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CONTRACT REPORT

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Factors Affecting Shelf-Life of a Range of Vegetable Crops

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Commercial in Confidence

ADAS

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

.... R C Balls, Contract Manager

.........10/3/93......................... Date

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ADAS

SUMMARY AND RECOMMENDATIONS

The literature review did not establish any published experimental work relating speed of heat removal to post-harvest life of vegetables. Current practice might have developed from a basis of unpublished research work or empirical observations. There was no evidence suggesting that vegetables could be damaged by rapid heat removal. Much of the published post-harvest research related to work carried out ten or more years ago. Whilst there are documented laboratory research results giving optimum post-harvest conditions for a large variety of produce, there appears little available information on how it can be interpreted practically under commercial conditions.

There was no effect on subsequent shelf-life of extending the delay between harvesting and cooling from two to six hours. The shelf-life of produce cooled and held at 10°C was similar to that cooled and held at 6°C. The method of harvesting affected the shelf-life of sprouts but showed little effect on cauliflower or calabrese.

The August/September 1992 harvest period tended to be cloudy and wet, so the trial crops were not subjected to high daytime temperatures at cutting and loading into the cooler. The shelf-life trials results should be verified by carrying out the same work on crops harvested during the hottest part of the day in a warm year.

There was no correlation between microbiological spoilage organism activity and the temperature regimes used in the trials.

OBJECTIVE

To determine by literature review and experimentation the optimum post-harvest cooling regimes for maintaining shelf-life of temperate leafy vegetables.

To identify documented work on the factors affecting shelf-life of temperate vegetables.

METHOD

Conducting a full-scale literature review, using worldwide data bases, to identify documented experimental or other published works relating to vegetable shelf-life. This work forms Section 1 of the combined report.

Using HRI shelf-life assay techniques to determine the quality of a range of vegetable crops subjected to different rates of cooling, target cooling temperature and delay to commencement of cooling. This work forms Section 2 of the combined report.

Using microbiologically assay techniques, to test for correlation between increase of spoilage organisms and loss of shelf-life quality. This work forms Section 3 of the combined report.

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East Midlands Electricity plc for provision of fans and controllers for the shelf-life rigs.

Ms Mandy Jones, ADAS Cambridge, and the Plant Diagnostics and Microbiology laboratory services, ADAS Cambridge, for the microbiological assays.

DATA STORAGE

The review abstracts and papers will be held by ADAS or Martin Browne for five years.

Raw experimental data will be held at HRI Kirton or ADAS Cambridge, as appropriate for ten years.

A REVIEW OF FACTORS AFFECTING SHELF-LIFE IN A RANGE OF VEGETABLE CROPS

SECTION 1, LITERATURE REVIEW

1 AIM

To review the effects of heat removal on the shelf-life of vegetables, in particular summer harvested crops such as cauliflower, calabrese, Brussels sprouts and leeks, **with special reference to the effects of RAPID FIELD HEAT REMOVAL ONCE COOLING HAS STARTED.**

To review the effects of the delay between harvest and the start of cooling.

To identify and review the currently accepted physiological and pathological factors, physical damage and chemical injury involved in deterioration during shelf-life and then to relate these to the cool chain and the effects of cooling on freshly harvested summer crops.

2 INTRODUCTION

Plant tissue continues to age after harvest and the rate of this ageing process is directly related to respiration (21). It therefore follows that by reducing temperature and therefore reducing respiration, ageing (deterioration, maturation, senescence, ripening) are all slowed and in theory at least, and often in practice, fresh produce shelf-life can be extended. There is plenty of evidence to support this overall view that the the shelf-life of many plant products can be extended by judicious use of temperature control. It is the fundamental principle of the cool-chain, relying on the commencement of heat removal from product as soon as possible after harvest and then, once cooling has started, removing the heat as rapidly as possible. Thereafter, the optimum temperature and rh should be maintained throughout the marketing chain right up to the time of consumer purchase. That is the theory, but in practice there is always a "cut-off" point where it is no longer to enhance cooling further, because the value of any results do not match the cost of the input. It is within everyone's interest to be aware of the point where the rate of heat removal becomes uneconomic and either ceases to increase shelf-life or only increases shelf-life beyond what is required by good commercial practice.

3 PHYSIOLOGY

Summer crops such as those listed in appendix 2, can be especially susceptible to the effects of field heat, but it is likely that any effects of field heat will be tempered by a multitude of other factors. While much of the information given in this report will apply to year round production, this project is specifically targeted at summer crops harvested between early June and early October - the time of year when field heat is most likely to be a major contributing factor to deterioration of product quality during marketing.

Plants are essentially a very complicated series of biochemical reactions, most of which increase as the temperature rises and slow down as temperature falls. Plant tissue temperature follows very closely (43) that of the surrounding ambient air and therefore rises and falls with the time of day, and year. The speed of the reaction of plant metabolism, therefore, is closely linked to the air temperature.

3.1 Respiration

It has long been accepted that temperature and respiration are closely associated in quality deterioration and many workers have produced information for a wide range of crops. Robinson, Browne and Burton (43) supply ample evidence that respiration and as a consequence, deterioration slow down as temperature is reduced, thus extending shelf-life. There are very few exceptions to this rule and they do not apply to the crops considered in this review.

Respiration rate also depends on the organ involved, eg young leaves and inflorescences have a very high respiration rate whilst mature leaves have a lower rate. Respiration determines the perishability of the produce (21), ie the higher the respiration rate the shorter the shelf-life.

Respiration supplies the tissues with the necessary energy to sustain all life processes. Carbon dioxide (CO_2) is a by-product of rate which is extremely closely linked to the speed of respiration. This is already used in the refrigeration industry where CO_2 output is used to calculate the heat of respiration to be removed from store (43).

3.2 Transpiration

Weight loss is a very important aspect of post-harvest handling. While small amounts of weight loss may be due to carbon and oxygen loss as CO_2, this can be overlooked during the relatively short time span of the cool chain when no long-term storage is carried out. Under these circumstances all practical weight loss is due to escape of water as evaporation or transpiration, and sometimes as liquid drip from damaged tissue. The amount of water that is lost during transpiration is related to the resistance of the product to water loss, the humidity of the surrounding atmosphere, the air flow rate, and the time over which the crop is subjected to that atmosphere.

3.2.1 Product Resistance

Product resistance to water loss is primarily related to species and variety. Products with a large surface area/weight ratio, eg lettuce, will lose water faster than products like apple or courgette. In addition, apples for example have a waxy coating which reduces water loss in comparison to courgettes. Type, variety, age and many other factors all contribute to the rate at which a crop is liable to lose water (weight), and it is unlikely that even two varieties of the same species will have exactly the same ability to resist water loss.

3.2.2 Humidity

The humidity of the surrounding atmosphere has a direct effect on water loss and generally needs to be maintained at a maximum optimum level for any given product. The higher the humidity, the slower a product will lose water, assuming other factors such as temperature and atmosphere movement remain unchanged. At 100% rh, there should be no transpiration loss from any product. This, however, may not be ideal for most produce, as any improvement in crop quality due to elimination of water loss will be outweighed by deterioration due to other factors. Excess condensation and wet produce whilst in themselves undesirable, can also lead to attack from micro-organisms. It has been shown, however, that under certain circumstances crops such as carrots and some leafy salads are best stored at 100% rh but only if maintained at 0°C. In practice, by operating the cool chain at required humidities of between 90 and 97% will be more satisfactory, leading to less condensation and micro-organism activity at the expense of slightly increased weight loss.

Relative humidity is closely related to the temperature of the atmosphere and rh will generally rise as temperature falls, or vice versa, thus it can be misleading to try to relate weight loss to rh if no account of temperature is incorporated in the calculations.

3.2.3 Airflow Rate and Time

For normal ventilation rates used for crop cooling, provided the atmosphere is not saturated, water is removed from produce at a rate that is associated with the speed of that atmosphere movement. Thus a rapidly circulating store atmosphere will remove moisture faster than a reduced rate.

3.3 The Effects of Ethylene and Similar Gases

Ethylene is a naturally produced hydrocarbon which is associated with ripening and maturation of plant tissue. In vegetable crops, it is generally harmful to quality and steps should be taken to keep its concentration in store to a minimum, ideally below a half a part per million. Damage caused by ethylene is usually seen as chlorophyll and leaf abscission. By operating a minimum temperature regime, ethylene production, whether originating from fungal diseases or the plant tissue itself will be reduced to a minimum.

