chinese mustard (Lazan et al., 1987) and garland chrysanthemum (Yang, 1992). With the aim of identifying the potential for specific atmosphere combinations for the vegetables in this project, controlled atmosphere storage trials were conducted. All trials were performed at 10°C (temperature directly influences shelf life). Normal air (21%O_2, 0%CO_2) has been included as a treatment and was used as a benchmark against which the impact of specific atmosphere combinations could be judged.

Initial trials used a mixture of leaf ages, but as initial physiological age directly affects shelf life (see Effect of Leaf Age on Shelf life), later studies were confined to leaves of a single physiological age in order to compare atmospheric effects. The studies presented below were conducted with the youngest fully-expanded leaf on a plant. While younger leaves are expected to have longer shelflives, and older leaves shorter, the degree that atmosphere treatments affect shelf life is expected to remain largely constant in respect to each other.

Vegetables were harvested at the six leaf stage and brought to the laboratory on the same day. After washing and drying, leaves were excised from plants midway along the petiole, and placed in unsealed plastic bags. The youngest fully expanded leaves were chosen and rated for general appearance (1, dislike extremely; 9, like extremely). Ten replicates were used per atmosphere. Leaves were withdrawn over the course of the trial and judged for acceptability.

Atmosphere modification significantly increased shelf life of all vegetables studied. A shelf life comparison between vegetables held under air and under optimum atmospheres is shown in Table 1. Increases were quite substantial for the leaves studied (youngest fully-expanded leaf), although it should be noted that leaves with a greater initial physiological age will have a shorter total shelf life than those listed in Table 1.

Table 1. Shelf life of leaves stored at 10°C under air, optimum atmosphere and 'safe' optimum atmosphere. A 'safe' optimum atmosphere was defined as an atmosphere with a moderate to high impact on shelf life with an oxygen concentration above 0.5% and a carbon dioxide concentration below 10%.

	Air (days)	Optimum atmosphere (days)	Optimum safe atmosphere (days)
Choy sum	10	23	21
Tatsoi	10	21	21
Pak choy	8	21	19
Mibuna	18	43	27
Mizuna	15	25	24
Chinese mustard	8	26	23
Garland chrysanthemum	6	17	12

Under the atmosphere recording the longest shelf life for each vegetable (at 10°C), shelf life was increased by 130% for choy sum, 110% for tatsoi, 160% for pak choy, 140% for mibuna, 70% for mizuna, 225% for Chinese mustard and 160% for garland chrysanthemum. Taking into account that the optimum atmosphere may be difficult to maintain under a commercial situation (eg. oxygen concentration is low enough to be risking anaerobic conditions), 'safer' atmospheres gave shelf life increases of 110%, 110%, 140%, 50%, 60%, 190% and 85%, respectively.

Individual trials for each vegetable are shown over the following pages. The data is summarised firstly as oxygen and carbon dioxide main effects (which show general atmosphere trends on shelf life) and then more specifically as individual atmosphere treatment combinations. Specific combinations are of direct practical use and have been listed as either having high, moderate or low impact for each vegetable.

It should be noted that atmospheres containing very low oxygen (ie. 0.5%O_2) or high carbon dioxide concentrations (10-15%CO_2) will incur a higher risk in a commercial situation where temperature abuse conditions are likely to occur. A temperature increase will lead to a further lowering of oxygen concentration and an increase in carbon dioxide concentration that could lead to off-odours and leaf breakdown.

Choy sum

Oxygen
An increase of shelf life (3 days) became significant as oxygen concentrations were reduced below 4% (Figure 1). Reducing the oxygen concentration below 1% resulted in a further increase in shelf life (3 days), a total of six days increase over normal atmospheric oxygen (ie. 21%O_2).

Carbon dioxide
Shelf life was increased by raising the carbon dioxide concentration. Carbon dioxide concentrations between 2% and 15% were effective in increasing shelf life by 3-4 days (Figure 1).

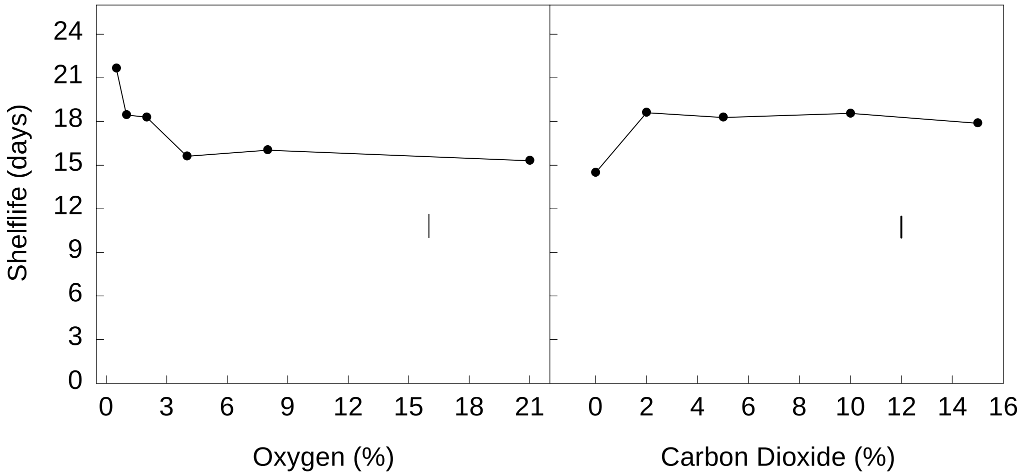

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of choy sum. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations
Increasing carbon dioxide concentration to 2% and above (up to 15%) resulted in a significant increase in shelf life at all accompanying oxygen concentrations, with the exception of 0.5% O_2 (Figure 2). At 0.5%O_2, increasing the carbon dioxide concentration at 0.5%O_2 had no further positive impact, and actually reduced shelf life slightly at 15%.

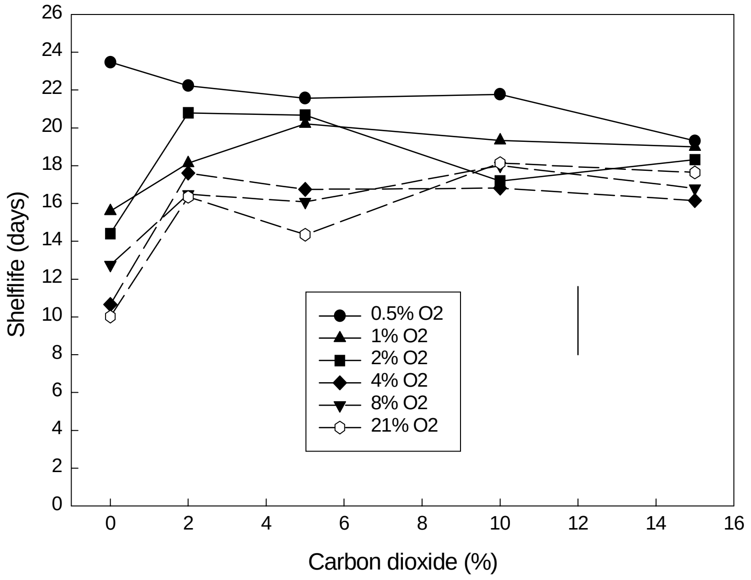

Figure 2. Effect of individual atmosphere combinations on the shelf life of choy sum. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact:	*0.5/0, 0.5/2, 0.5/5, 0.5/10, 1/5, 2/2, 2/5*
Moderate-low impact:	*0.5/15, 1/0, 1/2, 1/10, 1/15, 2/0, 2/10, 2/15, 4/2, 4/5, 4/10, 4/15, 8/2, 8/5, 8/10, 8/15, 21/2, 21/5, 21/10, 21/15*
Nil impact:	*4/0, 8/0, air*

Tatsoi

Oxygen

Shelf life gradually increased as oxygen concentration was decreased. Concentrations below 4% were needed to provide a significant increase in shelf life (Figure 1). An increase of 2-4 days was provided by oxygen concentrations of 1-2%O_2, while 4.5 days was attained at 0.5%O_2.

