Session 3.3 Storage, chilling, freezing and ripening

Key learning points

- ❒ Storage
- ❒ Storage methods and structures
- ❒ Temperature, humidity and commodity considerations
- ❒ Basic pre-storage treatments
- ❒ Ethylene and compatibility groups
- ❒ Ripening and de-greening of fruits
- ❒ Cooling methods and freezing technologies
- ❒ Refrigeration temperature and humidity
- ❒ Design, construction and management of refrigerated stores

Main objectives of the session

By the end of the session participants will be better able to:

- ❒ Understand the strengths and weaknesses of storing fruit and vegetables
- ❒ Evaluate the alternative methods of storage
- ❒ Store products effectively
- ❒ Define the maximum storage life of different fruit and vegetables
- ❒ Design, construct and manage different storage structures
- ❒ Apply different post-storage treatments
- ❒ Understand the importance of temperature, humidity, ethylene and product compatibility groups in storing fresh fruit and vegetables
- ❒ Ripen and de-green fresh produce
- ❒ Select the most appropriate cooling methods and freezing technologies

3.3.1 Storage

The term "storage", as now applied to fresh produce, is almost automatically assumed to mean the holding of fresh fruit and vegetables under controlled conditions. Although this includes the large-scale storage of some major European crops, such as potatoes, to meet a regular continuous domestic demand and provide a degree of price stabilisation, it also meets the demands of providing year-round availability of various more exotic fruits and vegetables. Many horticultural crops are highly perishable and can only be stored for a few days but some produce may be stored for much longer periods The main reasons for storing products are primarily related to marketing i.e.:

- Because there is no immediate buyer
- Because transportation or some other essential facility is not available
- To extend the marketing period and so increase the volume of sales
- To wait for a price increase

In temperate countries the production of fruits and vegetables is largely confined to relatively short growing seasons and thus storage is important to enable sales of produce outside of the harvest season. With the modern greenhouse cultivation methods, as well as other improved technologies, the production season may be extended but storage is still often desirable to enable an extended supply for the consumer.

Storage adds to the cost of a product and the more elaborate the storage method, the higher the added cost. Short-term storage is used to provide flexibility in marketing but it is not usually worthwhile storing fresh produce if the price increase that results from the storage does not exceed the costs of storage. Storage will reduce quality and shelf life. It is costly and, in most instances, when the produce is withdrawn from storage it has to compete in the market against freshly arrived produce.

However pre-cooling and/or storage of fresh produce is sometimes a standard requirement for some markets and its cost is assumed as an accepted part of the production and marketing strategy. Provided that storage is accomplished successfully then the price increase resulting can often be forecast from previous seasons. The costs of storage of fresh produce are often difficult to assess precisely and must take into account:

- Operating costs - labour, utilities and administrative costs
- Fixed costs - the costs of financing and constructing the store discounted over a reasonable period, rent and overheads
- Financing - the cost of financing the crop while it is in store, whether it be by the party who has stored the product, or other parties on an interest basis. In either case, each day of storage adds cost to the product in addition to the direct storage costs

Occasionally it is acceptable simply to break-even on the cost/return ratio if this means that a greater volume of produce is sold overall or that the storage facility is being used more efficiently.

***TABLE:* Storage life and recommended storage conditions of crops suitable for long-term storage**

Crop	°C	Relative humidity (%)	Storage life (months)
Fruit			
Apple **+	0-4	90-95	2-6
Grapes**+	-1-0	90-95	1-4
Pears**+	0	90	2-5
Honeydew melon	9-13	85-90	1
Vegetables			
Cabbage**	0	95	1-3
Carrot	0	95	5-6
(topped)**+	0	95	1-3
Celery	0	65-70	6-7
Garlic+	0	95	1-3
Leek	0	65-70	6-8
Onion (dry)**+	0	90-95	2-6
Parsnip	0	90-95	4-5
Turnip	4-6	90-95	4-8
Potato+	13	65	6
Ginger+	10-13	50-75	2-5
Pumpkin			

** Dependant on cultivar and origin
+ Commonly held in long term storage

3.3.2 Storage methods and structures

There are various different forms of storage and choice mostly depends on its cost and the produce to be stored. However, other factors must also be taken into account. The maximum storage life of a harvested crop depends on its production history and its quality and maturity at harvest. The actual storage life that can be achieved in practice may be quite different and depends upon harvesting and handling procedures and the storage environment. Not all fresh produce can be simply stored and some produce may require specific post-harvest treatments such as "curing" or "waxing" prior to storage. The market structure or availability of product might also create constraints whereby stored produce competes at a disadvantage alongside freshly harvested produce. Consideration of each of these factors will depend largely on storage economics.