At the same time, the response of plant tissue to its presence will also be suppressed.

Gases similar to ethylene such as acetylene and products of combustion can also result in harmful effects. Again, the lower the temperature the slower will be the response to these products.

4 PRODUCT QUALITY AND SHELF-LIFE TERMINATION

Fresh vegetable produce becomes unsaleable for one or more of a number of reasons. These include:

Weight loss and/or wilting (5, 23, 43, 54);

Physical damage (16, 48, 54);

Appearance and/or colour change, for example looking "tired" and "old", and loss of colour (43, 54);

Attack by fungal or bacterial pathogen causing rotting (8, 10, 15, 48, 53);

Over-maturity, ie the product becomes too soft and over-ripe, eg apples and tomatoes (11);

Change of flavour, eg loss of, and/or the addition of a stale, old or stored flavour (1, 54);

Change in texture - usually toughening (43);

Low temperature injury (24, 54);

Chemical injury (54).

These factors are further complicated because retailers vary in their concept of quality, as does their decision by which produce is removed from the shelf because it is no longer considered saleable.

At the minimum level of quality control, only appearance will be considered in shelf-life termination decisions. The better retailers, however, will also take into account flavour and texture.

4.1 Weight Loss

Weight loss is largely related to the air relative humidity (rh), the speed at which that air is moving around the product and the nature of the crop. In direct expansion (DX) cooling systems temperature differential between the evaporator plates and the store air will reduce rh, and this reduction becomes greater as the temperature differential widens. In practical terms, the evaporator plates operate at several degrees below the air temperature, resulting in a low rh and significant weight loss. Wet air cooling systems are less likely to cause this problem because of the higher inherent air humidity. However, in a wet air store with inadequate refrigeration capacity, fast heat removal from the produce will raise the store temperature which in turn results in a fall in rh and an increase in product weight loss. This can be over 5% for the first 48 hours after harvest, depending on product type and store conditions (unpublished work, Browne K M).

Transpiration is the loss of water by evaporation, a major problem in immature crops and loose structured crops, eg cabbage.

If the product is physically damaged or becomes subsequently damaged by eg *Botrytis, Sclerotinia,* it will experience increased weight loss through a greater moisture loss from damaged areas or drip from rotted areas.

Tissue shrinkage and wilting is the visible sign of weight (water) loss and is the single most common cause of shelf-life termination, especially if the commodity is leafy or has high surface area to weight ratio, eg cauliflower.

4.2 Physical Damage

This is often the primary cause of many losses (Coursey and Booth, 1972 (50)). Damage increases respiration rate and therefore heat output, and causes increased moisture loss and ethylene production.

4.3 Colour

Colour change in leafy crops such as those being studied in this review is usually related to tissue activity and respiration. A well operated cool chain should minimise this occurrence, especially chlorophyll loss, associated with leaf yellowing.

4.4 Pathological Decay

Post-harvest diseases are one of the most severe sources of production loss. The economic cost is proportionally greater than for field losses because of the additional costs of harvesting, transport and storage.

Disease development is divided into two stages; infection followed by symptoms expression. It is a battle between host and pathogen (physiological conditions in host, eg maturity or preformed inhibitors) with environmental factors notably temperature, humidity and atmosphere interacting to determine the extent of the damage.

Although there is information available on the temperature limits for the growth of spoilage bacteria, there is little information on the effect of temperature on growth rates. The recommended storage temperatures of 0-1°C for many vegetables should retard senescence and spoilage as this is below the minimum temperature for many bacteria. *Pseudomonas marginalis*, a major spoilage organism of a wide range of crops, however, can multiply at 0.2°C (15-20 hour doubling time) (27).

An rh of at least 95% is recommended for most vegetables. Storage at rh 98-100% results in reduction in water loss and wilting and may not incur an increase in microbial decay if the temperature is below 4°C (34, 36).

At high rh values, small temperature fluctuations, <1°C, can result in condensation and water film formation on crop surfaces leading to a heightened risk of soft root.

An rh 94-95% probably prevents most bacterial spoilage provided there is no local high humidity due to poor ventilation, overloading, wrong packaging and sap due to damaged tissue.

In storage, leafy vegetables and certain root crops benefit from humidity close to saturation if the temperature is near 0°C (at higher temperatures there is risk of mould growth).

In general, the lower the temperature and humidity the slower the growth of micro-organisms and the smaller the likelihood of new infections.

4.5 Ripening and Over-maturity

Ripening is not such a problem for most vegetable crops as over-maturity. The manifestation of over-maturity is likely to be chlorophyll loss, growing, opening, bending, changes in flavour and toughening. Fungal pathogens are most likely to attack over-mature tissue and this likelihood increases as produce tissue ages. Green vegetables which are becoming over-mature exhibit characteristic yellowing due to chlorophyll loss or abscission, of outer leaves. Internally toughening of tissues, deterioration in flavour and aroma may occur (11). All the factors can be hastened by the presence of ethylene.

4.6 Flavour

Flavour changes within produce are more subtle and far less obvious than the external visual ones. Normally, sugars and other flavours essential to a specific produce, are continuously lost during the post-harvest period.

Sugars are depleted as part of the biochemical activity and the loss of these can be slowed by removing field heat and maintaining a minimum temperature. Sweetcorn provides an excellent example of this fact. Before the appearance of sugar enhanced and extra sweet varieties of sweetcorn, older varieties, eg Jubilee (1), suffered badly from sugar loss during a four to five day post-harvest period. Because there was often no cool chain in operation, most of the sugar present at harvest was lost within two days, and by day five the corn was virtually inedible. However, prompt removal of field heat and a cool chain at 2°C meant that the eating quality of Jubilee and other standard varieties could be maintained well past the five day period. In general, this applies to nearly all crops where a sweetness is an essential part of the overall flavour.

Flavours other than sugars in food crops are also affected by temperature and tend to disappear more slowly when a minimum temperature regime is operated. Volatile flavour components are less volatile at lower temperatures and therefore remain in the plant tissue longer. On the other hand, acids can increase as the product becomes older or at least may not change much, thus allowing an impression of sourness or bitterness to become present as some products age, eg lettuce.

Sometimes, unwanted flavours can taint produce and these can arrive from a number of sources. First, musty flavours can be produced by fungal rots in store, for example *Botrytis, Penicillium.* Flavour can be transferred direct from a rot on the same tissue or as volatile compounds from nearby rotted tissue. Foreign flavour can also be transferred from damp wood and store fabric. Reduced temperature slows fungal activity and also reduces volatility and therefore decreases the likelihood of post-harvest contamination.

4.7 Texture Changes

Many commodities, and asparagus is one of the best examples (43), toughen with age: as this is usually irreversible, and is unlikely to be improved by cooking. Lignification is perhaps the most common form of tissue toughening and once again is temperature related to some extent. A correct temperature regime after harvest undoubtedly slows toughening and therefore helps to maintain post-harvest texture quality for longer.

4.8 Low Temperature Injury

Notwithstanding all that has been said above, and disregarding economic considerations of refrigeration costs, there are some instances where low temperature (not freezing) can be physically damaging to crops. It is an accepted fact (although perhaps not completely understood by biochemists) that some crop species can be irreversibly damaged by temperatures that are too low for too long. Tissue becomes damaged and eventually breaks down. This particularly applies to crops of subtropical or tropical origin, eg tomato, cucumber, banana, sweetcorn. For most crops of temperate origin, eg the main four being considered in this project, there is little likelihood of obvious low temperature damage but this does not mean that it cannot occur and possibly does, without sufficient effect to be noticeable.

One of the manifestations of low temperature injury to plant tissue is an increased susceptibility to attack by pathogens. Another is the likelihood of increased weight loss through the inability of tissue to operate the normal barriers to water loss, eg the stomata remain open when they should be shut. "Shock" may be caused by very rapid heat removal (especially where produce is harvested in hot weather when the eventual temperature drop can be over 20°C) and is thought to be possible for temperate crops. However, Lutz and Hardenbury (54) found no evidence of this.

4.9 Chemical Injury

Both field application or post-harvest treatments may induce injury (54). Browne (unpublished) has found examples of the incorrect dosage of post-harvest fungicides to storage cabbage causing phytotoxicity problems to the outer leaves, which encouraged attack by microbial organisms.