Carbon dioxide

Shelf life was increased by raising carbon dioxide concentrations. While 2%CO_2 significantly increased shelf life by 3 days, higher concentrations (5-15%CO_2) were more effective, recording a shelf life increase of 5 days (Figure 1).

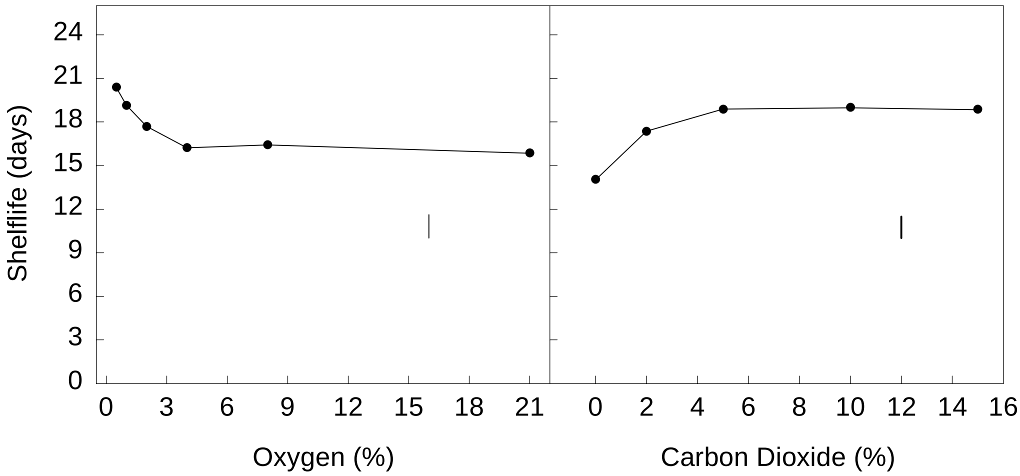

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of tatsoi. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations

Increasing the carbon dioxide concentration to 2% and above (up to 15%) resulted in a significant increase in shelf life at all accompanying oxygen concentrations, with the exception of 0.5% O_2 (Figure 2). Altering the carbon dioxide concentration at 0.5%O_2 did not affect shelf life.

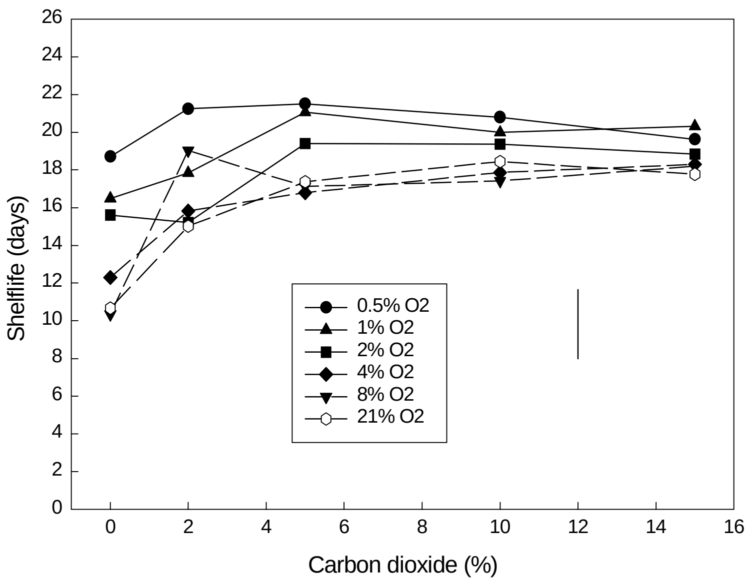

Figure 2. Effect of individual atmosphere combinations on the shelf life of tatsoi. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact:	*0.5/0, 0.5/2, 0.5/5, 0.5/10, 0.5/15, 1/2,1/5, 1/10, 1/15, 2/5, 2/10, 2/15, 4/10, 4/15, 8/2, 8/15, 21/10, 21/15*
Moderate-low impact:	*1/0, 2/0, 2/2, 4/2, 4/5, 8/5, 8/10, 21/2, 21/5*
Nil impact:	*4/0, 8/0, air*

Pak choy

Oxygen
An increase in shelf life was possible by decreasing the oxygen concentration below 4% (Figure 1). A concentration of 2%O_2 resulted in an increase in shelf life of 2 days, while further decreasing oxygen to 0.5-1%O_2 resulted in a significantly longer shelf life by 4-5 days.

Carbon dioxide
Shelf life was increased by raising the concentration of carbon dioxide to at least 2%, with concentrations of 5-15% providing the greatest increases in shelf life (4-6 days) (Figure 1).

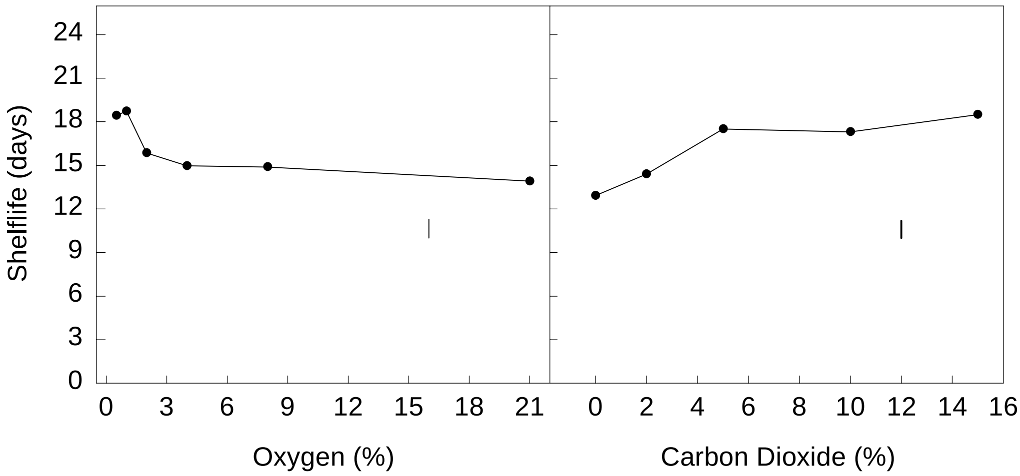

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of pak choy. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations
Increasing the carbon dioxide concentration increased shelf life at all oxygen concentrations with the exception of 0.5%O_2, where no change was recorded apart from a slight decrease at 15%CO_2 (Figure 2).

