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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

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Executive Summary

- The majority of horticultural crops require a period of cooling and storage, though this may vary from the very short-term, associated with field heat removal to long-term storage.

- Crops with longest period of refrigerated storage, up to 7 months or more, are apples and pears, bulb onions and winter white cabbage, with approximate tonnages of 200,000, 300,000 and 100,000 respectively. This storage enables the market to be supplied over an extended period with products which are harvested on a single occasion. Effectively, this allows production at higher levels than the market could absorb at the time of harvest and so enables producers to compete with other sources of supply.

- Otherwise cooling and storage is more usually associated with field heat removal and temporary storage from just a few hours to 48 hours. The main purposes of this are logistical, i.e. to accumulate an appropriate quantity for transport at a required temperature to fulfil orders, or for evening out of supply to the market when that from the field is fluctuating (e.g. in a period of glut) or over a weekend or bank holiday.

- There are occasions when crops are stored for intermediate periods e.g. red beet and swedes for up to 4 months, brassicas for up to 3 weeks and plums up to 3 weeks to extend the season of production and even out market requirements.

- The introduction of cool chain marketing by supermarkets has meant that all growers supplying these outlets, which account for 70-80% of production in the UK, must have access to cooling facilities and refrigerated transport. In addition, some growers supplying other outlets are similarly equipped.

- Many growers do not know the cost of field heat removal, cooling and/or storage of their crops and there appears to be no standard basis for reporting. This raises serious doubts about the practicality of levy-payers being able to report such costs to the HDC.

- Even approximate information on storage costs is often not readily available as both electricity and labour are regarded as a general farm overhead. Although this is beginning to change, there is often only one electricity meter on site, recording consumption to stores, packhouses, work shops, offices and even student hostels. Stores may have been built and refurbished at different times, making it difficult to calculate capital costs, though there is not a consensus on whether or how capital costs should be included. This also applies to labour costs associated with crop storage.

- The question of store ownership also arises, with some growers having their own stores, others renting and others reliant on stores owned and run by packers, Producer Organisations (POs) or marketing agents.

- Nevertheless, it has been possible to obtain some information on storage costs for a range of crops, (including contract hire and rental data) from the industry though, as described above, achieving a consistent basis for the figures proved extremely difficult. Based on the information obtained, typical costs of storage reported by established growers for 1 tonne of produce for the 'relevant' *(see crop descriptions)* storage period would be:

Crop	**Price range**	**Storage type**
Winter white cabbage	£73-91	Refrigerated long-term storage
Bulb onions	£82-97	Drying & refrigerated long-term storage
Carrots	£50	Field storage November to April
Lettuce	Up to £60	Vacuum cooling & short-term
Apples	Up to £89	Large complex to end March
Apples	Up to £99	Specialist Bramley
Strawberries	£22	Cooling & short-term
Raspberries	Up to £86	Cooling & short-term

- Crop yields and enterprise size obviously vary considerably amongst levy-payers, but putting the above data in a 'cost per season' context for individual producers, using selected average 'model' areas and yields, might produce the following picture:

	Area (ha)	Tonnage	Cost/season (£)
Winter white cabbage	20	1,100	90,200
Bulb onions	50	40	179,000
Lettuce	250	6,250	375,000
Apples (farm storage)	25	650	47,850
Bramley (farm storage)	25	800	66,000
Strawberries	15	330	7,313
Raspberries	7	65	5,590

Terms of Reference

The HDC has commissioned this study to determine the relative importance and costs of crop storage in each of the major horticultural crop sectors. This is in response to representations made by some levy-paying members growing apples and pears, following the decision made by Defra to change the basis of their liability for levy from an area to a turnover calculation. This is to help test the premise put forward that storage regimes are more exacting and storage costs greater for top fruit than for other sectors and that due consideration should therefore be given to permitting this as an allowable expense, prior to the levy being calculated. This report provides comparative data for a range of major crops including:

- brassicas (including winter white cabbage)
- salads crops
- onions
- carrots
- soft fruit
- top fruit
- cut flowers
- other crops that have a significant storage/refrigeration input within the annual cropping cycle

Although the emphasis of the report is be on refrigerated storage, i.e. cooling is seen as included in the definition, carrots have also been included in the report as a major

crop, which required special treatment for storage, even though for the most part this was carried out *in situ* in the field.

The work aims to determine what the 'typical' grower may have in terms of:

- Store type and regimes used for particular crops
- Proportion of growers using these stores
- Typical storage capacities
- Purpose and duration of the storage e.g. cooling and holding for a short period prior to marketing or long-term such as apples, pears, onions or winter white cabbage
- Number of days storage used in a year – in total and/or per crop; any periods when not used and potentially available for other uses/crops
- Average storage costs per tonne for the crop (e.g. per month or season)
- Any unique features

Introduction

Consumers and retailers increasingly require that all horticultural produce meets the highest standards for quality, reliability and availability. Volume sold, market price and hence profit are all directly related to the maintenance of quality.