5 COOLING METHODS CURRENTLY USED IN THE UK

Cooling processes currently in use are summarised below, together with their advantages and disadvantages for the different crop types (19).

5.1 Air Cooling by Conventional (DX) Store (With or Without Forced Air Ventilation)

This method is not so suitable for leafy crops because of potential moisture loss through inherently low rh.

5.2 Wet Air Cooling Using Forced Air Ventilation

This system can provide an almost ideal environment for heat removal and storage without moisture loss. If the system is suitably modified, it can safely be used for crops which suffer chill injury at 1°-2°C such as courgettes.

5.3 Hydrocooling

This can be used where crops are to be washed and can be successfully drained of water prior to marketing.

5.4 Vacuum Cooling

A very fast and efficient way of removing heat from crops that have large surface area, it can be used post-packaging. Some moisture loss will be experienced, although this can be minimised by initially wetting the crops.

5.5 Crushed Ice

This can offer extremely rapid cooling for produce in boxes, such as calabrese, where the retailer will accept a meltwater residue. Chill injury is possible if the ice is too cold and is inevitable for products which cannot tolerate 0°C such as courgettes.

6 OTHER POST-HARVEST TECHNIQUES

As an addition to careful handling and correct cool chain operation, there are techniques that may be used to improve further quality maintenance and allow more flexibility for the grower, packer and retailer. These include:

6.1 Packaging Protection

Packaging, apart from being attractive to the consumer and protecting the produce from undesirable external influences such as damage and contamination with dust, should also always be aimed at maintaining the optimum environmental conditions within. As well as being at the correct temperature, the pack should generate the correct rh and gaseous atmosphere. Where the gaseous atmosphere within a pack is different from air it is termed MODIFIED and this may be done intentionally or otherwise. (See below).

6.2 Modified Atmosphere Packaging

Packaging films can create modification to the ratios of oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2) gases present within, as well as to rh. N_2 is essentially inert but its concentration can be used to control the amounts of O_2 and CO_2. Any decrease in O_2 and/or increase in CO_2 concentration compared to air, will be likely to slow respiration and therefore should prolong shelf-life. For some crops this is now a commercially accepted practice and a range of commercially available films is now being used to package a number of vegetable commodities to some considerable advantage (see crops listed under REVIEW) below. Sometimes, if atmospheric modification is overdone, physical damage to the product can occur. For example, if CO_2 levels are too high, fermentation may take place leading to alcoholic off flavours or undesirable anaerobic bacteria may multiply to significant levels. This can be a significant problem in well sealed packages in which the modified atmosphere has not been intentionally created.

7 REVIEW RESULTS

The specific review results for eight vegetable crops grown and marketed in the UK between June and October are shown in appendix 2.

8 DISCUSSION

Much of the information on optimum conditions cannot be traced back to documented research despite its forming the basis for current practice. The information supplied by the publications mostly originates from research that is not recent and for the most part was based on small scale experimental treatments. However, for most crops the optimum humidity and temperature have been well established. The apparent inability of the retail industry to maintain these optimum conditions is an obvious complication and detracts from the maximum benefits that could be had if supermarkets operated better transport and shop conditions.

As soon as it becomes impossible to operate the minimum temperatures then factors pertaining to optimum humidity levels are thrown into question, the two being very closely linked. For many temperate crops, eg cabbage, lettuce, leeks, cauliflower etc, there is no evidence to suggest that 0°C or just below (provided freezing does not take place) is NOT the optimum temperature for maximum shelf-life. Van den Berg and Lentz (46) established that at this temperature, 100% humidity did not increase pathogen activity on certain crops and that, after a given period, the quality of these crops was better than where the temperature had been allowed to remain at about 2°C. For example, carrots stored at 0-1°C and 100 rh were found to be less likely to be affected by fungal pathogens than those stored at the same temperature but with an rh of 95%.

For a variety of reasons, the industry does not always maintain crops at the perceived optimum temperature; where there are temperature variations during the cool chain, the product and its package can become wet with condensation and this is undesirable. Retailers and consumers alike do not look favourably on wet packages and this can also increase the amount of pathogen activity, especially if the temperature is not kept near 0°C. Because the cool chain is so often broken due to the involvement of several operators, the theoretical maximum shelf-life is rarely obtained.

A few open ground crops originate from climates warmer than the UK and it is these that are usually most susceptible to low temperature injury. Courgettes are subject to low temperature injury at temperatures below 7°C, so should not be marketed at temperatures lower than this if injury is to be avoided. In practice this sometimes occurs if they are mixed with more temperate crops in the cold chain. Because fungal and bacterial rots are more active at these temperatures than at 0°C, this kind of produce should be handled at humidities between 90 and 95% rh. This drier atmosphere and lead to more rapid weight loss which will in turn reduce further the post-harvest shelf-life.

There are continuing pressures within the industry to "improve" on the cool chain. It is widely believed that one way is to reduce the time between harvest and cooling start, and another is to increase the speed at which heat is removed once cooling has started. There is no hard evidence to indicate when the point is reached at which there are no longer benefits to be gained. This is further underlined when ideal conditions in the cool chain are not maintained by supermarkets and retailers. To subject produce to violent changes in temperature during field heat removal could promote initial damage which, if followed by handling at higher than optimum temperatures for some days before consumption, will considerably undermine its eventual quality and shorten its shelf-life (47).

Every crop species, and often every variety, has its own post-harvest handling requirements, and optimum post-harvest handling conditions for one crop may not necessarily be those best suited to another. This must be borne in mind when attempting to model empirically the optimum for one crop using the data for another.

9 CONCLUSIONS

9.1 No published work RELATING the speed of heat removal TO POST-HARVEST LIFE was found. *(Note, the 1991 HDC Project on Rapid Cooling (FV 108) was not cited as a publication at the time of this review).*

9.2 Current practice might well be based on unpublished R & D work.

9.3 No evidence suggesting that damage can be caused by rapid heat removal was seen although Longmore (47) does mention such damage or its possibilities.

9.4 Most of the literature available originated from research older than ten years.

9.5 Only one paper, that of Brennan and Shewfelt (5), published in 1988, reports that broccoli benefited from commencement of cooling less than three hours after harvest.

9.6 Whilst there is plenty of laboratory research evidence of optimum post-harvest conditions for a large variety of produce, there appears to be little available information on how that should be interpreted under commercial conditions.

PUBLICATIONS LIST

In chronological order starting with the most recent:
FP = seen as full paper;
AB = seen as abstract.

1 Geeson, J D; Browne, K M; Griffiths, N M. 1991
FP Quality Changes in Sweetcorn Cobs of Several Cultivars During Short-Term Ice-Bank Storage.
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SHELF-LIFE CONDITIONS FOR CROPS UNDER REVIEW

APPENDIX II

Crops covered

1	2
Brussels sprouts	Courgettes
Leeks	Summer cabbage
Cauliflowers	Sweetcorn
Calabrese (broccoli spears)	Lettuce

For the crops in list 1, the published and other data have been reviewed for:

Nominal shelf-life expectancy;
Holding temperature (once cooled);
Cooling system normally used;
Time to cooling start;
Cooling rate;
Optimum humidity;
Most common causes of shelf-life termination.

The information is classified for scientific authenticity as follows:

- ** Fully documented experimental results
- * Some documentary evidence (review)
- P Common practice - no documentary evidence
- C Private correspondence with packers to gauge opinion.
- X Not known

Crops in list 2 were not specifically reviewed, but useful information found during the reviews for the main crops is shown on page 29.

BRUSSELS SPROUTS

Shelf-Life Expectancy (in days)	Holding Temperature (°C)	Reference
21-35	0	16*
4	1-2	24*
3-5	20	43**
7-10	0-1	46**

There are very large differences in the documentation for post-harvest life and this is certainly closely associated with the temperature used. There is no known evidence that 0°C is damaging to Brussels sprouts and it is likely to be very close to the optimum for maximum shelf-life. High quality sprouts will be consumable for a least 14 days at this temperature, but as commercial practice operates the cool chain at up to 10°C, life after packing could then be reduced to three days.

Cooling System Normally Used

Forced moist air - MAFF leaflet 860 (19*).

Time to Cooling Start

Little documented evidence is available. Commercial practice in the UK at present appears to operate delays of between one and six hours (C).