Ventilated stores. Before refrigeration, ventilated storage was the only means available for storage of fresh produce and today it is still widely used all over the world for a variety of crops. Ventilated storage is ambient air storage and makes use of controlled ventilation for cooling of the produce and maintaining lower temperatures. Ventilated stores in the right conditions with good management are extremely cost effective. They require much lower capital investment and operating costs than refrigerated storage and are perfectly adequate for crops and conditions where:

- Production is stored for local use
- Crops to be stored have a relatively long natural storage life
- Regular inspection is possible to remove spoiled crops
- There is a significant difference between day and night temperatures, for example at altitudes above 1000 metres and in most temperate latitudes
- The storage need is for relatively short periods

Ideally ventilated stores require cool night temperatures and the building should be protected from the suns heat by such techniques as shady trees, painting the building white and building double skinned walls. The building should be positioned to intercept the prevailing night time winds. When the ambient air temperature falls below that of the produce, normally at night, the air is allowed to flow through the stored produce by the opening of louvres. This process can be automated and fans can be used to increase air flow rates.

Incoming air assists in cooling and humidifying the store. This kind of store can be used for holding potatoes through the winter (three to nine months) providing they have been cured and treated with sprout suppressant. Onions and garlic can also be stored using the same techniques but with lower humidities. In onions there are great differences between varieties and production locations. Both crops will need to have been dried and cured in the field. Cabbages, carrots, pumpkins, apples and pears have all been successfully stored using this technique.

*Clamps***.** These are simple, inexpensive structures used to store root crops, particularly potatoes. The potatoes are placed on a bed of straw 1 to 3 m wide, but not more than 1.5 m wide in warm climates. A ventilating duct should be placed along the bottom. The piled potatoes are covered with about 20 cm of compacted straw that can subsequently be encased in soil and applied without compaction up to 30 cm deep. The clamp system can be modified for different climatic conditions. In warm climates extra straw casing may be used instead of soil in order to give added ventilation.

Other simple storage methods. Windbreaks are narrow, wire-mesh, basket-like structures about 1 m wide and 2 m high and of any convenient length, on a raised wooden base, and are used for short-term storage of dried onions in the field. The onions are covered on top with a 30 cm layer of straw, which is in turn held down by a polythene sheet fastened to the wire mesh. The windbreak is built at right angles to the prevailing wind to obtain maximum drying and ventilation. Onions can also be woven into plaits on twine and hung in a cool dry place, where they will keep for several months.

*Refrigerated storage***.** For large-scale commercial operations, refrigerated storage may be used in a cold-chain operation to carry regular consignments from production areas to urban markets and retailers. This can be a highly complex operation requiring specialist organisation and management. Cold storage can also be used for long-term storage of seasonal crops such as potatoes and onions. The storage life of some fruits, such as apples, can be extended by combining refrigeration with a controlled environment consisting of a mixture of oxygen and carbon dioxide. These are high cost operations that demand skilled and experienced management and careful planning.

Refrigerated storage is much emphasised in technical literature but extended shelf life can be achieved without investment in expensive equipment. In practice the quality of the produce and provision for humid, shady conditions are higher priorities.

Controlled atmosphere storage consists of placing a commodity is a gas-tight refrigerated chamber and allowing the natural respiration of the fruit to decrease the oxygen and increase the carbon dioxide content of the atmosphere in the chamber. Typically, for storage of apples the oxygen content is lowered to about 3% and carbon dioxide is allowed to increase to 1 to 5%. This atmosphere can extend the storage life of apples by several months and allows fresh apples to be marketed every month of the year. This technology requires sophisticated storage chambers and close supervision of the composition of the atmosphere.

A new technology is emerging that maintains reduced pressure in the refrigerated storage chamber by means of vacuum pumps. In this system produce is placed in a flowing stream of highly humidified air that is maintained at a reduced pressure and controlled temperature. Under these conditions, chemicals that are released by the commodity and that limit its storage life are flushed away. The storage life of certain fruits and vegetables can be extended substantially by this procedure.

Very often cold stores are located in urban areas because:

- Produce can be released immediately on to the market in response to high prices
- Facilities can also be used for other crops e.g. apples in the winter and other produce such as butter

3.3.3 Temperature, humidity and commodity considerations

The natural limits to the post-harvest life of all types of fresh produce are affected by biological and environmental conditions, including:

*Temperature***.** An increase in temperature causes an increase in the rate of natural breakdown of all produce as food reserves and water content become depleted. The cooling of produce will extend its life by slowing the rate of breakdown.

*Water loss***.** High temperature and injuries to produce can greatly increase the loss of water from stored produce beyond that unavoidably lost from natural causes. Maximum storage life can be achieved by storing only undamaged produce at the lowest temperature tolerable by the crop.

Mechanical damage. Damage caused during harvesting and subsequent handling increases the rate of deterioration of produce and renders it liable to attacks by decay organisms. Mechanical damage to root crops will cause heavy losses owing to bacterial decay and must be remedied by curing the roots or tubers before storage. Curing is a way of healing wounds prior to storage.