The quality of most fruit (particularly soft fruit) and vegetables deteriorates rapidly after harvest, due to continuing respiration of the crop. The main influence is temperature, which affects all living processes such as growth, ripening and speed of deterioration. These processes are rapid at high temperatures of 15-21^{O}C and slow at temperatures of 2-7^{O}C. However, the rate of deterioration also depends very much on the nature of the commodity and the conditions under which it is harvested and handled. Lettuce, for example, exposed to hot dry conditions, wilts within a few hours of harvest but bulb onions show no ill effects at all with such treatment. Successful marketing depends on reducing any deterioration to a minimum so that the quality of the product reaching the consumer resembles that of a freshly harvested crop as closely as possible. (In a few cases curing or maturation can improve some aspects of crop quality, e.g. bulb onions and squash).

It is widely recognised that field heat should be removed as quickly as possible after harvesting to reduce the metabolic rate of produce. The process of field heat removal is therefore the first essential link in any cool chain system followed by short or long-term storage, as appropriate and refrigerated transport to the customer. Refrigerated storage and controlled atmosphere (CA) storage is used to accommodate fluctuations in supply and demand and to obtain orderly marketing over an extended season.

The introduction of cool chain marketing by supermarkets, the principal market outlets in the fruit and vegetables sectors, has meant that all growers supplying these outlets must have access to cooling facilities and refrigerated transport.

For many crops, maintenance of product quality in store by proper handling and management during both cooling and storage is of equal importance to the growing and harvesting operations.

Storage Equipment

Field heat removal is usually an essential first stage. Various types of plant are used for this, some for this purpose only and others for subsequent short-term holding or longer-term storage as well:

Vacuum cooling

This system is ideal for leafy crops with high surface area e.g. lettuce, leafy cabbage and celery, but is unsuitable for bulky crops or those with a thick waxy surface. It has the advantage of being a quick batch system but has the disadvantage of having high power requirements, can freeze the product and requires the additional cost of a holding store.

Air cooling, conventional cold stores

In these stores, produce is cooled by exposure to cold air which is circulated inside an insulated room. Heat is extracted from the air by a refrigerated cooler. The cooling performance of cold stores is enhanced by positive or forced ventilation. This ensures that cooling air comes into close contact with the produce. A direct expansion refrigeration system can be used for cooling and short-term cool storage of most fruit and vegetables, but the process may be slow, depending on the crop. The conventional cold store is ideal as buffer storage to prevent produce reheating after being cooled and for storage over a 2-3 day period.

Cooling times depend very much on the way the stores are used and the crop, with soft fruit cooled in 2.5 hours if positive ventilation is used, while Brussels sprouts can take at least 24 hours.

Wet air cooling with positive ventilation

This system is similar to the direct expansion system but air is moistened by water which has been cooled by a block of ice ('ice bank'). It can be used for a wide range of crops e.g. Brussels sprouts, cabbage, celery, root crops, soft fruit and salads, though not for bulb onions. It has the advantage that air is forced through the crop to achieve uniform cooling. It does not dehydrate or freeze crops and can be used on off-peak electricity to minimise running costs.

Hydrocooling

This system is used extensively in the USA on root crops. It uses the same principle as the moist air cooling system but with water being cooled by a block of ice. It is a continuous process and is an ideal system for any crop that is either washed or moved in water e.g. carrots, cherries, parsnips, radish and celery. However, the system can spread disease and requires a holding store to maintain produce in cooled state.

Controlled atmosphere (CA) storage

In CA storage, not only is the temperature controlled but the ventilation of the store is restricted to permit carbon dioxide produced by the respiring crop to accumulate in the storage atmosphere. This, together with the fall in concentration of oxygen which accompanies it, has the effect of delaying ripening changes. To obtain this accumulation of carbon dioxide the store has to be gas proof. A gas store is therefore a cold store which is rendered gas tight and fitted with a ventilation device, by which the rise in concentration of carbon dioxide and the fall in the concentration of oxygen can be regulated.

Ethylene is now suppressed or removed from some modern apple stores, particularly for Bramley. Flushing with nitrogen can be used to establish CA conditions quickly when stores are first sealed or after they are opened for partial fruit removal, with the remaining fruit requiring continuing CA conditions.

Vegetable crop storage

Vegetables vary greatly in their storage potential, ranging from those of a leafy nature, such as lettuce, which are naturally short-lived, to those which are naturally long-lived, such as carrots and onions. Except in the case of onions, storage does not improve the quality of the produce but merely extends its potential life.

To successfully store vegetables it is necessary to understand the specific conditions needed to keep the different types in good condition for as long as possible. The primary consideration is that any crop going into storage should be in a sound, undamaged state. Beyond that the factors concerned are temperature, humidity and ventilation, with specific requirements varying from crop to crop.

Traditionally large scale cooling and long-term storage has been restricted to a very few vegetable crops, principally winter white cabbage and bulb onions and to a lesser extent beetroot. However, with the establishment of cool chain marketing, the range and volume of crops being treated has expanded rapidly, such that most vegetable crops are now cooled or stored, though for many this may only be for a few hours or overnight.

In practice two types of storage are in common use:

Short-term

Forward harvesting is often necessary for many vegetables and short-term storage allows for gluts or lulls in harvesting over weekends and bank holidays to be evened out. By this means delivery schedules can be met and increases in orders accommodated. This form of storage applies particularly to salad crops.

For small scale production a cool store may not be necessary if the produce can be picked on the packing day or the evening before, if the packhouse itself is cool and if the produce is despatched frequently.

Second-hand refrigerated lorry/van chilling compartments can offer a relatively cheap cold store option for the short-term, though their cooling capability may be limited.