Cooling Rate

Bulk bins of Brussels sprouts are difficult to force air through and Bartlett (31**) suggests a time of 12-18 hours using forced air cooling to a temperature of about 2°C. Gibbon (ref 43-B) found that farms varied between 11 and 57 hours for bulk bin pulldown to a minimum of 3°C, but these figures are unlikely to relate to forced air ventilation.

Optimum Humidity

Robinson et al (43**) suggests 100% at 1 to 2°C.

Van den Berg and Lentz (39**) suggests 98 to to 100% at 0 to 1°C.

Most Common Causes of Shelf-life Termination

(in perceived order of importance, from a trade survey) (C)

- Wilting
- Butt darkening
- Mould growth
- Yellowing

LEEKS

Shelf-Life Expectancy (in days)	Holding Temperature (°C)	Reference
7	1-2	24*
30-90	0	16*
28-42	0	43**

Documented leek post-harvest life is extremely variable but is likely to be very closely linked to temperature and be less than five days at 20°C, but over four weeks in a well run store at minus 0.5°C.

Cooling System Normally Used

Forced moist air or hydrocooling - MAFF leaflet 860 (19*)

Time to Cooling Start

0.5 to six hours - (C)

Cooling Rate

12 to 18 hours - Bartlett (31*)

Optimum Humidity

90 to 100% - Ledger (16*)
95 to 100% - Robinson (43**)

Most Common Causes of Shelf-life Termination

Growth
Bacterial rots - (C)

CAULIFLOWER

Shelf-Life Expectancy (in days)	Holding Temperature (°C)	Reference
14-28	0	16*
4	1-2	24*
3-4	0	43**

The same comments apply as those made about calabrese, papers being mostly aimed at cooling rates rather than establishing optimum post-harvest temperatures. There is no established evidence that 0°C is damaging and probably should be the aimed at cool chain temperature.

Cooling System Normally Used

Forced moist air - MAFF leaflet 860 (19*).

Time to Cooling Start

Current commercial practice indicates 0.5 to six hours, but the minimum should be operated if at all possible.

Cooling Rate

Bartlett (31**) suggests eight to 12 hours as the practical time required for cauliflower to be cooled in bulk.

Optimum Humidity

100% - Robinson et al (43**)
95-100% - Ledger (16*).

Most Common Causes of Shelf-life Termination

Discoloration caused by bruising (in perceived order of importance) - (C)

Opening
Softening due to weight loss
Leaf yellowing

Cauliflowers are very susceptible to physical damage during harvesting and this often manifests itself in curd discoloration some days after harvest. The discoloration is partly due to enzymic oxidative browning of wounded tissue coming in contact with air and also due to bacterial activity (see ref 53). Both of these causes of discoloration are likely to be temperature sensitive and reduced in speed if rapid cooling after harvest is operated and the temperature then maintained at the optimum minimum.

CALABRESE OR GREEN BROCCOLI

Shelf-Life Expectancy (days)	Holding Temperature (°C)	Reference
10-14	0	16*
4	1-2	24*

Most documentation relating to broccoli post-harvest temperature is related to methods of cooling rather than optimum temperature. However, there is again no evidence to suggest that 0°C is in anyway harmful to broccoli and is probably the optimum.

Brennan and Shewfelt (5**) noted that in 1972 and 1983, broccoli had been successfully stored for two to four weeks at 0°C, and 95% rh.

Cooling System Normally Used

Forced moist air
Hydrocooling (P)

Both often followed by crushed ice being mixed with the florets in the boxes for transportation from the producer - (P).

Time to Cooling Start

Brennan and Shewfelt (5**) did a series of experiments with broccoli and looked at cooling delay for between 0.5 and three hours. There was every indication that the shortest cooling delay was the best treatment. The authors also said that the three hour delay time resulted in the greatest significant post-harvest losses.

Cooling Rate

Bartlett (ref 31**) groups broccoli and sprouts and suggests the same conditions. Ledger (16*) suggests a maximum of six hours to the optimum temperature.

Optimum Humidity

95-100% - Ledger (16*).

Most Common Causes of Shelf-life Termination
(in perceived order of importance) - (C)

Yellowing of floret buds
Wilting
Wet rot

OTHER CROPS

The crops listed below were not subjected to a literature search, but all respond favourably to the correct cool chain operation. Where information is known it is provided.

	Sweetcorn	Courgette	Lettuce	Summer cabbage
Post-harvest life (days)	2-3	7	7	4
Temperature (0°C)	1-2	7-10	0	0
Cooling system*	NA	DX or FDX	V	WA or V
Cooling rate (hours)	-	-	8-12	8-12
Optimum humidity (% rh)	95-100	96	95-100	95-100

Key to cooling system types:

WA = Wet air
DX = Conventional direct expansion
FDX = Direct expansion with air forced through crop
V = Vacuum cooling

CONTRACT REPORT 30496 FV 137
FACTORS AFFECTING SHELF-LIFE OF A RANGE OF VEGETABLE CROPS.
SHELF-LIFE STUDIES

UNDERTAKEN FOR THE HDC.

CONTENTS

Report to:	The Horticultural Development Council 18 Lavant Street Petersfield Hants GU32 3EW
HRI-Kirton Contract Manager	Mr M B Wood Kirton EHS Government Buildings Willington Road Kirton Boston Lincs PE20 1EJ
Period of investigation:	June 1992-January 1993
Date of report issue:	January 1993
Principal workers:	R W P Hiron, PhD Horticulturist (author of the report)

Authentication:

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

....
Signature

R W P Hiron

Date 3-2-93.........................

Report authorised by

....
Signature

M B WOOD
(Contract Manager on behalf of Dr M R Shipway, Head of Horticultural Development Division, Horticulture Research International)

.........3/2/93.........
Date

COMMERCIAL IN CONFIDENCE

FACTORS AFFECTING SHELF-LIFE OF A RANGE OF VEGETABLE CROPS. SHELF-LIFE STUDIES.

SUMMARY

The test crops were: cauliflowers, calabrese and Brussels sprouts. Produce was either carefully harvested by technicians or harvested by growers staff on a commercial rig, and transported to the packhouse. The produce was weighed and then left at ambient for two, four or six hours after harvesting before rapidly cooling to, and holding at, either 6 or 10°C, until the following morning when the produce was weighed inspected and put into simulated supermarket shelf-life conditions at HRI-Kirton. The produce was weighed and inspected daily for up to one week. When produce was downgraded from Class 1 to Class 2 it was discarded.

Hand picked sprouts were cleaner of debris and had better shelf-life characteristics than machine stripped sprouts but carefully harvested cauliflower were no better than those done commercially probably because a lot of the problems were due to overpacking the plastic crates. Carefully harvested calabrese had little advantage over commercially harvested.

The shelf-life of produce cooled and kept at a holding and dispatch temperature of 10°C was very similar to that at 6°C the temperature currently used commercially. Varying the length of time between harvest to the start of cooling from two to six hours had no effect upon subsequent shelf-life.

The implications of these findings are discussed.

OBJECT

To compare the shelf-life of commercially harvested cauliflower, calabrese and Brussels sprout crops with carefully harvested, and to investigate the effects of, different times to commencement of cooling, and, final cooled temperature, for holding and distribution of produce, on subsequent shelf-life.

INTRODUCTION

In 1991 a joint ADAS/HRI project, HDC ref FV108, looked at the rapid cooling of vegetable produce initially using the 'Hydrair' method, this was in response to a suggestion that rapid removal of field heat dramatically enhanced the shelf-life of vegetables. The outcome of that project was that using rapid air flows of cool humid air, cauliflowers could be cooled from 21°C to 6°C in 90 minutes. However, subsequent shelf-life studies on rapid or conventionally cooled cauliflowers showed that the rapid cooling of cauliflower using the Hydrair method had no effect on cauliflower shelf-life. This was because any potentially beneficial effect resulting from rapid cooling was in all probability masked by the expression, during the early stages of shelf-life, of damage caused during harvesting, trimming and especially packing. The report also recommended that some time in the future carefully harvested produce should be compared with commercially harvested batches.

In the early summer of 1992 a meeting of HDC, HRI, ADAS staff and local growers met to hear the initial findings of a literature survey of all published data on shelf-life of vegetables and, in the light of this plus the findings of FV108, plan the work to be done in 1992.