*Decay in storage***.** Decay of fresh produce during storage is mostly caused by infection due to mechanical injury. However fruit and vegetable can also be attacked by decay organisms that penetrate through natural opening or even through intact skin. These infections may be established during the growth of the plant in the field but lie dormant until after harvest and often only becoming visible during storage or ripening.

Much fresh produce (i.e. that which is most perishable) cannot be stored without cooling, but the possibilities for extending the storage life of even the most durable fresh produce under ambient conditions are limited, although lowering storage temperatures while maintaining high relative humidities and good air circulation will assist in preserving the life of fresh produce.

Low storage temperatures offer the additional advantage of greatly reduced water loss from the produce with reduced transpiration. High relative humidity slows down water loss and enhances storage life of the produce. Stores should ideally be maintained at the highest relative humidity (RH) that a crop can tolerate. Humidifiers of various types are generally available, and although 100% RH would totally prevent water loss, this can rarely be maintained because:

- Disease organisms often develop rapidly at 100% RH
- Condensation can easily be caused by slight temperature fluctuations at, or near, 100% RH and giving rise to increased spoilage,
- Ventilation with unsaturated air is often necessary to remove heat and volatile gases such as ethylene

It is important to retain adequate circulation of the air within a store *and* around the produce to ensure efficient cooling. However, over-rapid air movement can drastically increase water loss by the produce.

In summary, the choice of the correct storage technique is governed by:

- The type of produce, including the type and variety its temperature from harvest, its respiration rate and quality
- The storage temperature and humidity best suited to the produce for the intended storage life and not creating additional problems due to chill damage or unnecessary microbial spoilage
- Market requirements
- The economics of the whole operation

3.3.4 Basic pre-storage treatments

There are some basic pre-treatments which could be performed before storage and/or marketing of any fresh produce:

1. *Cleaning* - all stones, soil clods and plant debris must be removed before storage, particularly if the crop is to be stored in bulk. Stones damage the produce and soil and plant debris compacts and restricts ventilation. This leads to localised build-up of heat, but dirt may also contain spoilage pathogens. For some products such as for citrus, onion and garlic, larger pieces of debris may be removed by passing the produce over a graded griddle. Further cleaning is sometimes carried out with rotating dry brushes.

2. *Washing produce* with water is more common, and since many types of produce float, water makes a good transport system. Some highly perishable produce, notably fruits should not come into contact with water. Orange and mango, however may be soaked and rinsed sufficiently clean, but soft rotating brushes may also be used for high-priced market fruit. For some commodities, the risk of cross-contamination in

the washing tank is high (healthy produce may be infected by bad produce and assisted by the water), and it is often safer to wipe clean with a cloth (e.g. eggplant, sweet pepper). Produce may be allowed to dry naturally after washing, or dried artificially using air-blowers that are sometimes heated. Water used for washing should be changed at regular intervals before it becomes heavily contaminated with fungi and bacteria and spreads infection. In some cases the water used for washing is treated with chlorine or some other chemical in order to reduce the count of viable organisms.

3. *Grading and selecting* - Small, damaged, infected and over-mature produce must be removed. Very small produce loses water more rapidly leading to wilting in storage. Produce that has been bruised or cut loses water and is easily invaded by spoilage pathogens during storage. Infected produce deteriorates rapidly, heats up, and provides a source of infection for healthy produce. Over-mature produce has less resistance to disease and reduced storage potential. It may also produce ethylene gas that stimulates premature ripening and decay throughout the store.

4. *Field heat removal* - Regardless of the type of storage facility employed, it is important to remove the 'field heat' from the produce before bulking up the produce in a store. This field heat removal may be carried out by temporarily stacking the produce in a shaded, cool, ventilated area, or more usually by resorting to refrigeration techniques. Failure to remove field heat can result in rapid temperature rises and accumulation of high concentrations of carbon dioxide, to possibly damaging levels, once the produce in confined in the store.

5. *Waxing the surface* of horticultural products is a treatment used on a number of commodities including citrus fruits, apples, peppers and cucumbers. It retards the rate of moisture loss, and maintains rigidity and plumpness and may modify the internal atmosphere of the commodity. It is performed primarily for its cosmetic effect; the wax imparts a gloss to the skin and gives the produce a more shiny appearance than the unwaxed commodity. However, problems might arise if unregistered wax formulations are used and the skin is eaten by humans or fed to animals.

6. *Drying* is the lowest cost preservation technology it should develop as a major method of preservation of horticultural products. A great deal of drying can be accomplished by means of solar energy or simple drying systems can be established as small-scale units.

7. *Chemical* companies continue to search for new chemicals to control the pests and diseases that attach crops and products. Post-harvest chemicals are classified into groups that include:

   - Fungicides that prevent or delay the appearance of moulds on the product.
   - Chemicals that delay or hasten ripening or decay.
   - Growth retardants that inhibit sprouting and growth.
   - Chemicals to give increased fruit firmness, better colour and early maturation
   - Inhibitors that block certain biochemical reactions

- Chemicals to remove ethylene (usually placed in close proximity to the commodity and leaving no residue)
- Fumigants to control insects

8. *Irradiation* of horticultural products kills infesting insects and allows products to be shipped into areas that have a product quarantine restrictions and to protect against certain insects. It also delays sprouting of bulbs and tubers, permitting long-term storage of commodities such as onions and potatoes without sprouting. However this technology is rarely used.