Long-term

The aim is to store produce for as long as possible using both refrigerated cold stores and CA stores. This enables crops such as onions, winter white cabbage and beetroot to be available throughout most of the year. Carrots and parsnips are also stored long-term, but in the soil rather than being lifted and then stored.

Long-term box storage of many vegetable crop offers increased flexibility and improved efficiency, both during the loading and especially the unloading operations. Box storage permits several varieties of a crop to be stored together without the difficulty of accessing one or the other variety for early sale.

Produce may be cooled before storage by hydrocooling (e.g. carrot and parsnips) or vacuum cooling for salads and some brassicas.

Except for some onion and winter white cabbage crops, large-scale storage tends to be owned by packers or grower/packers and is used as holding storage, usually of 500 to 1000 tonne capacity. Most stores are direct expansion cold stores, though often with improved design to maintain the high humidity required for some vegetable crops.

For vegetable crops, stores tend to be used continuously and are never empty, apart from onion and cabbage stores, which have an empty period from May to September and August to October respectively.

There are examples of cabbage stores being used for imported lettuce in April and May, after the cabbage has been marketed and then for short-term storage of farm-produced lettuce through the summer.

Carrot and parsnips

Typical storage period: 1 to 9 months
Storage temperature: 0-10^{O}C

At present the best way to store carrots in the UK is in the ground by covering with a deep layer of straw which provides good frost protection and enables crops to be

lifted during periods when the soil is otherwise frozen. The thicker the straw layer and the longer the straw length, the better the insulation.

Improved protection for long-term storage until May is given by using black plastic under a deep straw layer. This technique is essential to reduce light levels, to stop re-growth, to keep the crop turgid and to limit the effect of warming spring temperatures between February and April.

About 3,000 ha (30% of the UK carrot area) is strawed for storage, with some 2,500 ha also using black plastic and greater quantities of straw, up to 50 tonne/ha. Straw covering is practised in all carrot-producing areas, but mostly in Norfolk, Nottinghamshire, Lincolnshire, Yorkshire and the East coast of Scotland.

A small area of parsnips are also covered with straw to ensure availability in periods of severe penetrating frost.

Strawing is an expensive technique requiring large amounts of energy to bale, move, spread straw and to dispose of straw residues.

There is a limited amount of earthing over of carrots on organic soils where the peaty soil texture can give some insulation against frosting. It is a low-cost technique, but there can be a yield penalty caused by the row configuration necessary for earthing up, which does not make full use of the available space. This system is also not totally secure against frosting.

A layer of black plastic film secured over the ridge can give improvements in frost protection.

Cool storage in wet air systems is an established technique for buffering supplies from the field to the pack house or for short-term storage of packed produce. Long-term cold storage is currently not used in the UK as carrot skin quality deteriorates during storage and the resultant product does not appeal to the main fresh market customers. The high cost is also a major disadvantage, but there is some interest in developing the method for wider commercial use.

Swedes

Typical storage period:	Up to 5 months
Storage temperature:	$3^{O}C$
Relative humidity:	90-95%

Like carrots and parsnips swedes are usually field-stored for as long as possible. However, some are stored in bulk bins from November to April to guarantee availability in periods of severe weather.

Red beet and also small quantities of celeriac and chicory

Typical storage period:	4 to 6 months in temperature-controlled stores
Storage temperature:	$3^{O}C$
Relative humidity:	95-98%

As well as in cold stores, red beet can be kept in clamps or barn-stored during the earlier part of the winter, subsequently being moved into temperature-controlled chambers as outdoor temperatures rise.

Salads (lettuce, endive, spinach, etc.)

Typical storage period:	3 to 4 days per batch for the marketing period of late May to October
Storage temperature:	$0.5\text{-}10^{O}C$
Relative humidity:	95%.

All salad growers will have some form of field heat removal and short-term storage, with typical storage capacity up to 1500 tonnes.

Lettuce demand is greatly influenced by the weather with weather forecasts used to predict surges in demand. To overcome shortages at the start of a fine spell crops may be cut in advance and stored for a short period.

Lettuce is usually harvested by hand and packed in the field to avoid deterioration and mechanical damage. Heads are wrapped or bagged in plastic, packed in boxes, often vacuum cooled to 0^{O}C to remove field heat, transported to cold store and cool stored at 0.5-10^{O}C. This technique greatly retards deterioration but, as lettuce is easily damaged by freezing, it is important that all parts of the storage room are kept above freezing point. High humidity is essential to maintain fresh turgid condition.

Lettuce is highly perishable and should therefore be stored only in periods of surplus and over weekends or holidays. Successful storage depends on prompt cooling after harvest.

Stores are either owned by growers or the packing/marketing company, including POs.

Celery

Typical storage period:	Seldom stored
Storage temperature:	4^{O}C
Relative humidity:	90-95%

Cooling (field heat removal) is essential during the marketing period of July to November.

Brassicas (cabbage, cauliflower, Brussels sprouts and broccoli)

Typical storage period:	1 day to 3 weeks per batch depending on market requirements. Field heat removal is likely to be required during the summer months
Storage temperature:	1^{O}C
Relative humidity:	95-98%

For cauliflower and calabrese, only a few growers (5% or so) will have any form of cold storage and this will be primarily to remove field heat as quickly as possible to 1^{O}C before sending produce to a packer. Occasionally short-term storage of 1-7 days will occur to hold over a weekend or to even out supply during periods of glut.