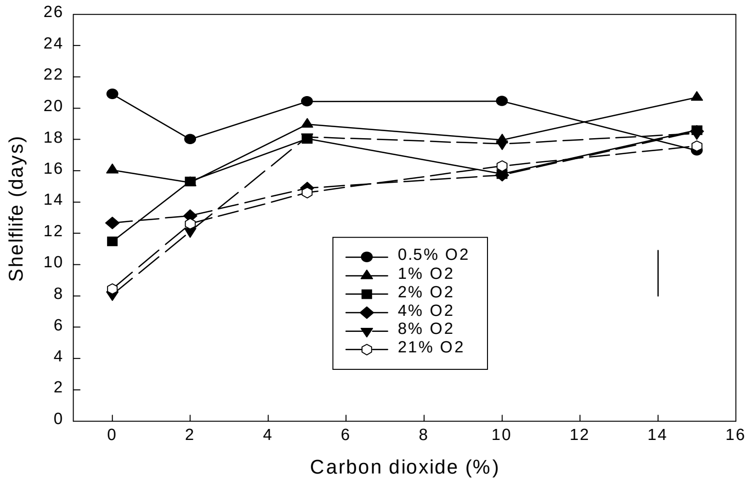

Figure 2. Effect of individual atmosphere combinations on the shelf life of pak choy. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact:	*0.5/0, 0.5/2, 0.5/5, 0.5/10, 1/5, 1/10, 1/15, 2/5, 2/15, 4/15, 8/5, 8/10, 8/15, 21/15*
Moderate-low impact:	*0.5/15, 1/0, 1/2, 2/0, 2/2, 2/10, 4/0, 4/2, 4/5, 4/10, 8/2, 21/2, 21/5, 21/10*
Nil impact:	*8/0, air*

Mibuna

Oxygen

Shelf life was increased by decreasing oxygen concentrations to at least 4%, resulting in an increase of 2-3 days shelf life at 1-4%O_2, and of 5 days at 0.5%O_2 (Figure 1).

Carbon dioxide

Increasing the carbon dioxide concentration generally had little benefit on the shelf life of mibuna. In fact, concentrations of 5-15% generally resulted in a significant reduction in shelf life (Figure 1).

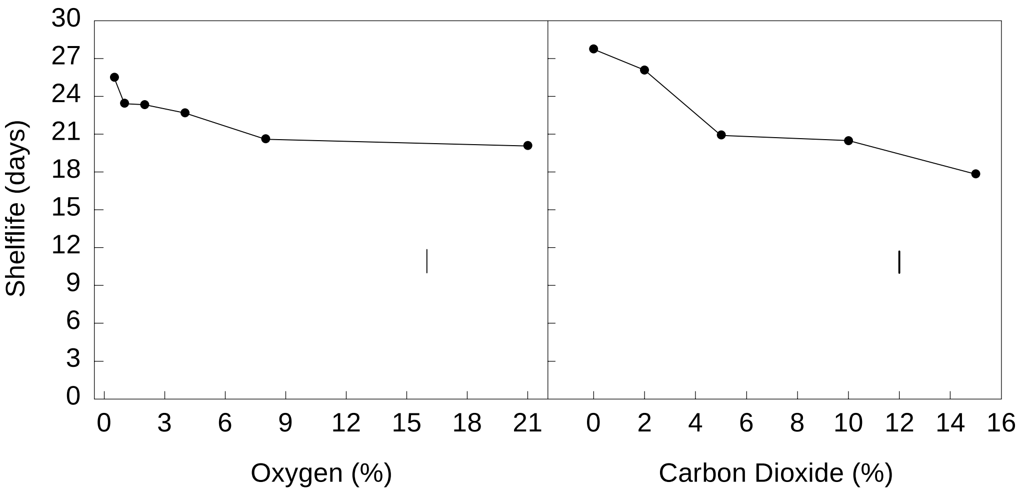

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of mibuna. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations

Increasing the carbon dioxide to 2% led to an increase in shelf life only at high oxygen concentrations (4-21%O_2) (Figure 2). At low oxygen concentrations (0.5-2%), increasing the carbon dioxide concentration to even 2% resulted in a decline in shelf life over oxygen reduction alone. Generally, atmospheres containing carbon dioxide at 5% or above had a similar shelf life to mibuna held under air.

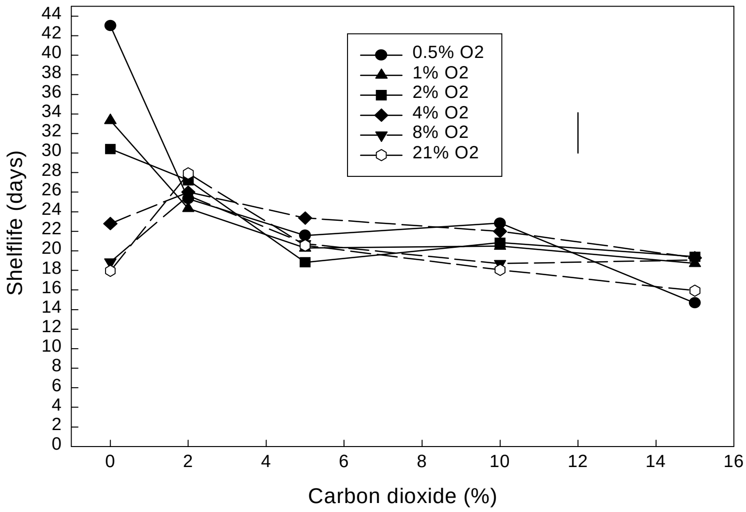

Figure 2. Effect of individual atmosphere combinations on the shelf life of mibuna. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact:	*0.5/0*
Moderate impact:	*0.5/2, 1/0, 1/2, 2/0, 2/2, 4/2, 8/2, 21/2*
Low impact:	*0.5/10, 4/0, 4/5*
Nil impact:	*0.5/5, 0.5/15, 1/5, 1/10, 1/15, 2/5, 2/10, 2/15, 4/10, 4/15, 8/0, 8/5, 8/10, 8/15, air, 21/5, 21/10, 21/15*

Mizuna

Oxygen

Reducing oxygen concentration to at least 4% resulted in an increase of shelf life (Figure 1). Concentrations of 2-4%O_2 recorded a shelf life increase of 3-4 days, while 0.5-1%O_2 recorded an increase of 4.5-5.5 days.

Carbon dioxide

Increasing carbon dioxide concentration to 2% or 5% resulted in a 1-2 day increase in shelf life (Figure 1). As concentration was increased, shelf life declined to levels at or below nil carbon dioxide.

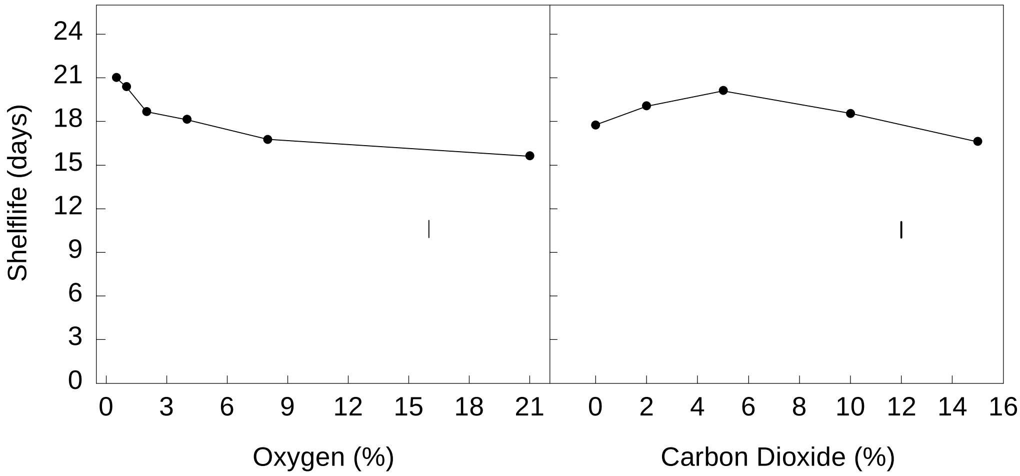

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of mizuna. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations

Increasing carbon dioxide concentration increased shelf life at all intermediate oxygen concentrations. No increase was observed at 0.5% and 21%O_2, with carbon dioxide concentrations greater than 2% actually reducing shelf life at 0.5%O_2 (Figure 2).