9. *Vapour heat treatment* may be used where other fumigants may damage the produce. This treatment comprises of circulating saturated water vapour at high temperature around the produce in an enclosed store until the produce reaches the required temperature, usually in about eight hours, and the produce is then held at that temperature for a further six hours. Most fruits such as avocado, lemon and most vegetables are injured by this treatment, but other kinds of citrus can be treated with vapour heat without serious injury. However the method is not in widespread use on account of its cost and impracticality.

10. *Genetic control of shelf life*. Each variety of a horticultural crop has a limited storage life even under optimum storage conditions. Storage life is partly related to genetics and can be manipulated by breeding. Horticultural products have a wide range of storage life and this is a high priority consideration for plant breeders and for growers considering which variety to plant.

3.3.5 Ethylene and compatibility groups

Ethylene gas is produced in most plant tissues and is known to be an important factor in starting the ripening of fruits. Ethylene is important in fresh produce marketing because it can be used commercially for the artificial ripening of fruits. This has made it possible for these fruits to be harvested green and shipped to distant markets and where they can be ripened under controlled conditions.

However natural ethylene production by fruit can cause problems in storage facilities. Ethylene destroys the green colour of plants, so lettuce and other vegetables marketed in the mature green but unripe state will be damaged if put into storage with ripening fruit. Ethylene production is increased when fruits are injured or attacked by moulds causing decay. This can stimulate the ripening process and result in early ripening of fruit during transport. All produce needs to be handled with care to avoid injuries leading to decay. Damaged or decaying produce should not be stored

A further problem arising from ethylene is due to mixed loads of fruit and vegetables. This can cause the cross product absorption of flavours. Fresh fruit and vegetables can be divided into three groups in terms of ethylene effects:

- Those that produce ethylene, such as, apricots, peaches, quince, pears, plums, apples, melons and tomatoes

- Those sensitive to ethylene, such as, apricots, quince, pears, peaches, plums, apples, peas, cabbage, green onions, carrots, parsley, lettuce, spinach, oranges, peppers, water melon, marrows, lemons, cucumber, celery and tomatoes
- Those which do not produce significant amounts of ethylene and are not affected adversely by exposure to it, such as, grapes, cherries, strawberries, barberry, raspberry, nuts, radishes, gooseberries, dill, corn, beet, cauliflower, onions, garlic, pomegranates, tangerines, chilli peppers, green kidney beans, pumpkins and potatoes

During the transport of mixed product loads, ethylene gas generated by some products begins to effect ethylene sensitive fruit and vegetables and the concentration needed is often exceedingly low. Some products are particularly sensitive to ethylene, such as lettuces, shown by browning of leaf edges and cucumbers and celery (permanent yellowing). Other products absorb the smells of others. For example, citrus fruits in particular absorb strong smells of other products and the smell of onion is absorbed by apples, pears and citrus.

If products in mixed loads are not compatible this can cause losses in quality and therefore a reduction in the sales price and lower profits. To prevent, or reduce the effects of ethylene the transport trailer should be well ventilated (or doors regularly opened) and compatibility groups have to be considered. Ideally the transport trailer should be vented but care must be taken in the positioning of vent holes as vehicle and refrigeration exhaust gases also contain ethylene. Good air circulation within refrigerated sections is also important so as to reduce the build up of ethylene in stagnant air pockets.

Having the right temperature and compatibility of products can be extremely important when unexpected delays occur. Choosing the correct grouping of products is determined by determining which are the most expensive. Results may also be different, depending on the initial quality of the products, type, conditions of loading, transportation means, the way products are treated and other factors.

Compatibility groups as shown below constitute the optimal groupings for products for transport periods of between 2-10 days. In inappropriate conditions some products may last for even less than 2 days.

***TABLE:* Compatibility groups**

Group A	Group B
Apricots, Raspberry (B), Quince, Nuts, Grapes (B), Peaches, Cherry (B), Radish (B), Pears (G), Plums, Strawberries (B), Gooseberries (B), Barberry (B), Apples Products not sensitive to cold	Peas, Parsley, Dill, Radishes (A), Cabbage, Lettuce, Corn (A), Beet (A), Green onions, Spinach, Carrots, Cauliflower, Diced Vegetables (A) Products not sensitive to cold
Group C	**Group D**
Onions Garlic Products not sensitive to cold but cooling with ice is not acceptable. Avoid increased humidity	Pomegranates (A,B,E) Tangerine Sensitive to cold
Group E	**Group F**
Oranges (A,B), Chilli peppers (D,F), Potatoes (F,G,H), Green kidney beans (D,F), Peppers (D,F) Sensitive to cold	Water Melons (E,H), Lemons (E), Melons, Cucumbers, Marrow (D,E), Pumpkins (G,H) Sensitive to cold
Group G	**Group H**
Early potatoes (H) Green tomatoes Half ripened tomatoes (E) Sensitive to cold	Egg potatoes (F) Sensitive to cold.