More commonly any short-term storage of up to 3 weeks will be at the packer who is likely to be a PO. The PO will own the stores. Only the packers have advanced cold storage with humidity control for these crops.

For the wholesale market, there is a limited amount of 'top icing' of broccoli with ice added over the broccoli heads after packing in waxed cardboard boxes.

Winter white cabbage (for processing)

Typical storage period:	Up to 9-10 months
Storage temperature:	0^{O}C
Relative humidity:	95%

Currently some 2,700 ha winter white cabbage are grown, of which approximately 100,000 tonnes are stored for up to 10 months in both cold stores and CA stores. Most winter white cabbage for processing will have been stored.

1,000-1,200 tonne stores are typical, though older stores will have a capacity of about 500 tonnes.

One estimate indicates that there are up to 100 cabbage stores in the UK in current use. About half of these will be converted potato stores with additional insulation added and with good fan capacity - though they will not lower the cabbage temperature quickly enough or low enough to be considered valuable stores for long-term storage. With such a slow and prolonged draw down time, the crop quality would deteriorate too quickly.

The other stores have been constructed in last 5 years, with improved insulated lining material, ranging from high quality white plastic-coated panels to polystyrene foam. Cooling systems are of the letter-box design, in which the air is blown through the slats in the bottom of the box, or overhead cooling in which the air drops down from the coolers in the store ceiling or is blown from fans located at the end of the store

over the top of the boxes. In addition, there a few CA stores used for winter white cabbage

It is essential that the cabbages are harvested by early to mid-November in advance of severe or prolonged frost. They may be stacked up to 3m high or alternatively stored in bulk bins. Cabbage goes into cold store in October / November, to be marketed principally between March and May. CA stores can hold cabbage until August. A weight loss averaging 1-$1^1/_2$% per month occurs. Losses may also occur from various storage disorders, which are only infrequently evident at harvest, but can develop rapidly in store.

A typical cost of storing winter white cabbage from Nov to May 2007 was £73 per tonne. This figure includes an 8 year capital write-off period. The cost will be about 25% higher for an old store with poor insulation and an inefficient refrigeration system.

Cabbage stores are mainly in the ownership of growers.

Bulb Onions

Typical storage period:	3-4 weeks to 11 months
Storage temperature:	Varies according to storage period
Relative humidity:	Varies

The main bulb onion crop for long-term storage is drilled in March and April and harvested in late August and September. The total crop is some 330,000 tonnes, most of which will be cured and stored for varying periods.

Bulb onions can be stored in:

- ambient ventilated stores from September until the end of March
- refrigerated storage for marketing during April-June, but can be earlier
- CA storage is necessary for extending the season as long as possible into July.

All onions need to be dried initially either in an ambient store or a cold store by blowing high volumes of air, at a predetermined temperature, through the crop. After

this initial drying, the warm air is re-circulated through the onions at a controlled humidity to complete the curing process, and produce the golden brown colour on the outer skins.

Once the onions have been dried it is necessary to cool them and to keep them in that condition for the duration of the storage period. Humidity control is essential and although 70-75% is optimal, it is both costly and difficult to achieve. Dry bulb onions will store well in relative humidities between 75-80% but above 85% the bulbs develop roots and shoots, making them unfit for market.

If the onions are dried initially in an insulated store then by early November the store temperature can be reduced to $0^{O}C$. Alternatively, the dried onions can be kept in an ambient ventilated store either for marketing through to the following May or for transfer to a refrigerated store in late December or early January. The second method allows greater flexibility than can be achieved if the cool store is used for both drying and storage. The main disadvantage is the double handling, which increases labour costs and can add to the level of mechanical damage.

There are 3 types of storage systems:

- in bulk to a depth of 3 m.
- 1 tonne containers (bulk bins) is the preferred size for the vast majority of stores, although a few growers have introduced a 3 tonne box.
- larger containers (17/18 tonnes) reduce handling operations by up to 60% and so improve efficiency of operation, but the same large box may pose serious practical difficulties when transporting the onions off the farm. Therefore the larger box is best suited to growers with their own grading and packing on site.

The period in store is now as important as the growing and harvesting of the crop, therefore the equipment used and the management of the stored crop are very important. Only when storage systems are well designed can the required crop quality be achieved.

Many factors are involved in the overall cost of storage, apart from the major cost of energy. For example, large containers (17/18 tonne) are cheaper to store and handle, but have a higher capital cost.

Typical drying and curing costs are £35-39/tonne, plus storage costs (inclusive of management, capital depreciation, etc) of £17-28 per tonne for a 6 month period. (Electricity costs are estimated at around £5 per tonne per month, though this cost could double for crops being stored in 2008/09).

There has been an increase in onion box stores and an upgrading of stores to a box storage specification, with capacities of 800 to 4,000+ tonnes with, 2,000 tonnes being typical. However, some traditional ambient stores are much smaller, of only 100 tonnes capacity.

Most major packers will have on-site storage, both in cold stores and CA storage, which enables UK grown onions to be packed for almost twelve months of the year without compromising significantly on quality.

Onion stores may be empty for a 3 to 6 month period from April to September and therefore available for other produce.

Summary

- Traditionally long-term storage has been restricted to a very few vegetable crops, principally carrots, winter white cabbage and bulb onions.