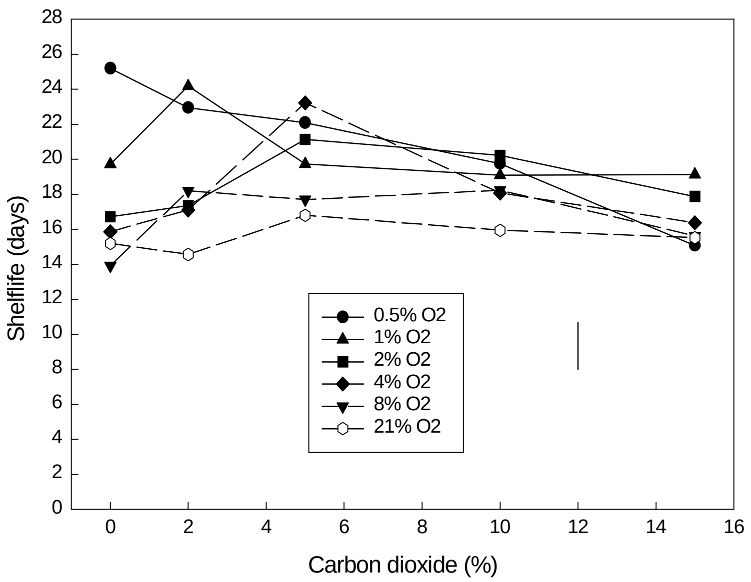

Figure 2. Effect of individual atmosphere combinations on the shelf life of mizuna. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact:	*0.5/0, 0.5/2, 1/2, 4/5*
Moderate-low impact:	*0.5/5, 0.5/10, 1/0, 1/5, 1/10, 1/15, 2/5, 2/10, 4/10, 8/2, 8/10*
Nil impact:	*0.5/15, 2/0, 2/2, 2/15, 4/0, 4/2,4/15, 8/0, 8/5, 8/15, air, 21/2, 21/5, 21/10, 21/15*

Chinese mustard

Oxygen

Shelf life increased as oxygen concentration was reduced from 4% downwards (Figure 1). Concentrations of 4%, 2% and 1% or below resulted in a shelf life increase of 2, 4 and 8 days, respectively.

Carbon dioxide

Increasing the carbon dioxide concentration to 2% or above (up to 15%) significantly increased shelf life (Figure 1). The greatest increase was recorded at 5% and 10%CO_2 (increase of 7 days), with a slightly lesser shelf life at 15%CO_2.

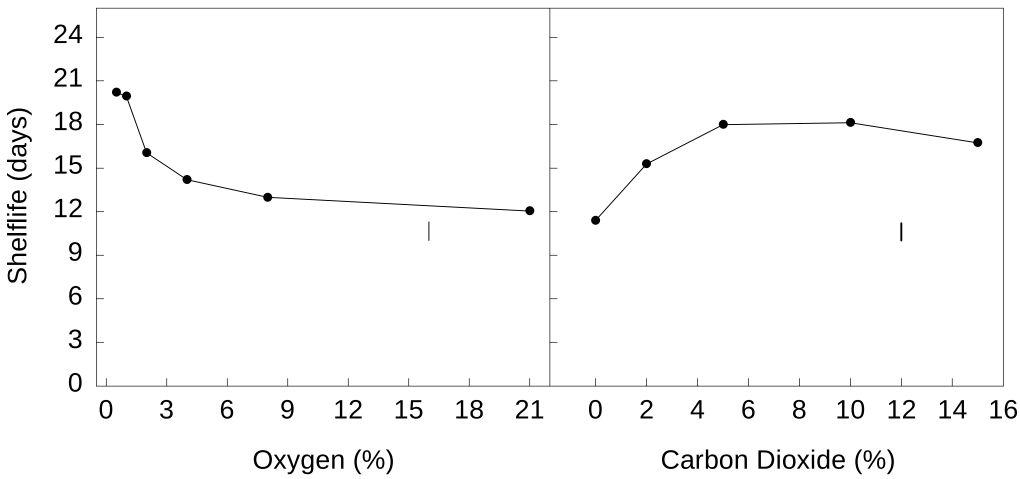

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of Chinese mustard. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations

Increasing the carbon dioxide level significantly increased shelf life at all oxygen concentrations. Optimum carbon dioxide concentration was generally 5-15%CO_2 at all oxygen concentrations, with the exception of 0.5%O_2 which had an optima of 2-5% (Figure 2). Evidence of carbon dioxide toxicity was low, apart from at 0.5%O_2 which appeared to be more susceptible to injury.

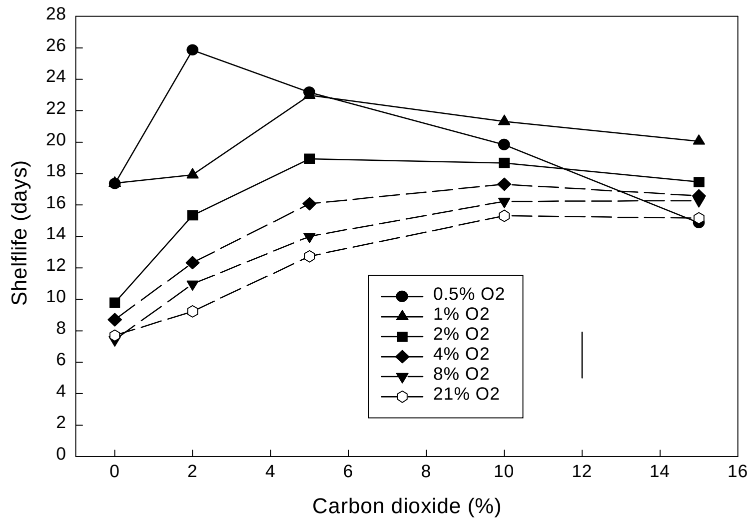

Figure 2. Effect of individual atmosphere combinations on the shelf life of Chinese mustard. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact: *0.5/2, 0.5/5, 1/5*
Moderate impact: *0.5/0, 0.5/10, 1/0, 1/2, 1/10, 1/15, 2/2, 2/5, 2/10, 2/15, 4/5, 4/10, 4/15, 8/10, 8/15, 21/10, 21/15*
Low impact: *0.5/15, 4/2, 8/2, 8/5, 21/5*
Nil impact: *2/0, 4/0, 8/0, air, 21/2*

Garland chrysanthemum

Oxygen

Oxygen concentration had to be reduced to 0.5% for a significant increase in shelf life (4 days) to be recorded (Figure 1).

Carbon dioxide

An increase in shelf life (2-3 days) was recorded under 2% and 5%CO_2 (Figure 1). No increase occurred at 10%CO_2, and a strong reduction in shelf life occurred at 15%CO_2 due to carbon dioxide toxicity.