3.3.6 Ripening and de-greening of fruits

Fleshy fruits undergo a natural stage of development known as ripening. This occurs when the fruit has ceased growing and is said to be mature. Ripeness is followed by ageing and breakdown of the fruit. These fruits include those used as vegetables or salads, such as aubergine, sweet pepper and tomato.

Ripening of fruits is a perfectly natural and highly desirable phenomenon leading to increased sweetness, flavour development and softening of the edible tissue. However, ripening of certain fruits presents a dilemma to the export industry because the very act of ripening clearly marks the onset of ageing rapidly leading to decay and spoilage. Fruits that ripen off the tree, such as, banana, avocado and mango are harvested and shipped for export in the green state while still hard and capable of surviving the physical handling with minimum damage and spoilage during transit.

There are two characteristic types of fruit ripening that show different patterns of respiration:

- *Non-climacteric* fruit ripening refers to those fruits that ripen only while still attached to the parent plant. Their eating quality suffers if they are harvested before they are fully ripe because their sugar and acid content does not increase further. Respiration rate slows gradually during growth and after harvest. Maturation and ripening are a gradual process. Examples are, cherry, cucumber, grape, lemon and pineapple.

- *Climacteric* fruit ripening refers to fruits that can be harvested when mature but before ripening has begun, thus enabling transport and distribution to be carefully planned. Citrus fruit even remain green after becoming fully ripe on the tree. These fruits may be further ripened naturally or artificially. The start of ripening is accompanied by a rapid rise in respiration rate. After the climacteric, the respiration slows down as the fruit ripens and develops good eating quality. Examples are, apple, banana, melon, papaya and tomato.

After harvesting climacteric fruits will remain green, partly green, or will reach full colouration depending on various environmental factors but especially night-time temperatures. In warmer climates ripening can be achieved by simply harvesting fuller fruits and waiting for them to ripen at ambient temperatures. Regardless of colour, most local markets will recognise that the fruits are perfectly good to eat and consumers worry more about fullness of flavour, juiciness and sweetness than the appearance of the fruits.

However export markets demand full-coloured fruits and so a de-greening process is normally necessary. De-greening is the process where the green chlorophyll pigments in the peel are broken down and yellow and orange pigments are formed. In citrus, this natural process is stimulated by exposing the fruits to 10 to 20 parts per million (ppm) of (manufactured) ethylene gas under controlled conditions of temperature, humidity and ventilation and in special de-greening rooms operated by skilled management. De-greening is generally considered uneconomic unless large quantities of fruit can be treated at one time and high value export or domestic markets can be exploited.

Occasionally, some traders and growers may also trigger ripening in the same way as with ethylene but by using acetylene generated from small quantities of calcium carbide and water in an enclosed room. This practice tends to produce fruit that is overly soft in appearance and has a short market life. Acetylene also has explosive properties.

3.3 .7 Cooling methods and freezing technologies

Cooling horticultural produce extends its storage life by reducing the rate of physiological change and retarding the growth of spoilage fungi and bacteria. Cooling is the basis for maintaining quality fresh produce**.**

There are several ways of reducing the storage temperature of horticultural crops, including:

1. Keeping produce out of the direct rays of sun. This is an easy low-cost method with minimal effect on the environment

2. Using natural cooling, e.g., by harvesting during the cool early morning hours, opening stores for ventilation during the cool of the night or utilizing the cool temperature of high altitudes or natural sources of cold water when available

3. Using evaporative cooling by drawing dry air over a moist surface. This techniques is often restricted to areas of low humidity and low-cost water

4. Using mechanical refrigeration. Energy costs and overall economic costs are relatively high but the technique does give the best control of temperature

5. Cooling promptly after harvest

Since every degree reduction from the ambient temperature increases storage life all cooling is beneficial even if it is not optimum cooling. Simple low-cost cooling or refreshing the product is better than no cooling at all.

The optimum storage temperature for most temperate horticultural crops is close to 0°C. If they are cooled slightly below this temperature they freeze and suffer from "freezing injury" and spoil quickly. Most tropical horticulture crops however can be injured often at temperatures above freezing point and causes rapid deterioration in quality.

Once produce is placed in a cold store it will radiate heat from field heat and by respiration. The sooner the produce is brought to its optimum storage temperature then the sooner will respiration be brought under control and the maximum storage life of the produce will be realised.

The time it takes for the produce to reach the optimum storage temperature will be limited by the overall refrigeration capacity of the equipment and the speed of the air passing over the evaporator and over the produce. This is assuming that there are no barriers to air circulation around the produce.