- The advent of cool chain marketing has resulted in most vegetable crops being now cooled or stored, though in many instances this may only be for a few hours or overnight.

- Unlike other vegetable crops, carrots and to a lesser extent parsnips, are usually stored in the ground by covering with a deep layer of straw which provides good frost protection.

Top fruit storage

The objective of top fruit storage techniques is to delay ripening so that fruit can be marketed at the optimum time without loss of quality. Increasingly, most stores now being built are controlled atmosphere (CA) stores in order to maintain optimum quality for all but the earliest marketed fruit. Even tree-ripened Cox, which is sold soon after harvest, is held in CA conditions for some buyers. Successful storage depends on efficient control of temperature and humidity and, for most apple varieties, modification of the gaseous composition of the store atmosphere.

The variety of apples or pears determines the length of time over which they can be stored. Plums and cherries are generally only stored for short periods.

Apples and Pears

Typical storage period:	2-8 months, though Bramley is an exception and can be stored for up to 13 months
Storage temperature:	Varies, see below

After picking and initial grading in August to October, depending on the variety, apples and pears are stored in bulk bins and then graded and packed preceding marketing. Without the use of refrigeration and CA storage, apples can rarely be kept in good condition beyond November. To extend the marketing of apples and pears ripening processes are retarded by the use of refrigerated and CA storage. Increasingly, as mentioned above, fruit is stored in CA conditions even for short-term periods as the fruit quality is maintained to a better standard. For short-term storage, for marketing to November, fruit can be stored in normal cold stores, apples at 3-4^{O}C and pears at -1^{o} C, though CA storage is now more common. For medium to long-term storage, CA stores are utilized for marketing through to April (or August for Bramley).

It is vital when picking and loading fruit into store that the operations should be done at the optimum time and that mechanical damage to the fruit should be kept to the absolute minimum to maximise storage life. However, even when kept under the best conditions, there is a limit to the storage life of top fruit. Successful storage is dependent on orchard factors such as nutrition and, in some years and for some

varieties, calcium sprays may be needed to boost intrinsic levels. Seasonal weather conditions also have a significant effect on storage potential, as does the manipulation of gas levels in store according to season. It is also important during the early stages of storage that temperatures are reduced according to established guidelines and that CA levels are accurately controlled to optimise quality. Gas levels outside the recommended guidelines will result in quality loss. Increasingly gas and temperatures levels are computer-controlled, with fruit samples from the store monitored at regular intervals.

The vast majority of commercial apple and pear growers would have some storage capacity, with one estimate suggesting that approximately 80% of commercial UK apples are placed in CA stores each year.

The average grower has 200+ tonnes of storage capacity, though there are several large storage complexes of 1000 tonnes or more.

When stores are not in use during the summer they can, on mixed fruit farms, be used for cooling and holding soft fruit. On top fruit farms they can be used for cooling and holding plums and cherries in July and August. Some fruit farms and some central cold storage facilities for POs will also store southern hemisphere apples during the late spring and early summer.

The likely cost for a new build for CA/cold store is of the order of £600/ tonne, with running costs of £1 to £1.25 per bin of approximately 300 kg of fruit. for the first month and 71p for subsequent months.

Unique features

- pear stores have to be capable of storing fruit at around freezing (-1^{O}C) but apples only as low as 3^{O}C for most varieties.
- some POs, e.g. Wye Fruit, do have some central stores but the majority is still stored on growers holdings.
- several large growers have built their own stores to high quality standards and store other growers' fruit as well as their own.

Plums

Typical storage period: Short-term, 2-3 days
Storage temperature: Varies with variety

Some growers store plums at 5-6^{O}C for up to 3 weeks to extend the season of a particular variety; on occasion longer storage using CA is utilised.

Cherries

Typical storage period: Short-term, 2-3 days but can be 2 – 3 weeks

There are virtually no dedicated plum and cherry stores, most growers utilising apple stores. Typically fruit would be put in store to remove field heat, graded and back stored to await distribution. This would be for short-term, perhaps only 24-48 hours depending on the market.

Tree storage

The majority of fruit trees are imported and are delivered direct to the customer, with only a small proportion of trees being held temporarily in cold storage.

Cold storage of UK-grown trees is very limited. The trees would be lifted in the late autumn and cold stored until late winter. However, wherever possible trees are lifted and sent directly to the customer.

Summary

- Storage is essential to delay ripening and to extend the marketing season of apples and pears beyond November.

- Increasingly top fruit is stored in CA conditions, even for short-term periods, as quality is maintained to a better standard

- The majority of growers store their own fruit rather than use centralised facilities.

Soft fruit storage

Growers supplying the supermarkets use cool chain marketing, as this helps preserve product quality by keeping the fruit at a temperature that will delay deterioration throughout distribution. Other factors essential in maintaining quality are:

- careful picking at the correct stage of ripeness
- packing to avoid bruising and mechanical damage
- careful handling and transport

Success therefore depends on a contractual close communication between grower/marketing agent and retailer so as to coordinate the supply of fruit with demand and on the provision of refrigerated transport to maintain the cool chain from farm to retail counter.

Cooling is not normally necessary for fruit for processing, which is either picked under-ripe, pulped or juiced. However the development of nitrogen freezing plants for the preservation of whole raspberries demands a supply of top quality fruit which may benefit from pre-cooling.