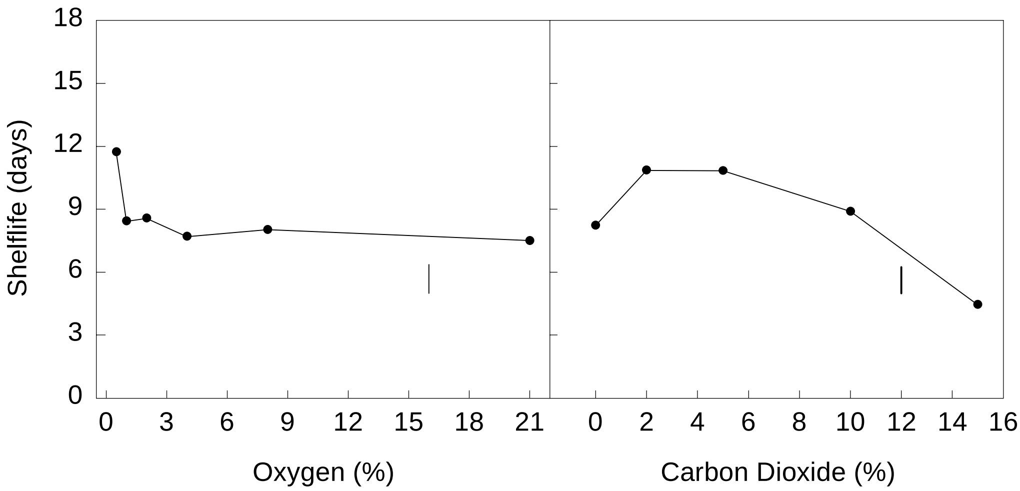

Figure 1. Oxygen and carbon dioxide main effects on the shelf life of garland chrysanthemum. Least significant differences ($P<0.05$) are indicated by a vertical bar.

Oxygen / Carbon dioxide combinations

Increasing carbon dioxide levels was effective in increasing shelf life at all oxygen concentrations, with the optimum carbon dioxide concentration generally falling within 2-10%CO_2 (Figure 2). Carbon dioxide toxicity was quite apparent at 15%CO_2, especially at higher oxygen concentrations (4-21%) where shelf life was significantly reduced compared to leaves held under air.

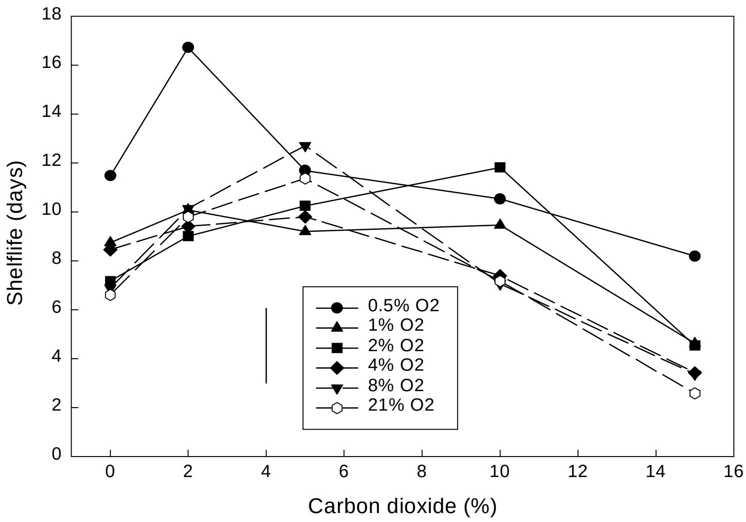

Figure 2. Effect of individual atmosphere combinations on the shelf life of garland chrysanthemum. Least significant difference (P<0.05) is indicated by a vertical bar.

In order of efficacy in increasing shelf life, the following atmosphere combinations were grouped together (%oxygen/%carbon dioxide):

High impact:	*0.5/2*
Moderate/low impact:	*0.5/0, 0.5/5, 0.5/10, 1/2, 2/5, 2/10, 4/5, 8/2, 8/5, 21/2, 21/5*
Nil impact:	*0.5/15, 1/0, 1/5, 1/10, 1/15, 2/0, 2/2, 2/15, 4/0, 4/2, 4/10, 8/0, 8/10, air, 21/10*
Negative impact:	*4/15, 8/15, 21/15*

Respiration rates under optimum atmospheres

Before a package can be designed to produce an optimum atmosphere to prolong shelf life, the rate of respiration of the product has to be estimated. This is because the equilibrium atmosphere that forms within the package is a function of both the rate of gas usage by the product (ie. leaves) and the permeance of the plastic used for packaging.

The rate of gas usage (respiration rate) has to be measured for both oxygen and carbon dioxide, as both gases have been shown to influence the shelf life of the Asian vegetables we have studied. The rate of respiration must be measured under conditions that simulate the atmosphere we are trying to achieve. For example, if we were trying to achieve a final atmosphere of 2%O_2 and 5%CO_2 in our package, we would measure respiration of the leaves held under this atmosphere.

With this in mind, respiratory rates were calculated for each vegetable (each replicate consisted of a mix of leaf ages) within a small atmosphere matrix (1-2%O_2 x 2-5%CO_2) that was considered optimal for the vegetables. Atmospheres containing less than 1%O_2 or greater than 5%CO_2 were not measured due to the potential risk of developing anaerobic conditions or carbon dioxide toxicity within a commercial cold-chain.

All measurements were conducted at 10°C and were conducted using a static measurement procedure. This involved equilibrating the vegetables under the target atmosphere for two days, followed by sealing the leaves within a gas-impermeable foil bag and observing the change in gas composition over a given time period

The respiratory rates for oxygen and carbon dioxide are shown in Table 1. No significant difference ($P<0.05$) in respiration rate existed between the four atmospheres tested. This indicates that changes in the atmospheric composition within this range do not have a large impact on respiration. Generally, volume of oxygen consumption closely paralleled carbon dioxide production for all vegetables, indicating aerobic respiration most probably based on a carbohydrate substrate.

Table 1. Respiration rates for carbon dioxide and oxygen (in parentheses) under selected atmospheres. Only rates for atmospheres (within the trial matrix) that had a high or moderate impact on shelf life are shown.

Respiration rate $mlCO_2/kg/h$ ($mlO_2/kg/h$)	1%O_2/2%CO_2	1%O_2/5%CO_2	2%O_2/2%CO_2	2%O_2/5%CO_2
pak choy		25 (22)		27 (23)
tatsoi	18 (19)	17 (17)		17 (18)
mibuna	23 (25)		18 (16)	
mizuna	21 (21)	21 (21)		26 (24)
Chinese mustard	19 (20)	18 (18)	22 (22)	22 (25)
choy sum		18 (18)	16 (17)	20 (17)
garland chrysanthemum	15 (19)			15 (16)

Respiration rates remained reasonably constant between 1997 and 1998 (Table 2). As the four atmospheres were not significantly different in terms of respiration rate, confirmation was performed only at 2%O_2/5%CO_2 (for all vegetables) and 2%O_2/2%CO_2 for mibuna.

Some differences did exist between years (eg. mizuna), indicating that other factors such as preharvest conditions may also influence leaf respiration rate.

Table 2. Respiration rates for carbon dioxide and oxygen (in parentheses) of leafy Asian vegetables under $2\%O_2/5\%CO_2$ (all vegetables) and $2\%O_2/2\%CO_2$ (mibuna only).