MATERIALS AND METHODS

i. Site

HRI Kirton is located in the village of Kirton situated five miles south of the town of Boston in Lincolnshire. The facilities used included the packing shed with grading line, the ice bank, cool store, direct expansion and small temperature controlled stores, the shelf-life room and purpose built on-site, cooling units.

ii. Initial cooling unit construction

The cooling units were designed and calibrated by ADAS Engineering Development Centre, and built on site by the HRI workshops, with components supplied by a project co-sponsor, East Midlands Electricity plc.

The cooling unit consisted of a plywood lid which would fit directly over the top of a standard pallet stack of 35 supermarket trays, placed five to a layer, seven layers high. The lid contained a 350 mm propeller fan to draw cold store air up through the trays from the pallet base. To ensure that the air travelled vertically, and that the outer edges of the stack did not cool by local conduction, the pallet load was wrapped with bubble plastic (Pillasol) which was stapled tightly to the edges of the lid.

To ensure that the crop in each treatment was fully ventilated with cold air, it was decided to run the fans at full capacity but to vary their run times, by switching the fans on and off at regular intervals. A variable rate pulse timer was therefore fitted to each fan, enabling both the on and off periods to be selected to suit the theoretical gross air-flow needed to achieve the differences in cooling sites. Termination of cooling, at the desired temperature, was effected by a simple probe thermostat with its sensor in the crop.

iii. Final cooling unit construction

Due to problems of fan resistance and the logistics of cutting 35 trays of crop per treatment, the cooling unit was reduced in quantity to two layers of trays. As it was found impossible to prevent natural convection continuing cooling when the fans were switched off by the limit thermostat, termination of cooling was effected by removing the unit from the icebank once it had reach temperature.

iv Initial trial treatment

1. Treatments

a) Produce
   (i) Commercially cut and packed
   (ii) Carefully cut packed

b) Time delays between harvest and start of cooling:-
   (i) 2 hours
   (ii) 4 hours
   (iii) 6 hours

c) Cooling rate - time to target temperature
   (i) 12 - 18 hours

d) Target temperatures (in ice bank store)
   (i) 6°C
   (ii) 10°C

e) Holding stage (direct expansion store)
   (i) 24 hours at 6°C
   (ii) 24 hours at 10°C

f) Shelf-life assessments
   Representative trays of produce to be removed from each cooling/holding treatment, batch recorded and arranged in replicated 'plots' in the shelf-life room, and recorded daily for up to one week.

2. Initial trial procedure

On the day of the commencement of each experiment at 7.00 am a cutting gang would be sent to a local field where a commercial rig would be in operation. The HRI cutting gang would carefully harvest 20 plastic supermarket crates of produce and then collect 190 further crates from the rig. Cauliflowers were probed and attached to a squirrel data logger for temperature records during the pre-cooling phase. Time nought to calculate the time into cooling was taken as the time the tenth carefully cut crate was harvested.

The crates were returned to the packhouse where the cooling units were assembled each containing three labelled and weighed trays of each of the harvest procedures plus 29 unmarked crates for packing. After two hours two of the units were put in the ice bank and activated to blow cold air 5 minutes in every 30 until one had a stack temperature of 6°C and the other 10°C when the units were automatically switched off. This procedure was repeated after 4 and 6 hours from harvest.

The following morning those three units cooled to 6°C were moved to a holding store at 6°C and those three cooled to 10°C to a holding store at 10°C and held for 24 hours.

The following morning the units were unloaded the labelled crates reweighed and the produce inspected to see if any was downgraded to Class II. If it was, it was removed from the crate the reason noted and the crate reweighed, the produce (36 crates in total) were then randomly placed in a shelf-life room at a constant 21°C, 50% RH and high light intensity. On each subsequent morning for the next three days the crates were weighed, inspected and reweighed if produce had been removed.

v. Final treatments and trial design

1. Treatments

a) Produce
as above

b) Time delays between harvest and start of cooling:-
as above

c) Cooling rate - time to target temperature
As quickly as possible 2-3 hours

d) Target temperatures (in ice bank store)
as above

e) Holding stage (DX store)
(i) Overnight at 6°C
(ii) Overnight at 10°C

f) Shelf-life assessments
Three representative trays of produce to be removed from each cooling/holding treatment, batch recorded and arranged in replicated 'plots' in the shelf-life room. Produce inspected daily until all produce was downgraded and removed.

2. Final trial procedure

The field cutting procedure, and transport to the packhouse, was as before except only 40 crates were collected from the commercial rig. The cooling units were assembled as before but only using four crates for packing. At the designated time the units were put into the ice bank where cold air was pulsed through the stack one minute in every two to cool the units rapidly to designated temperature when they were immediately moved into the relevant holding store, the following morning they were recorded into the shelf-life room.

The above procedures were developed for the cauliflower trials which are field packed and were also followed for calabrese, however the procedure had to be modified for Brussels sprout crops which are graded and packed in the packhouse. The Brussels sprouts trials were further complicated by the fact that in commerce they can either be cooled before or after grading. With the sprout trials the HRI harvest gang was dispatched to the field to hand pick 20 plastic supermarket crates of sprouts and then pick up a bulk bin of machine stripped sprouts from the commercial rig, which was sufficient for a further 40 crates, they returned to the packhouse and either

i Graded, recorded, cooled, stored and recorded into shelf-life or,

ii Cooled, stored, graded and recorded into shelf-life.

Both sequences were done twice.

vi. Husbandry

Crops were grown by local growers for local cooperatives who were supplying the supermarket trade.

vii. Records

a) Temperature records during pre-cooling delay, cooling, holding and shelf-life.
b) Percentage weight loss during shelf-life.
c) Weight of produce downgraded and discarded.
d) Comments on reason for downgrading and discarding produce.

RESULTS AND DISCUSSION

1. Testing and calibration of cooling rigs

A stack of 35 crates of cauliflowers was built on a pallet, a cooling unit placed on top and the stack sealed with bubble plastic to direct the air through the crop from bottom to top. The fans were run to allow a measurement of air flow to calculate the relevant period for pulsing with cool air to cool the stack to the required temperature in the designated time. The calculations being based on data collected in the previous years trial (FV108).

Air resistance through the stack was found to be such that the fan went into an aerodynamic stall. This was overcome by reducing the stack size from seven layers of five crates to two layers. This reduction in stack size and crate numbers had an immediate advantageous effect as it had become apparent that the logistics of harvesting and handling 210 crates in the short time to commencement of cooling was impossible with a reasonable size labour force but the reduction to 60 crates made the trial manageable.

2. Preliminary run through of the initial trial procedure

The cauliflowers were cut and collected in and from a neighbouring growers field, brought back to the packhouse and the six, ten-crate stacks were assembles with the cooling rigs attached. They were placed into store at the appropriate time 2, 4 or 6 hours after harvest, the pulsing activated and stacks left overnight to cool. The pulsing was switched off automatically when the stack reached its correct temperature. The following morning the ice bank was reopened and stacks moved to a holding store of 6 or 10°C the temperature of all stacks had been monitored overnight using squirrel data loggers.

A summary of data collected for the two stacks put into store 2 hours after harvest is given in Table 1 where it can be seen that the procedure under test was unsatisfactory as the stacks continued to cool after being switched off and both stacks ended up at a very low similar temperature. Following further discussions with HDC and ADAS collaborators the procedure was modified to that given in the final version in materials and methods section and which is probably closer to commercial practice in any case. Over the following 10 weeks three runs of cauliflowers, three runs of calabrese and four runs of Brussels sprouts were assessed.

Table 1 Cooling of produce put into store, cooled slowly and left overnight in the ice bank.

Time		Temperature °C desired stack end temp 10°C	6°C	Comments
12.00	10 Aug	16.2	15.4	Pulsing activated
14.00		13.0	13.8	
16.00		10.2	11.0	Pulsing switched off 10°C unit
18.00		8.4	8.5	
20.00		7.2	6.8	
22.00		6.2	5.8	Pulsing switched off 6°C unit
24.00		5.7	5.0	
2.00	11 Aug	4.8	4.4	
4.00		4.2	4.0	
6.00		3.6	3.4	
8.00		3.6	3.1	
9.00		3.6	3.0	

Cauliflower 1. Cooling regimes achieved by the final trial procedure

The actual temperatures of all treatment of all 10 trials from field to shelf-life was monitored with squirrel data loggers taking a measurement every five minutes. A summary of one typical set of data is given in Table 2 which shows that the desired treatments were actually achieved within practical limits.