Strawberries, raspberries, black currants and other bush and cane fruits cannot be stored for any length of time unless frozen. However one or two growers are using CA conditions to extend the season of redcurrants by several weeks.

Strawberries and Raspberries

Typical storage period:	For every batch from 24 hours to 5 days for the marketing period May to October
Storage temperature:	Ideally raspberries require 2-3^{O}C and strawberries about 6^{O}C.
Relative humidity:	90-95%

For supermarket customers, growers cool and store these crops either by making use of existing apple cold stores or, for farms that only grow soft fruit, they have built specialist cold stores for this purpose. Most have one store to remove field heat and a second one to hold fruit at 2-6^{O}C prior to distribution. Often fruit is dispatched later

the same day or early the next day, within 24 hours of picking, but a significant proportion can be held for up to 5 days, as retailers require maximum supplies on Wednesday, Thursday and Friday; therefore fruit harvested over the weekend and on Monday and Tuesday is likely to be held in store longer. To maintain freshness and quality it is important that stocks are rotated in the store, though some buyers insist on only the very freshest fruit.

Some large-scale raspberry growers now have dedicated raspberry stores which are run at 2-3^{O}C.

Removal of field heat is paramount for every batch of fruit, which for strawberries is from April to October and for raspberries from June to October. In periods of extreme temperatures, field heat needs to be removed within 30 minutes; this may necessitate refrigerated lorry bodies being taken to the field.

Cooling may not be required by those selling direct (farm shop, farmers markets and some local sales), but experience shows that quality will be improved and shelf life prolonged with early field heat removal. As a result, many smaller growers and those with farm shops are now hiring portable cold stores or using refrigerated lorry bodies for field heat removal and short-term storage.

Fruit with a very short shelf life may be frozen for processing, e.g. for ‘smoothies’.

In general, there is insufficient cooling capacity in the industry as some growers use the same store for both raspberries and strawberries, despite raspberries requiring 2-3^{O}C and strawberries around 6^{O}C.

The cost of field heat removal and short term storage varies according to the season, with 20007 and 2008 being low cost years, due to the cool summer. Generally growers have limited knowledge of the costs as often electricity is not metered separately from other farm activities. A wide range of costs was quoted within the soft fruit sector; for farms producing both strawberries and raspberries had costs of between £11.50 and £86/tonne.

Strawberry runners and Raspberry canes

Propagators lift their strawberry plants and long cane raspberries in the late autumn/early winter after they have gone dormant. They are then stored at -1 to +1^{O}C until they are taken out of store from mid-January to mid-July, depending on the growing system of the individual customer.

Most UK propagators have limited storage capacity of their own and so rent cold storage for the majority of their needs. However, importers of strawberry runners tend to have specialist stores.

Summary

- Cooling soft fruit and keeping at a temperature sufficiently low to delay deterioration is now an essential part of marketing
- All those supplying the supermarkets use field heat removal, short-term storage and cool chain marketing
- Growers either use existing apple cold stores or, for farms that only grow soft fruit, purpose-built cold stores
- Most UK strawberry runner and raspberry cane propagators have limited storage capacity of their own and so rent cold storage for the majority of their needs.

Protected salad crop storage

The main protected edible crops grown/stored include tomatoes, cucumbers, lettuce, sweet peppers, plus “minor” crops such as celery, herbs, and aubergines.

Unless they are situated a long way from a central packhouse, most growers will rely on cold storage facilities at the packer/distribution centre, rather than having their own cooling facilities. In this case, produce is usually stored in a cool, dark shed until transport off the nursery can be arranged.

Those growers that have storage facilities use them for relatively short-term storage (usually maximum overnight), removing some of the field heat. These stores are usually refrigerated cold stores, with no additional features such as controlled atmosphere or humidification.

With glasshouse temperatures often reaching 25-30ºC when harvesting takes place, there is often a need to cool the produce while waiting for grading, or before despatch and delivery. Storage is usually for only 3-4 hrs. but occasionally overnight. Instead of a cold store, some growers may use a transport trailer for the chilling, with the trailer delivered the day before dispatch.

Cold stores may be used for leafy salads in all but the coldest months of the year. For fruiting vegetables such as tomatoes and cucumbers the stores may be idle for several months of the year, only being used from April to September in a typical season.

Tomatoes

Typical storage period:	24 hours but can be up to 1-2 weeks for the marketing period February to November
Storage temperature:	8-12ºC
Relative humidity:	90-95%

Glasshouse tomatoes are harvested from March to November and after harvesting they are chilled to take out field heat. Generally no other longer- term storage is used.

A typical storage capacity for a day's harvest on an average tomato nursery of 2 ha would be in the region of 15 tonnes.

Lettuce

Typical storage period:	Less than 2 days
Storage temperature:	0-1ºC
Relative humidity:	95-100%

Leafy salads grown under protection are marketed all year round and those harvested during periods of hot weather may benefit from vacuum cooling. However, as few growers will have these facilities on site they rely on a central packhouse or marketing group to vacuum cool produce before moving it into a cold store.

An additional use of cold stores on leafy salad nurseries/packhouses is for "holding" lettuce plants prior to planting (if delivered too early or crops are not being cut to clear planting areas). While chilling the plants for up to two days may be possible, the absence of light when trays are closely stacked quickly leads to loss of quality due to the plants becoming etiolated.