Respiration rate $mlCO_2/kg/h$ ($mlO_2/kg/h$)	(1997) $2\%O_2/5\%CO_2$	(1998) $2\%O_2/5\%CO_2$	(1997) $2\%O_2/2\%CO_2$	(1998) $2\%O_2/2\%CO_2$
pak choy	27 (23)	23 (22)		
Tatsoi	17 (18)	16 (21)		
Mibuna			18 (16)	27 (18)
Mizuna	26 (24)	34 (29)		
Chinese mustard	22 (25)	24 (17)		
choy sum	20 (17)	25 (26)		
garland chrysanthemum	15 (16)	19 (18)		

Plastic film recommendations

Design of a plastic film to generate an optimum package atmosphere requires the following information:

1. weight of the product
2. respiration rate of the product under the required atmosphere
3. surface area of the package

This information can be used to estimate the plastic film permeance required for both carbon dioxide and oxygen to produce an equilibrium atmosphere. Data can be entered into the following equations:

CO_2 permeance ($mlCO_2/m^2/day$):

$$\frac{\text{Respiration } (mlCO_2/kg/h) * \text{weight (kg)} * 24 * 100}{\text{film area } (m^2) * \text{required } CO_2 \text{ concentration (\%)}}$$

O_2 permeance ($mlO_2/m^2/day$):

$$\frac{\text{Respiration } (mlO_2/kg/h) * \text{weight (kg)} * 24 * 100}{\text{film area } (m^2) * (21 - \text{required } O_2 \text{ concentration (\%)})}$$

Using this data, we have calculated plastics required to generate a $2\%O_2/5\%CO_2$ atmosphere for a retail and wholesale package stored at 10^oC (Table 1). In general, the plastic permeance parameters will only change if the ratio of weight to film area is changed. Respiration rate should remain static under the desired atmosphere.

Table 1. Permeance characteristics of plastic films required to produce an equilibrium atmosphere of 2%O_2 / 5%CO_2 for a range of fresh-processed leafy Asian vegetables handled at 10^oC. Values are shown for retail (180 g) and wholesale-sized packages (510 g).

Vegetable	Resp. rate (mlO_2/kg/h)	Resp. rate ($mlCO_2$/kg/h)	Product weight (g)	Package surface area (m^2)	Plastic oxygen permeance (mlO_2/m^2/day)	Plastic carbon dioxide permeance ($mlCO_2/m^2$/day)
pak choy	23	27	180	0.086	6100	27100
			510	0.266	5600	24900
tatsoi	18	17	180	0.086	4800	17100
			510	0.266	4400	15700
mizuna	24	26	180	0.086	6300	26100
			510	0.266	5800	24000
Mibuna (2%CO_2)	18	16	180	0.086	4800	40200
			510	0.266	4400	36800
Chinese mustard	25	22	180	0.086	6600	22100
			510	0.266	6100	20300
garland chrysanthemum	16	15	180	0.086	4200	15100
			510	0.266	3900	13800
choy sum	17	20	180	0.086	4500	20100
			510	0.266	4100	18400

Cold-chain assessment

As shown earlier, temperature has a direct effect on the shelf life of leafy Asian vegetables. More importantly however, high temperatures can upset the atmosphere equilibrium of a modified atmosphere package. High temperatures will cause the vegetables to use up oxygen and to produce more carbon dioxide faster than the gas can permeate through the plastic film. If severe enough and for a long enough period, oxygen depletion will result in anaerobiosis (leaves ferment) and high carbon dioxide concentrations will result in carbon dioxide toxicity (resulting in the development of off-odours and tissue damage).

Seven cold-chains were assessed in Autumn 1998 to determine potential areas of temperature abuse that could adversely affect the shelf life of the product. These included three farm to wholesale market (Brisbane, Sydney, Melbourne), three supermarket fresh produce distribution centre to supermarket outlets, and one supermarket (on shelf).

All assessments were carried out with produce originating in south-east Queensland. Temperature dataloggers were placed within plastic packages of mizuna and tatsoi leaves. A third datalogger was placed within the cardboard box in which the packages were held. The first three assessments followed a shipment of mizuna and tatsoi to metropolitan markets on the east coast of Australia. The shipment to the Brisbane markets was subsequently collected by a secondary processor based in Brisbane.

Assessment of the cold-chains showed generally good conditions for maintaining temperature control. Potential places of temperature abuse were observed in only two areas. The first of these involved transport in a non-refrigerated vehicle, while the second was linked to storage of the product under non-refrigerated conditions while awaiting collection by the next part of the cold-chain. These assessments were easily performed and provided good information for improvement of cold-chains under commercial conditions.

Farm to Brisbane market (4/3/98 – 5/3/98)

Figure 1 indicates that produce warming (above 10^oC) occurred during transport from farm (B) to the local transport company depot (C) (from 11^oC to 18^oC) and at the Brisbane markets (D to E) while awaiting pickup by the secondary processor (from 15^oC to 17^oC). From the data, it appeared that temperatures would have continued to rise if the distance to the transport depot had been longer, or if there had been a delay picking up the produce at the markets.

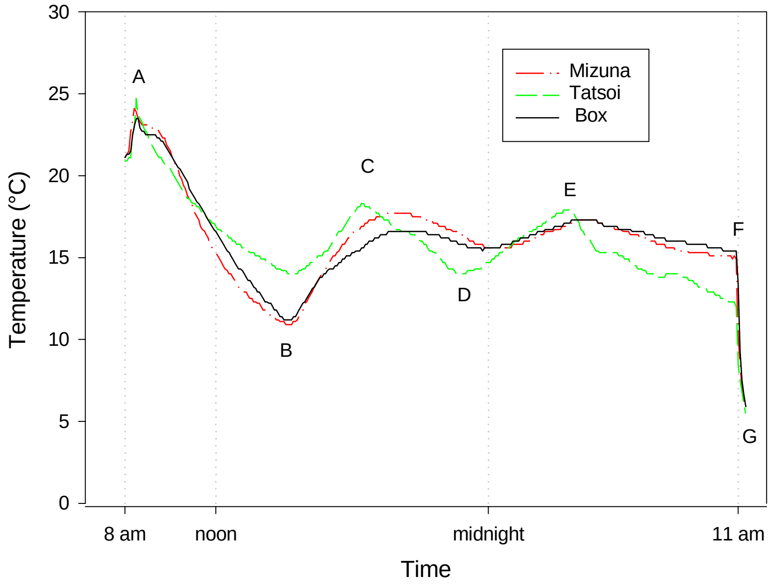

Figure 1. Cold-chain from farm to Brisbane markets. Harvest and cooling in farm coldroom (A to B); Transport from farm to local transport depot (B to C); Refrigerated transport from depot to market (C to D); Brisbane market floor (D to E); Collection and transport to secondary processor (E to F); Placement in secondary processor coldroom (F to G).

Farm to Sydney market (10/3/98 – 12/3/98)

The Sydney shipment showed a similar pattern to the Brisbane shipment, a key difference being the longer transport time to Sydney enabling the product to be cooled to 10°C during transit (Figure 2). Warming again occurred from the farm to the local depot and on the market floor, where the product remained non-refrigerated for almost 10 hours before being placed in the agent's cold-room.