Rapid air movement over produce enhances water loss and so in most refrigerated stores for long-term storage, air circulation is moderated to keep water loss to a minimum over the storage period. Produce temperature reduction under these conditions will be slow and so the rate of respiration will only be slowly reduced.

To overcome these problems various pre-cooling methods have been devised for the rapid cooling of produce prior to its placement into long-term cool storage.

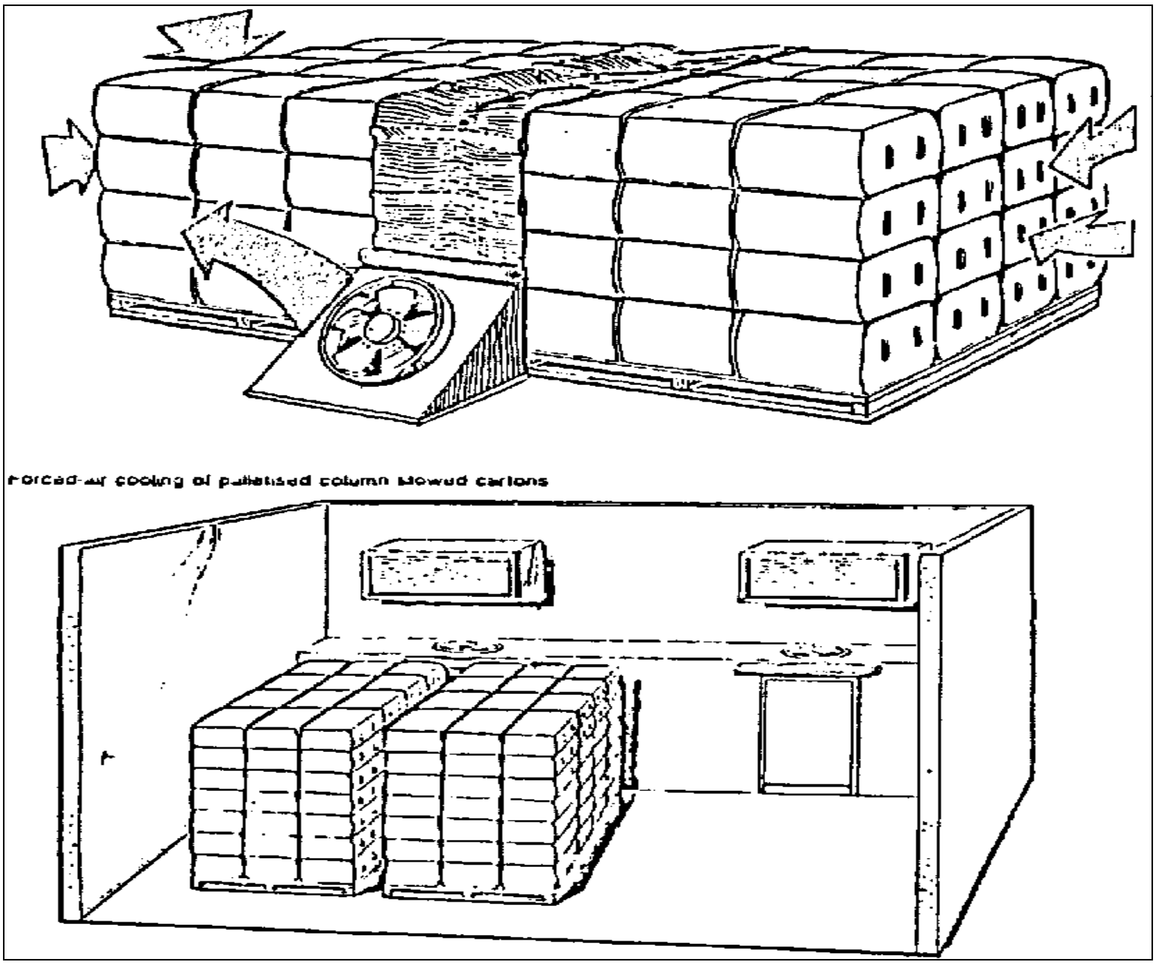
1. *Forced draught cooling* produce is stacked with a high refrigeration capacity. A sheet of canvas or other material is placed over the stacked produce and a powerful electric fan sucks cold air rapidly from the room through the packed produce. See figure below.

Although the rapid air movement creates more water loss from the produce, cooling is much more rapid than otherwise and the respiration rate is reduced very quickly. As soon as the produce has been cooled down to close to the optimum storage temperature it can be transferred to an ordinary cold store for the rest of its storage life. There are many different types of forced draught cooling and most depend upon the produce being in appropriate containers (normally often fibreboard cartons). Ships and containers adapted specifically for the refrigeration and carriage of fresh produce use a variation of this system.