Table 2. Cooling of produce put into store cooled rapidly and transferred to a holding store overnight.

Time		Temperature °C desired end temp stack 10°C	6°C	Comments
12.00	24 Aug	14.2	14.9	
14.00		9.7	8.9	10°C stack moved to holding store
16.00		8.5	6.8	6°C stack moved to holding store
18.00		8.9	6.7	
20.00		9.2	6.4	
22.00		9.6	6.0	
24.00		9.7	5.9	
2.00	25 Aug	9.8	5.9	
4.00		9.8	5.5	
6.00		9.9	5.4	
7.00		10.0	5.4	Moved into shelf-life

Cauliflower 2. A comparison of the shelf-life of carefully and commercially harvested produce

The trial was done three times however when looking at results comparisons must not be made between trials only within each one. The commencement dates were; 18 August when a dry crop was harvested at an internal core temperature of 10°C but which had warmed to 13.5 by the time of cooling commencement, 24 August when a wet crop was harvested at 13°C but which reached 16°C before cooling and 1 September when a damp crop was harvested at 8.5°C but had reached 11.5 before cooling.

The data relating to the comparison of the two harvest methods is presented in Tables 3 and 4. Table 3 shows percentage weight loss through dehydration and the results are similar for both methods. Somewhat surprising is that the percentage crop downgraded from Class I to Class II in shelf-life is not more dissimilar. There is a slight trend in all three trials to suggest that carefully harvested and packed is better than piece work on a commercial rig but it is not as large as would be expected. If we look at the reasons for downgrading, most of which occurred on days two and three, it was disease expression, often associated with bruising. If we look at the crop that was discarded on day one (ie going into shelf-life) and which accounted for about 5% of produce for both harvest methods it was due to obviously damaged crop and was the same for both methods suggesting that to carefully ram cauliflower into plastic containers is as damaging as to do it at speed.

Table 3. Percentage weight loss of cauliflowers in shelf-life from carefully and commercially harvested samples.

Trial date	Treatment	% weight loss No. of days in shelf-life 1	2	3	4	5	6	7	8
18 Aug	Careful	0.8	6.0	10.9	14.4	19.5	23.8	*	*
	Rig	0.7	4.2	8.5	13.3	18.4	24.0	*	*
24 Aug	Careful	0.81	3.9	7.7	12.3	15.8	21.2	25.2	29.9
	Rig	0.73	3.9	7.7	11.6	15.2	21.4	*	*
1 Sept	Careful	0.6	4.8	8.7	12.2	15.6	19.3	*	*
	Rig	0.6	3.4	7.3	11.6	16.2	18.9	*	*

* Denotes no produce left

Table 4. Percentage weight downgraded from Class I to Class II of careful or rig harvested cauliflower heads.

Trial date	Treatment	% weight loss No. of days in shelf-life 1	2	3	4	5	6	7	8
18 Aug	Careful	6.0	36.2	67.1	68.6	78.1	100		
	Rig	4.2	50.5	77.0	78.7	82.9	100		
24 Aug	Careful	3.9	61.6	79.7	87.7	88.2	90.4	90.7	100
	Rig	3.9	60.5	88.6	90.3	90.9	100	100	100
1 Sept	Careful	4.1	56.4	77.0	81.6	85.2	100		
	Rig	6.1	61.5	85.5	90.2	89.6	100		

Cauliflower 3. A comparison of the shelf-life of produce cooled to and held at either 6 or 10°C

Tables 5 and 6 show the data pertaining to this comparison Table 5 shows that there was no difference in the weight loss of produce held at these temperatures during storage (ie percentage weight loss on day 1) or in subsequent shelf-life over the next five days. Also Table 6 shows that in these cases produce held at 10°C performed just as well in shelf-life as produce held at 6°C.

Table 5. Percentage weight loss of cauliflowers in shelf-life from produce cooled to and held at 6 or 10°C.

Trial date	Treatment	% weight loss No. of days in shelf-life 1	2	3	4	5	6	7	8
18 Aug	6°C	0.8	5.0	9.5	13.3	18.3	23.9	*	*
	10°C	0.7	5.2	9.9	14.2	19.5	24.0	*	*
24 Aug	6°C	0.8	3.8	7.5	11.7	15.2	20.7	22.8	*
	10°C	0.8	4.0	7.9	12.6	16.1	21.5	25.8	29.9
1 Sept	6°C	0.6	3.5	7.6	10.7	15.6	*	*	*
	10°C	0.6	4.1	7.9	11.8	15.6	18.6	*	*

Table 6. Percentage weight downgraded from Class I to Class II of cauliflowers cooled to and held at 6 or 10°C.

Trial date	Treatment	% weight loss No. of days in shelf-life 1	2	3	4	5	6	7	8
18 Aug	6°C	5.0	44.3	71.5	71.8	81.2	100		
	10°C	5.1	42.4	73.2	74.8	80.9	100		
24 Aug	6°C	3.8	57.1	81.4	89.3	90.0	90.8	100	
	10°C	4.0	65.1	82.3	87.0	87.7	90.3	90.7	100
1 Sept	6°C	3.7	55.3	81.4	91.1	100			
	10°C	6.8	61.9	79.9	84.2	87.0	100		

Cauliflower 4. A comparison of the shelf-life of produce held for 2, 4 or 6 hours at ambient before cooling commenced

Tables 7 and 8 show that in these three trials holding at ambient for 2-6 hours after cutting had no effect upon subsequent shelf-life performance.

Table 7. Percentage weight loss of cauliflowers in shelf-life from produce held at ambient for 2, 4 or 6 hours prior to commencement of cooling.

Trial date	Treatment	% weight loss No. of days in shelf-life 1	2	3	4	5	6	7	8
18 Aug	2 hr	0.7	5.0	9.7	14.3	18.9	23.1	*	*
	4 hr	0.7	5.0	9.4	13.5	18.1	23.0	*	*
	6 hr	0.8	5.3	10.0	13.6	19.6	25.9	*	*
24 Aug	2 hr	0.8	4.2	8.3	13.1	17.3	22.4	26.0	30.2
	4 hr	0.7	3.9	7.7	11.7	16.4	22.3	30.0	25.5
	6 hr	0.8	3.6	7.1	11.3	14.1	19.4	23.3	24.0
1 Sept	2 hr	0.6	3.9	8.4	11.4	14.7	18.7	*	*
	4 hr	0.5	3.9	7.6	11.0	14.1	16.5	*	*
	6 hr	0.7	3.6	7.2	11.5	16.3	19.1	*	*

Table 8 Percentage weight downgraded from Class I to Class II of cauliflowers held at ambient for 2, 4 or 6 hours prior to commencement of cooling.

Trial date	Treatment	% weight loss No. of days in shelf-life 1	2	3	4	5	6	7	8
18 Aug	2 hr	5.0	50.0	72.4	73.8	80.2	100		
	4 hr	5.0	34.3	69.1	71.2	77.0	100		
	6 hr	5.3	46.2	73.6	77.6	86.4	100		
24 Aug	2 hr	4.2	64.7	24.4	88.9	89.5	89.8	90.3	100
	4 hr	3.9	54.9	79.8	87.1	87.4	91.6	92.1	100
	6 hr	3.6	63.3	81.0	89.2	89.8	90.2	90.8	100
1 Sept	2 hr	3.9	62.7	79.9	83.1	85.2	100		
	4 hr	7.9	57.4	76.6	88.2	88.5	100		
	6 hr	3.5	56.5	82.4	89.0	90.8	100		

<u>Calabrese 1. A comparison of the shelf-life of carefully and commercially harvested produce</u>

The three calabrese trials were commenced on: the 8 September when dry produce was brought from the field at a temp of 9.0°C which reached 11.0°C before cooling started; on the 14 September when damp produce harvested at 8.0°C but reached 11°C before cooling and 23 September when a wet crop was harvested at 12°C and reached 12.5°C before cooling.

Data pertaining to the two harvest methods are given in Tables 9 and 10 which shows that water loss in shelf-life was similar for both harvest methods and although there is an indication in the second two of the three trials that commercially harvested was downgraded faster than carefully harvested it was not as large as had been thought probable.

Table 9. Percentage weight loss of calabrese in shelf-life from carefully and commercially harvested samples.

Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5	6
8 Sept	Careful	1.1	6.5	13.5	20.2	26.1	*
	Rig	1.3	7.5	13.2	21.2	31.5	33.9
14 Sept	Careful	1.3	8.1	15.7	25.5	31.6	32.3
	Rig	1.2	7.7	13.8	20.4	26.5	*
23 Sept	Careful	1.0	6.6	14.3	19.2	26.1	*
	Rig	1.2	7.2	15.2	22.4	29.5	*

* Denotes no produce left

Table 10. Percentage weight downgraded from Class I to Class II of careful or rig harvested calabrese.

Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5	6
8 Sept	Careful	8.0	24.6	42.9	68.6	100	
	Rig	7.7	22.2	39.2	65.2	97.3	100
14 Sept	Careful	6.2	24.6	44.6	82.6	95.5	100
	Rig	7.4	37.9	58.4	95.4	100	
23 Sept	Careful	6.6	34.3	66.6	82.5	100	
	Rig	7.2	37.7	78.5	91.2	100	

Calabrese 2. A comparison of the shelf-life of produce cooled to and held at either 6 or 10°C

The data concerning this comparison is given in Tables 11 and 12. Water loss was similar for all three trials for the first three days but after that there is an indication with the last two trials that produce which had been kept at 10°C lost water slightly faster and similarly with percentage downgraded crop there is a slight trend for the crop held at 10°C to be downgraded faster at the later stages of the trials.

Table 11. Percentage weight loss of calabrese in shelf-life from produce cooled to and held at 6 and 10°C.

Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5	6
8 Sept	6°C	1.1	6.9	13.7	21.6	27.5	33.9
	10°C	1.2	7.1	12.9	19.7	27.0	32.6
14 Sept	6°C	1.3	8.1	14.5	21.2	27.4	31.8
	10°C	1.2	7.7	14.9	24.4	30.4	*
23 Sept	6°C	1.0	6.7	14.5	20	26.3	*
	10°C	1.2	7.2	15.1	21.9	30.3	*

Table 12. Percentage weight downgraded from Class I to Class II of calabrese cooled to and held at 6 or 10°C.

Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5	6
8 Sept	6°C	8.0	25.4	41.2	61.5	97.0	100
	10°C	7.6	21.3	41.0	72.5	97.7	100
14 Sept	6°C	6.83	31.5	56.3	79.2	95.5	100
	10°C	7.0	31.0	46.7	92.0	100	
23 Sept	6°C	6.6	33.9	67.5	83.3	100	
	10°C	7.1	38.2	78.7	92.8	100	

Calabrese 3. A comparison of the shelf-life of produce held for 2, 4 or 6 hours at ambient before cooling commenced

Tables 13 and 14 show that in these three trials holding at ambient for 2-6 hours after harvest had no effect upon subsequent shelf-life performance.

Table 13. Percentage weight loss of cabbage in shelf-life from produce held at ambient for 2, 4 or 6 hours prior to commencement of cooling.

Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5	6
8 Sept	2 hr	1.1	7.3	13.1	20.4	26.6	*
	4 hr	1.1	7.0	13.1	21.3	29.0	34.6
	6 hr	1.3	6.8	13.9	20.5	25.6	33.9
14 Sept	2 hr	1.2	8.1	16.3	23.4	29.0	*
	4 hr	1.2	7.9	14.3	25.2	31.5	*
	6 hr	1.3	7.7	13.4	20.1	26.2	32.9
23 Sept	2 hr	1.2	7.0	15.1	21.2	29.4	*
	4 hr	1.1	7.2	14.9	21.8	27.3	*
	6 hr	1.1	6.6	14.2	19.5	27.3	*

Table 14. Percentage weight downgraded from Class I to Class II of calabrese held at ambient for 2, 4 or 6 hours prior to commencement of cooling.

Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5	6
8 Sept	2 hr	8.1	22.8	42.4	68.9	100	
	4 hr	7.8	25.0	43.7	67.1	97.0	100
	6 hr	7.6	22.3	37.2	64.7	97.7	100
14 Sept	2 hr	7.2	35.3	54.4	80.2	100	
	4 hr	6.9	27.7	50.2	86.0	100	
	6 hr	6.7	30.7	49.9	87.1	95.5	100
23 Sept	2 hr	7.0	36.1	71.7	94.4	100	
	4 hr	7.1	36.8	75.1	91.7	100	
	6 hr	6.5	34.9	72.3	90.3	100	*

Brussels sprouts 1. A comparison of the shelf-life of hand picked and machine stripped produce

Four Brussels sprout trials were done because there are two possible packhouse procedures. Sprouts may be graded before cooling or after cooling and holding, therefore two runs of each were done. A further difference from the cauliflower and calabrese trials was that produce was not examined individually and downgraded as this was not practicable but whole crates were downgraded and discarded when 25% of the produce was deemed Class II.

The four trials were commenced on: the 29 September when wet produce was brought from the field at a temperature of 14°C which rose to 16°C before cooling; on the 6 October when dry produce was brought in at a temperature of 11°C which remained unchanged until cooling; on the 13 October when dry produce was brought in at a temperature of 5°C which rose to 8°C by commencement of cooling and on 20 October when wet produce was brought in at a temperature of 4°C and reached 5°C by time cooling commenced. Obviously where produce had not reached holding temperature it was put straight into holding store. Trials 1 and 3 were graded prior to cooling and 2 and 4 graded between cooling and shelf-life.

Data pertaining to the two harvest methods are given in Tables 15 and 16. The hand picked samples coming into the packhouse had much less waste and were easier to grade than the machine picked and although there was no difference in weight loss in store hand picked had a longer shelf-life than machine picked.

Table 15. Percentage weight loss of Brussels sprouts in shelf-life room hand picked and machine stripped produce.

Trial procedure	Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5
Grade cool store	29 Sept	Hand	1.4	4.0	6.7	*	*
		Machine	1.3	3.4	*	*	*
Grade cool store	13 Oct	Hand	1.9	6.5	8.6	*	*
		Machine	1.3	5.6	8.3	*	*
Cool store grade	6 Oct	Hand	0.8	3.3	6.1	8.7	12.0
		Machine	0.7	3.7	6.5	*	*
Cool store grade	20 Oct	Hand	0.8	4.3	7.6	10.8	*
		Machine	0.7	4.1	7.5	*	*

Table 16. Number of plastic supermarket crates remaining in shelf-life room of hand picked and machine stripped sprouts.

Trial procedure	Trial date	Treatment	No. of plastic crates No. of days in shelf-life 1	2	3	4	5
Grade cool store	29 Sept	Hand	18	18	15	0	
		Machine	18	18	0		
Grade cool store	13 Oct	Hand	18	18	13	0	
		Machine	18	18	3	0	
Cool store grade	6 Oct	Hand	18	18	17	11	4
		Machine	18	18	10	0	
Cool store grade	20 Oct	Hand	18	18	15	2	0
		Machine	18	18	13	0	

Brussels sprouts 2. A comparison of the shelf-life of sprouts cooled to and held at either 6 or 10°C.

The data relevant to this topic is given in Tables 17 and 18 where it is shown that there was no difference in weight loss from produce cooled to and held at the two temperatures. In the first and second trials there was little difference between the two temperature for the length of time in shelf-life, but with the third and fourth trials there was a very slight indication that produce held at 6°C lasted longer in shelf-life than produce at 10°C.

Table 17. Percentage weight loss of Brussels sprouts in shelf-life from produce cooled to and held at either 6 or 10°C.

Trial procedure	Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5
Grade cool store	29 Sept	6°C	1.4	2.9	6.6	*	*
		10°C	1.3	4.5	6.8	*	*
Grade cool store	13 Oct	6°C	1.8	6.6	9.5	*	*
		10°C	1.3	5.5	8.6	*	*
Cool store grade	6 Oct	6°C	0.9	3.5	6.4	8.9	11.2
		10°C	0.7	3.4	6.0	8.3	12.3
Cool store grade	20 Oct	6°C	0.9	4.5	7.9	10.8	*
		10°C	0.6	3.9	7.0	*	*

Table 18. Number of plastic supermarket crates remaining in shelf-life room of sprouts cooled to and held at either 6 or 10°C.