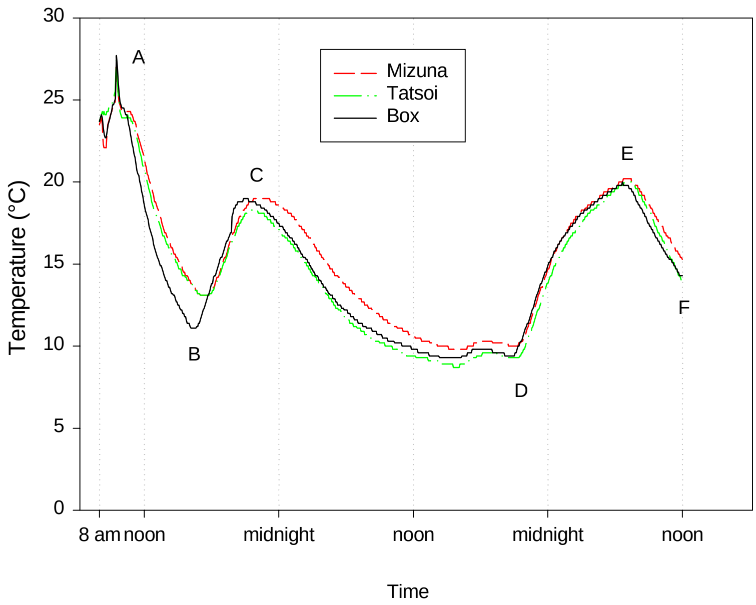

Figure 2. Cold-chain from farm to Sydney markets. Harvest and cooling in farm coldroom (A to B); Transport from farm to local transport depot (B to C); Refrigerated transport from depot to market (C to D); Sydney market floor (D to E); Sydney market agent coldroom (E to F).

Farm to Melbourne market (21/3/98 – 26/3/98)

The Melbourne shipment showed a similar pattern to the Sydney shipment, with the longer transport time enabling the product to be cooled to 5°C during transit (truck was operating at 5°C) (Figure 3). Warming again occurred from the farm to the local depot and on the market floor, where the product remained non-refrigerated for almost 8 hours before being placed in the agent's cold-room.

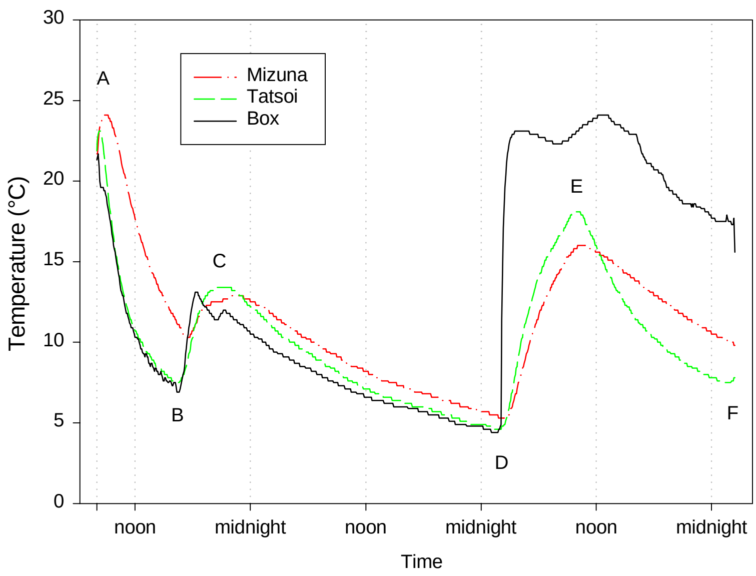

Figure 3. Cold-chain from farm to Melbourne markets. Harvest and cooling in farm coldroom (A to B); Transport from farm to local transport depot (B to C); Refrigerated transport from depot to market (C to D); Melbourne market floor (D to E); Melbourne market agent coldroom (E to F). Note that the box datalogger was removed at market arrival (D) by the agent.

Supermarket distribution centre (Brisbane) to Townsville store (29/4/98 – 30/4/98)

Transport of product from the central supermarket depot in Brisbane to a store in Townsville presented no fluctuations in temperature during transport. Product temperature however, did rise abruptly during offloading at the Townsville store (Figure 4).

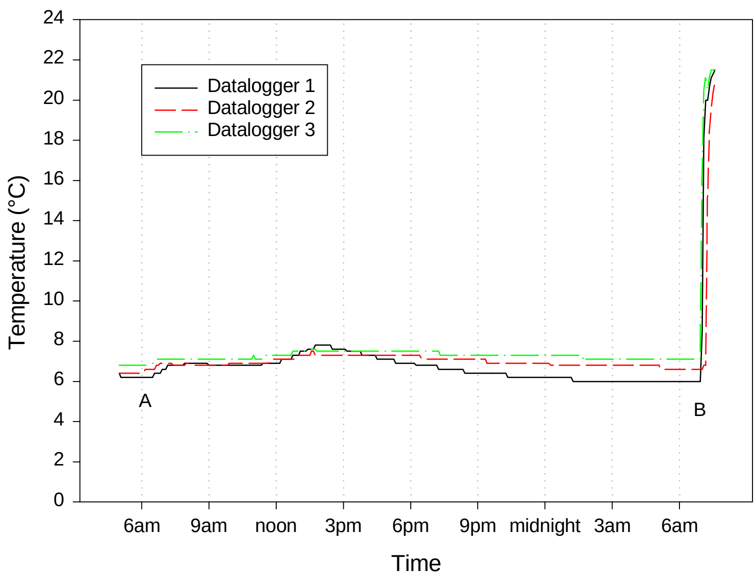

Figure 4. Transport from a Brisbane supermarket distribution centre to a supermarket in Townsville (A to B). Product was off-loaded at the store from B onwards to end of data.

Supermarket distribution centre (Brisbane) to Burpengary store (11/5/98 – 12/5/98)

Whole lettuce and fresh-cut leafy vegetables at two different initial temperatures were loaded onto a refrigerated truck (A) where both products reached an equal temperature (8°C) during transport. Temperature abruptly increased during unloading at the store and decreased again briefly within the store coldroom before rising again during handling (Figure 5).

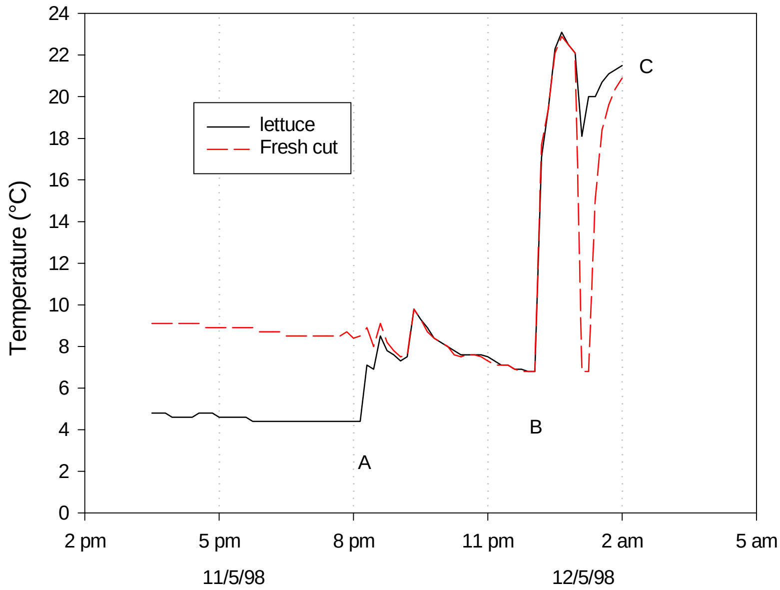

Figure 5. Transport from a Brisbane supermarket distribution centre to a supermarket in Burpengary (A to B). Product was off-loaded at the store (B to C).