Forced draught cooling has the advantages of being a relatively cheap pre-cooling method which is easily operated and maintained and is widely used for many different kinds of produce. Heat transfer from produce to air is less efficient than that from produce to water, but many fruits, especially soft fruits, and some vegetables will spoil rapidly in store following water contact.

2. *Hydro-cooling* - Water is an excellent medium for transferring heat from produce to a cooling source. With hydro-cooling, ice generated by a refrigeration plant is melted and the cold water is allowed to collect in a water bath in which either the produce is dipped, or serves as a reservoir for spray or cascade application to the produce. Alternatively, evaporator coils of a refrigeration plant directly cool the water to the required temperature and the produce is dipped or sprayed as before.

Figure: **Forced draught cooling of fresh produce**



(Source: Production in only half the battle: A training module for marketing of fresh produce, S. Harris, FAO, 1998)

The efficiency of the cooling technique depends upon rapid movement of the cold water over the produce. The rate of cooling is dependent on the surface to volume ratio of the produce. Hydro-cooling is only suitable for fruits that can withstand the excess of water but is widely used for rapid cooling of many vegetables.

3. *Vacuum cooling* - This method depends upon the fact that water absorbs heat as it evaporates and that evaporation (and hence cooling) is very rapid in a vacuum. In essence the produce is packed, stacked on pallets and placed in a special airtight chamber. Powerful pumps exert a strong vacuum on the chamber. Surface water on the produce, as well as some of the produces own water content, rapidly evaporates and directly cools the produce. The amount of water lost from the produce is not sufficient to impair quality and storage life.

Vacuum cooling is only of benefit for produce with a high surface area to volume ratio, such as cabbage, lettuce, celery and other leafy vegetables that allow for evaporation and can be cooled in about 20 minutes.

Full-scale vacuum cooling plants are expensive to install, but portable units are available and these can be powered by a farm tractor. In recent years a system known as 'Hydrovac' cooling has been introduced This is identical to ordinary vacuum cooling but water is added in a controlled manner before cooling commences. In this way water loss from the produce is restricted. The technique has been shown to be of benefit for some crops and allows longer treatment time and more intense cooling.

4. Ice-bank cooling - This is a relatively recent development in which heat is removed by melting a large block of ice which has been built up over a period of days by a small refrigeration unit. The heat is removed from air in the store by passing it through sprays of ice-cold melt water in a chamber separate from the store. In this way cool air of very high relative humidity can rapidly cool the store and the produce within. Units down to five tonne capacity are now available.

Once the produce has been cooled down to the required temperature it should be transferred as rapidly as possible to a store designed specifically for long-term storage. Occasionally this is the same store used for pre-cooling but normally it is an adjacent and often much larger storeroom.

For long-term storage it is important that the room air is well circulated but at a low velocity so that transpiration and water loss from the produce is kept to a minimum. Temperature of the store, and hence the produce within it, has to be carefully monitored and maintained and the humidity should be carefully checked and increased if necessary. Some form of ventilation is vital to prevent accumulation of carbon dioxide and ethylene gases or the depletion of oxygen to harmful levels.

Produce should be stacked so as not to hinder circulation and thus permit the creation of localised "hot-spots" and so create premature spoilage. Packed produce should not be stacked against the sidewalls nor directly against the evaporators. Stacking produce in regularly spaced 'corridors' will permit inspection of the produce at intervals during storage and hence removal and if necessary of infected, over-ripe or otherwise spoiled produce.

3.3.8 Refrigeration temperature and humidity

In recent years an integrated cool chain system from producer to consumer has developed across western Europe and many buyers require this facility from all their suppliers. Indeed few food products can be transported successfully over long distances or time periods without refrigeration or chilling. For a number of years refrigerated vehicles have been designed to carry frozen or stable chilled products. An envelope of cold air circulates around a solid stow of frozen cargo to offset heat entry through the container walls. However the same principle cannot be applied to carrying fresh fruit and vegetables.

Various fresh fruits and vegetables have to be stored and transported at different temperatures. For example grapes should ideally be kept at 0-1C, citrus 4-8C, depending on the type, apples at 0C and lines like melons and mangoes at between 8-10C. Pomegranates, tangerines, oranges, chilli peppers, potatoes, green kidney beans, peppers, water melons, lemons, melons, cucumbers, marrows, pumpkins, early potatoes, green tomatoes, half ripened tomatoes and egg potatoes are particularly sensitive to cold.

The moisture content of most fruit and vegetables varies between 80-95% of the total weight, although some products may have considerably lower moisture content, down to about 10%, such as garlic or nuts. To reduce the loss of water one can increase the relative humidity of the air. A humidity of 90% is optimal for preserving fresh fruit, while 98-100% humidity is good form leafy vegetables and some root vegetables. For products sensitive to fungal attacks, such as onions, humidity levels of 65-70% are recommended.