Trial procedure	Trial date	Treatment	No. of plastic crates No. of days in shelf-life 1	2	3	4	5
Grade cool store	29 Sept	6°C	18	18	6	0	
		10°C	18	18	9	0	
Grade cool store	13 Oct	6°C	18	18	11	0	
		10°C	18	18	5	0	
Cool store grade	6 Oct	6°C	18	18	15	7	1
		10°C	18	18	12	4	3
Cool store grade	20 Oct	6°C	18	18	18	2	0
		10°C	18	18	10	0	

Brussels sprouts 3. A comparison of the shelf-life of produce held for 2, 4 or 6 hours at ambient before cooling commenced.

Tables 19 and 20 show that in these four trials holding at ambient for 2-6 hours after harvest had no effect upon subsequent shelf-life performance.

Table 19. Percentage weight loss of Brussels sprouts in shelf-life from produce held at ambient for 2, 4 or 6 hours prior to commencement of cooling.

Trial procedure	Trial date	Treatment	% wt loss No. of days in shelf-life 1	2	3	4	5
Grade cool store	29 Sept	2 hr	1.4	3.8	6.4	*	*
		4 hr	1.2	3.5	7.5	*	*
		6 hr	1.5	3.9	6.3	*	*
Grade cool store	13 Oct	2 hr	1.9	6.7	11.6	*	*
		4 hr	1.5	5.7	8.6	*	*
		6 hr	1.4	5.7	8.7	*	*
Cool store grade	6 Oct	2 hr	0.7	3.5	6.5	9.0	11.6
		4 hr	0.8	3.2	5.9	8.2	11.8
		6 hr	0.8	3.7	6.3	8.9	13.0
Cool store grade	20 Oct	2 hr	0.7	4.6	7.8	*	*
		4 hr	0.7	3.9	7.2	*	*
		6 hr	0.8	4.1	7.9	10.8	*

Table 20. Number of plastic supermarket crates remaining in shelf-life room of sprouts held at ambient for 2, 4 or 6 hours prior to the commencement of cooling.

Trial procedure	Trial date	Treatment	No. of plastic crates No. of days in shelf-life 1	2	3	4	5
Grade cool store	29 Sept	2 hr	12	12	5	0	
		4 hr	12	12	5	0	
		6 hr	12	12	5	0	
Grade cool store	13 Oct	2 hr	12	12	3	0	
		4 hr	12	12	6	0	
		6 hr	12	12	7	0	
Cool store grade	6 Oct	2 hr	12	12	9	4	1
		4 hr	12	12	11	4	2
		6 hr	12	12	7	3	1
Cool store grade	20 Oct	2 hr	12	12	11	0	
		4 hr	12	12	11	0	
		6 hr	12	12	7	2	0

CONCLUSIONS

1. Hand picked sprouts were cleaner from debris and had better shelf-life characteristics than machine stripped ones but carefully harvested cauliflower were no better than those done commercially probably because a lot of problems stem from overpacking the plastic crates. Carefully harvested calabrese had little advantage over commercially harvested heads.

2. The shelf-life of produce cooled and kept at a holding and dispatch temperature of 10°C was very similar to that at 6°C the previously commercially used temperature.

3. Varying the length of time from harvest to the start of cooling from two to six hours had no effect upon subsequent shelf-life.

RECOMMENDATIONS FOR FURTHER WORK

1. Conclusions 2 and 3 above contain some commercially useful information if verified. But there needs to be further work to achieve verification as these trials were done with quite cool crops, therefore, the work needs to be repeated with crops harvested around midday during hot weather.

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STORAGE OF DATA

The raw data will be stored at HRI Kirton, Government Buildings, Willington Road, Kirton, Boston, Lincs PE20 1EJ for a period of 10 years.

SECTION 3, MICROBIOLOGICAL ASSAY

1 OBJECTIVE

To test for correlation between populations of spoilage organisms and the cooling regimes used in the HRI shelf-life trials.

2 CONCLUSIONS

There were no significant differences detected between treatments for any of the microbiological parameters tested on any specific harvest date.

All the temperature regimes used in the trials were above those normally expected to have a significant effect on bacterial spoilage.

3 MATERIALS AND METHODS

Spoilage organism assessments of shelf-life were carried out on cauliflowers harvested on 18 and 25 August 1992 and 1 September 1992, drawn from the same batches as those used for the HRI tests at Kirton. The cauliflowers were taken to laboratories at ADAS, Cambridge, for the tests.

Microbiological analyses

Three replicate samples of each treatment were assessed for *Pseudomonas* species total pectolytic bacteria, total *Erwinia* species per gram of curd and three further replicates were assessed for the presence of fungal pathogens, these organisms having been implicated as the most common causes of post-harvest pathological decay.

Bacterial assessments

Curds were separated from outer leaves by a single cut at the base of the curd, using a sterile knife. Care was taken to avoid contamination of the curd with soil from the leaves which were discarded.

Using a sterile knife, a layer 5 mm in depth was removed from the surface of the curd. A 20 g portion of the removed curd was stomached with 180 ml % peptone saline for two minutes. The resultant suspension was further diluted to 10^{-6} and 0.1 ml aliquots of each dilution were spread plated onto nutrient agar as follows:

Organism	Nutrient medium	Incubation temperature
Pseudomonas spp	King's B agar	25°C
Total pectolytic bacteria	Pectate agar	25°C
Erwinia spp	Crystal violet pectate agar	25°C

Plates were incubated for three days prior to assessment and enumeration of typical colonies.

Incubation and Assessment for Fungal Pathogens

The cauliflower heads were aseptically trimmed of all leaves to expose the curds and any defects or fungal lesions were recorded. The curds were then incubated for seven days at ambient temperature, in damp chambers lined with slightly dampened paper tissues before final assessment of fungal development.

Fungal lesions were scored as a percentage area of the curd.

Statistical analysis

The results were analysed by a two way factorial analysis guidance using Genstat version 5.0. Duncan's New Multiple-Range Test (1955) was applied to the treatment means to test for significant differences.

4 RESULTS

Table 1 Mean $\log_{10}$ counts of *Pseudomonas* species per gram of cauliflower curd (mean of three replicates)

Delay to cooling (hr)	Storage temperature (°C) 6			10		
Harvest date	18.8.92	25.8.92	1.9.92	18.8.92	25.8.92	1.9.92
2	5.73	5.63	5.03	5.89	6.60	5.10
4	6.55	6.22	5.87	6.12	6.37	5.78
6	6.36	6.01	5.90	6.74	5.80	5.31

Table 2 Mean $\log_{10}$ counts of petolytic bacteria per gram of cauliflower curd (mean of three replicates)

Delay to cooling (hr)	Storage temperature (°C) 6			10		
Harvest date	18.8.92	25.8.92	1.9.92	18.8.92	25.8.92	1.9.92
2	5.36	2.57	2.00	3.93	1.48	2.00
4	6.53	2.00	3.18	5.72	2.00	3.00
6	5.69	2.00	2.58	5.72	2.00	2.00

Table 3 Mean percentage area of cauliflower curds affected by fungal lesions (mean of three replicates)

Delay to cooling (hr)	Storage temperature (°C)					
	6			10		
Harvest date	18.8.92	25.8.92	1.9.92	18.8.92	25.8.92	1.9.92
2	3.67	6.33	6.00	5.33	6.67	4.00
4	11.67	3.00	2.00	3.33	5.33	4.67
6	8.33	4.00	4.33	2.33	2.33	1.67

Soft rotting *Erwinia* species were not detectable on any curd samples under any treatment regime.

There were no significant differences detected between treatments for any of the microbiological parameters tested on any specific harvest date.

Counts of *Pseudomonas* spp per gram were high, irrespective of harvest date and treatment, whilst counts of total pectolytic bacteria were lower at the later harvest dates.

Fungal assessments after seven days incubation revealed a fine dark speckling, some of which was due to the presence of *Alternaria alternata* but most of the speckling did not develop to any considerable extent. A soft while mycelium was also present on curds but this did not give rise to any spore development. *Botrytis* sp, the major cause of fungal decay on cauliflower curds, did not develop on any curd, whilst *Fusarium* sp did develop despite this being recorded as an infrequent cause of spoilage in the United Kingdom.

5 DISCUSSION

The cooling regimes and storage temperatures used during this investigation, were significantly above the temperature regimes (usually less than 3°C and probably 0-1°C) normally considered necessary to have a significant effect on bacterial spoilage. These results confirm that the bacterial spoilage was not signficantly influenced, even at the current cold chain temperature recommendations.

The test methods were unable to detect signifcant changes in spoilage pathogen levels between any of the regimes used in this investigation.