Cucumbers

Typical storage period:	Up to 1-2 weeks but usually less than 2 days for the marketing period February to November
Storage temperature:	8-11ºC
Relative humidity:	90-95%

A typical storage capacity for a day's harvest on an average cucumber nursery of 2 ha would be in the order of 15 tonnes.

Sweet pepper

Typical storage period:	Up to 1-3 weeks but usually less than 2 days for the marketing period March to November

Storage temperature:	7-10ºC
Relative humidity:	90-95%

Aubergine

Typical storage period:	Up to 1-2 weeks but usually less than 2 days for the marketing period June to October
Storage temperature:	8-12ºC
Relative humidity:	90-95%

Celery

Typical storage period:	Glasshouse celery is seldom stored for long periods during the marketing period of late June to early December though field heat removal will be required particularly in the summer months
Storage temperature:	0-1ºC
Relative humidity:	95-100%

In practice, storage times are usually less than 2 days for most crops, unless market requirements mean that crops are to be held for longer.

Summary

- Many growers do not have refrigerated stores, and those that do use them to remove field heat for short-term storage of 3-4 hours and occasionally overnight.

- Protected salad growers are more likely to use cooling facilities such as vacuum cooling and cold storage facilities of a packer/distribution centre, rather than have their own cooling facilities.

- Those protected salad growers most likely to have their own stores are tomato and cucumber producers, with a typical storage capacity of 15 tonnes for a 2 ha holding.

- Stores for tomatoes and cucumbers may not be in use from October to March.

Hardy nursery stock storage

Low temperature storage of hardy nursery stock provides growers with the opportunity to:

- Schedule production and even out labour profiles
- Manage and maintain plant quality
- Meet customer requirements and expectations
- Maximise sales
- Improve efficiency

It is a widely used technology, although its use is mainly limited to storing propagation material (seeds, cuttings, rootstock and transplants), holding finished plants and, to a lesser degree, inducing frost hardiness in some species. The type of storage used and the level of investment are dependent on the intended use, with field producers making the greatest investment in technology (ref. HDC project HNS 140).

Accurate scheduling is becoming increasingly important in the production of nursery stock in the UK. Low temperature storage can be used effectively by growers to 'store' material for short-medium periods to ensure continuity of supply and enable demand to be met during seasonal peaks. Many nurseries also face the problem of trying to find sufficient space for plants during the winter months. Low temperature storage provides another means of holding plants through the winter period in a 'controlled' environment.
The technique is perceived as being applicable to over 75% of businesses though currently fewer than 60% of UK growers use cold storage in their production systems.

Data from a HDC survey carried out in 2005/6 showed the following store types:

Purpose built - jacketed	31%
Purpose built - direct cooled	23%
Refrigerated unit/lorry body	23%
Rented	8%

For hardy nursery stock successful long-term cold storage requires

***a combination of low temperatures and high relative humidity. The recommended temperature for most nursery stock subjects is 0^{0}-2C, with a relative humidity approaching 100% in order to prevent drying out*.**

Maintaining the required temperature is relatively straightforward, providing the cold store is properly constructed and equipped. However, achieving high levels of relative humidity is more difficult and drying out rather than poor temperature control is the usual cause of damaged plants in a cold store.

The perceived high costs associated with cold storage facilities are usually the main reason why they are not adopted more widely by UK nursery stock growers, despite their many advantages. 40% of growers who participated in HNS 140 cited concerns over costs as the reason why they were not using cold storage. The same study also found that purchase (capital) costs varied considerably (£40,000 to £125,000), although the age of the facilities under discussion also varied markedly, making it more difficult to compare these accurately. General refrigerated cold stores such as converted lorry-backs used for cutting material are clearly much cheaper (typically, £1,700 to £4,000) but are usually quite small and so have limited capacity, particularly for larger grade nursery stock.

Participants in HNS 140 were generally unable to provide details on running costs, largely because the electricity supply to the cold store was not metered separately.

However, the average annual cost to build and run a cold store is in the order of £22/m^2, when spread over a ten year pay-back period, excluding the cost of any building that the store may be situated within. Over 50% of growers used self-contained stores such as converted lorry-backs, existing barns or new builds insulated to function as cold storage when required. Ultimately, the economics of using a cold store depend on how well the space is used and to what extent the technology can be harnessed to improve saleable yield.

Generally cold storage is more likely to be used from November to May. Often purpose-built stores will only be used for 6 months of the year, which has associated cost implications.

Summary

- Storage is an essential production tool and is widely used for production scheduling and maintaining plant quality.

- 57% of growers use cold storage in their production system though the technique is perceived as being applicable to over 75%. (2005/6 data).

- Cold storage most likely to be used from November to May.

- Of those not using cold storage, 60% thought it unnecessary for their production methods and the other 40% thought it too expensive for their scale of production.

Flowers, bulbs and bedding plants storage

Flowers and bulbs

Flower bulb storage capacity varies from holding to holding. Storage is either letter-box bin storage, in which the air is blown through the slats in the bottom of the box (bulbs occupy 1.5 m^2/tonne of floor space) or bulk on-floor positive drying storage (bulbs occupy 1.0 m^2/tonne of floor space). A few growers still use 'natural' tray drying systems.

All bulb and flower growers will have one or more stores. Some small-scale growers may use converted 'cold trailers' to condition flowers.