Supermarket distribution centre (Brisbane) to Roma store (20/5/98 – 21/5/98)

Produce temperature rose slowly during shipment from the Brisbane distribution centre to the Roma Supermarket (Figure 6). The rise in temperature was minimal during transport, but rose again during unloading at the store.

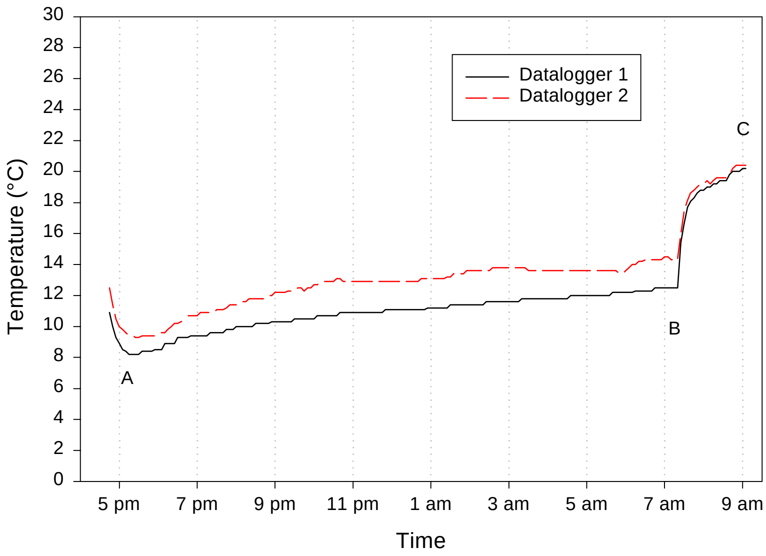

Figure 6. Transport from a Brisbane supermarket distribution centre to a supermarket in Roma (A to B). Product was off-loaded at the store (B to C).

Supermarket outlet (Brisbane) (25/6/98 – 29/6/98)

A temperature cabinet within a Brisbane supermarket which was monitored generally maintained low temperatures. Temperature spiking was due to the thermostat control system (Figure 7).

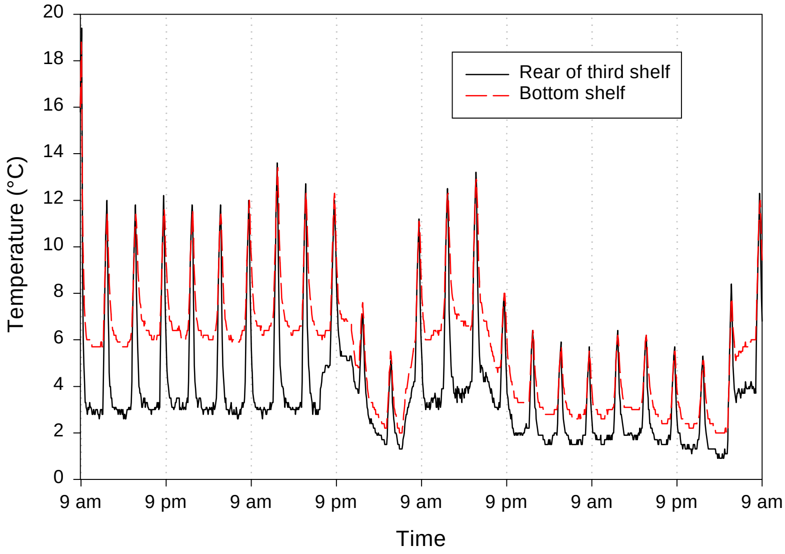

Figure 7. Temperature of a Brisbane supermarket salad cabinet over a four day period.

General conclusions

The present project highlights that the shelf life of fresh-processed leafy Asian vegetables is influenced by at least a number of factors. These include inherent factors such as initial physiological leaf age, as well as external conditions such as temperature and atmospheric composition.

In regard to leaf age, a number of leaf ages exist on any one plant at the time of harvest. In commercial practice, older leaves tend to get removed as they may already be starting to yellow, are being abscised naturally by the plant, or are of a juvenile appearance unsuitable for packaging. This procedure immediately improves product shelf life. Notwithstanding, the final package shelf life of a given vegetable will be limited by the leaf of oldest physiological age remaining.

Shelf life of all vegetables tended to be limited by leaf yellowing under normal conditions, with rots only occasionally limiting shelf life. The degree of yellowing tended to vary between vegetables, with pak choy and choy sum showing the most obvious signs, while changes in garland chrysanthemum and mizuna/mibuna tended to be more muted. Vegetables did however, tend to have similar shelflives under non-modified conditions, with mizuna and mibuna having a longer shelf life, perhaps due to less obvious signs of leaf yellowing.

Temperature influenced shelf life in a predictable way, in that shelf life decreased exponentially with an increase in temperature. All vegetables exhibited longest storage life under 1^oC (the lowest temperature under study), without any signs of chilling injury. Even without atmosphere modification, shelf life was almost doubled by decreasing storage temperature from 10^oC to 1^oC. This underlines the importance of the cold-chain, with temperatures close to zero providing the greatest benefit to extending shelf life.

Modified atmospheres had a significant impact on all vegetables, with both reduced oxygen and enhanced carbon dioxide generally improving shelf life. Increase in shelf life varied between vegetable, with 'safe' atmospheres (ie. $>0.5\%O_2$ and $<10\%CO_2$) providing an increase of between 50% and 190% at 10^oC. Taking into account that some vegetables had different shelflives to begin with, final shelflives achieved were between 19 and 27 days, with the exception of garland chrysanthemum which had the shortest shelf life of 12 days. These values were for the youngest fully-expanded leaf from each plant, so it should be noted that leaves of younger initial physiological age will last longer, and older leaves will expire in a shorter period. Similarly, other factors such as preharvest conditions may also decrease or increase potential shelf life, so the present project can only provide a guide to which atmospheres will give greatest shelf life extension.

Although a range of atmospheres were shown to significantly increase shelf life, some of these required extremely low oxygen concentrations or moderately high carbon dioxide concentrations that may present a risk under commercial conditions where strict temperature control may not always be present. Consequently, atmospheres of most 'safe' benefit to vegetables tended to be $1\text{-}2\%O_2$ in combination with $2\text{-}5\%CO_2$. Even these were not always safe to the plant, with mibuna preferring no greater than $2\%CO_2$.

A check of some commercial cold-chains showed that the potential for temperature abuse did exist, which could both directly influence the shelf life of the product, as well as the composition of the equilibrium atmosphere within an MA package. Packages that are designed for 10^{o}C will not fare well at 20^{o}C, with anaerobic or toxic conditions likely to develop if left for too long under these conditions. Such conditions could potentially occur under non-refrigerated transport or points in the cold-chain where no temperature control is being maintained. Obviously, temperature abuse will only be a problem if these conditions are maintained long enough to affect the product. The important point is to be aware of the need for cold-chain integrity, and to identify and overcome potential trouble points in the chain.

The present project has estimated the parameters of plastic films for the development of two different sized packages for each vegetable type. These are yet to be tested and constitute theoretical values only. Most of these plastics should be readily available, but 'inhouse' testing would be recommended before commercial usage is attempted. These films will be tested for efficacy in a new project (DAQ239A), with results to be publicly available.

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