Use of store

Bulbs are either dried at ambient or at 30-35^oC for 2-5 days followed by storage at ambient and conditioning prior to retail sale or preparation for hot water treatment and replanting. Stores are in use for this 'out of ground phase' between mid-June and mid-end September. Onion and cereal growers will also use the same facilities where on-floor drying systems are installed; also potato growers where bulk bins and letter-box drying systems are used.

Stores are also used for flower conditioning i.e. removal of field heat and storage at 2-4^oC. For daffodils, flowers are stored short-term in the marketing period January to April, whereas some other flower crops e.g. lilies are grown AYR and hence stored briefly throughout the year. Spring to autumn outdoor cut flowers will also be cooled prior to despatch.

Storage costs for bulbs

Initial drying at 35^oC for 3 days using oil £15/tonne + electricity for fans to ensure positive air flow through bulbs after drying @ £3/tonne, giving a total of £18/tonne.

Bedding plants

Use of low temperature storage of bedding plant plugs to delay their growth and development has been employed for some time in the USA and is currently being undertaken by a small but increasing number of propagators in the UK. If space is a limiting factor during the production season, cold storage of bedding plant plugs can be used in the short-term (up to 7 days) to maintain quality in plugs destined directly for sale, or longer (up to 21 days) in the case of plugs being held prior to transplanting into the final unit. There can be a positive financial benefit from using cold storage for:

- scheduling crops and reducing wastage
- holding crops prior to transplanting
- substitution for glasshouse space
- use of the cold store for seed germination and dormant plant storage

Further detail may be found in the report for HDC project PC 196.

An average storage temperature 4^{o}C for most species is more appropriate than 8^{o}C. Air circulation within the store is a critical factor, with good air movement reducing the risk of high humidity and disease establishment. However, too much air movement can lead to the rapid desiccation of plugs.

HDC projects PC 196 and PC 196a examined the potential to store a range of summer and autumn bedding plant species. Most species could be stored for up to 7-14 days at 4^{o}C with minimum loss of quality. Several species including begonia, antirrhinum, lobelia, pansy and viola were stored for 3-4 weeks and were still usable as plugs.

Store types

Stores appropriate for this purpose can vary from a refurbished/modified refrigerated lorry body to some kind of purpose-built facility. Although the first is relatively inexpensive to buy or lease, the direct expansion cooling system used in it can have a severe drying effect on plant material in store. Purpose-built stores are more expensive to construct, but other types of cooling systems can be installed in them that produce environments more suited to the storage of plant material. Stores are often used for other purposes such as holding planting material or flowers or even potted bulbs.

Summary

- All bulb and flower growers will have some form of storage.
- Cold storage of bedding plant plugs is used by a small but increasing number of propagators

Example comparative costs of storage

To obtain example costs for field heat removal and/or short or long-term storage, growers and storage providers for each of the main crops considered in the report were consulted.

As detailed in the report the crops where long-term storage is practiced are winter white cabbage, carrots (and to a lesser extent parsnips, swedes and beetroot), bulb onions and apples and pears. Field heat removal is essential for soft fruit and for many vegetable crops. The results of enquiries made have been used to produce examples of the relative costs for field heat removal and storage, which are summarised below.

However, it must be emphasised that most growers are not able to isolate those costs directly related to storage. In many packhouses the electricity supply is common for stores, grading, general use, student accommodation and forklifts etc. Also permanent labour is common across all farm activities and not always costed for individual activities. Both electricity and labour are therefore regarded as a general farm overhead.

Also, on most farms, stores have been built and refurbished at different times during the development of the business, making it difficult to calculate capital costs. Book values exist, but can give a distorted picture when trying to make comparisons between sites.

The above findings indicate that significant practical hurdles would need to be overcome to isolate the costs of cooling and storage on farms. Also, in some instances, storage remains a grower cost, with the facilities on farm, and in other instances, refrigeration and storage are located elsewhere e.g. at the packers, with costs in effect being recharged to the grower (but not itemised), which is likely to lead to inconsistencies in assessing storage costs.

Estimated costs per tonne for the storage period

Storage description	Capital cost	Running cost	Storage cost £/month	Storage cost £/tonne for storage period	Notes
Winter white cabbage					
Cold			7-10	73-91*	Includes capital charge over 8 years. *higher figure for older less efficient stores
Carrots					
In field				50	For period November to February
Cold	58.50	30		88.50	For November to May Capital costs could be up to £200/tonne
Bulb onions					
Initial drying in ambient store			35-39	35-39	
Refrigerated storage			7.80-10.70	47-58	Cost depends on length of storage, bulk or box storage, locality and quality of store
Lettuce					
Vacuum cooling and short term				60	Includes labour
Spinach					
Vacuum cooling and short term				81	Includes labour
Apples and pears					
High specification cold storage on a large farm			17		£20 for first month/£17 subsequent months. Contract rate
High specification CA storage on a large farm			19		£21.50 for first month/£17 subsequent months. Contract rate
Large commercial complex				66	To end December
Large commercial complex				89	To end March
Farm Storage with average quality stores			14		£15.70 first month
Specialist Bramley farm				82.5-99	
Flower bulbs					
Flower bulbs				18	Includes initial drying
Strawberries					
Cooling and short term				22	Excludes labour
Raspberries					
Cooling and short term				86	Excluding labour
Strawberry & raspberry enterprise				11.50	Excluding labour