It is important to regulate properly the movement of air around fruit and vegetable products so as to obtain the right circulation for preventing excess temperatures and to allow humidity levels that will reduce transpiration. Refrigeration and air circulation requirements within vehicles carrying all types of fresh fruit and vegetables are more critical than for any other chilled or frozen product because not only is heat entering the vehicle from outside, heat is also generated by the product itself. Therefore the block stowing of pre-cooled high respiration rate produce is potentially disastrous.

Ideally fresh packed product will require pre cooling but even when thoroughly pre-cooled, high respiration rate produce still produces enough heat at low temperatures to cause self heating unless there is some interchange between the in-package air and the outside cold air. Air circulation is necessary *around* the load to remove transmission heat and *through* the load to remove respiratory heat. If refrigerated air cannot circulate through the load, the additional cost of using refrigerated transport cannot be justified.

Fresh fruit and vegetables contained in packages often have to content with two distinct environments - the one inside the package and the one outside. Controlling the environment outside the package does not necessarily control the environment inside the package. Failure to recognise this creates some of the problems of post harvest handling of fresh produce.

Fresh produce is often contained in corrugated fibreboard packages. The fibreboard itself is a poor conductor of heat. The corrugations trap many thin air layers between the inner and outer walls, one of the requirements for good insulation. This insulation lies between the in-package environment and the outside environment offering an effective barrier to heat transfer. When the produce itself is rapidly generating heat and giving off water vapour, this barrier can spell disaster.

What can happen when such a package is placed in a cold air environment? If the rate of heat production exceeds the rate of heat transfer, the product will get hotter not colder, a distinct possibility with high respiration rate crops. If the walls of the package become colder than the air inside the package, moisture given off by the produce can condense on t he inside of the package walls. Weakening walls, made of fibreboard and resulting in a collapsed carton.

These potential problems are real hazards when warm produce is loaded into a refrigerated transport container. All too often produce is block stowed into a transport van with little or no chance for interchange between the in-package environment and the cold air within the van. Even if interchange was possible, the refrigeration capacity of a typical refrigerated transport vehicle is far too small to cool produce in a reasonable time.

Provided the air temperature is adequate and the product is pre-cooled to the desired transport temperature, then temperature can be maintained by modern refrigerated transport. Humidity on the other hand is not usually controlled and transport operators are at the mercy of the inherent equilibrium humidity maintained by the refrigeration plant.

Refrigerated vehicles designed primarily for frozen produce maintain humidity too low for fresh fruit and vegetables, and the air temperature off the evaporator is usually too low and this frequently causes produce freezing on the top of the load.

An agreement on "the international carriage of perishable foodstuffs and on the special equipment to be used for such carriage" called the ATP agreement, is part of EU law. The objectives are to facilitate the international carriage of perishable foodstuffs, to raise standards and improve competition between operators and to promote public health by protecting perishable foodstuffs from deterioration To achieve these aims the ATP agreement lays down technical standards for the thermal efficiency of vehicles and containers and sets down the methods by which equipment can be tested and approved.

The agreement applies to insulated, refrigerated and heated road and rail transport used for the international carriage of certain foodstuffs and for such carriage by sea where the sea journey is less than 150 kms. Affected equipment must undergo an individual test or a type approval test at an approved testing station.

Humidity measurement in stores or of ambient air can be made either electronically or by the wet and dry bulb thermometer principle. Static wet and dry bulb thermometers are far too slow in measuring humidity but in the form of a whirling hygrometer or sling psychrometer are very reliable, cheap and rapid methods for humidity measurements. Whirling hygrometers come in several designs and types and the choice should be based on price and durability for field use.

Air temperature measurement can often be reliably measured using an accurate mercury thermometer such as the dry bulb thermometer in a whirling hygrometer, or a static maximum/minimum thermometer of the 'Taylor' type which is usually only seen in a Stephenson Screen.

Max/Min thermometers are also very useful in registering the extremes of air temperature experienced in a store and will thus give a good indication of when things go wrong with refrigeration. Many different suppliers exist.

Measurement of produce temperature is actually far more crucial when storing, ripening, or distributing produce and requires insertion of a reinforced glass pulp thermometer or a thermister type metal probe linked to an electronic metering device.

For nearly all purposes, the electronic type with a solid chisel-type thermister probe are preferred, and can usually be obtained relatively cheaply.

3.3.9 Design, construction and management of refrigerated stores

The popularity of refrigerated storage in some countries has suffered setbacks due to the occasional poor design of units or bad management. This has sometimes resulted in the impression that refrigerated storage is costly and unsuited for use. This is not necessary the case. Good design and proper management are essential ingredients in considering the introduction of refrigeration as are the supporting infrastructures available within the post-harvest system.

There are four basic principles that must be correctly applied for successful refrigeration of perishable crops:

1. Select only healthy products. Refrigeration does not destroy pathogens responsible for product deterioration but only slows their activity. It does not improve product quality but only maintains it.

2. Timely cooling: Since refrigeration slows the development of micro-organisms and the physiological changes responsible for deterioration of perishable crops, it is obvious that cooling should be applied as soon as possible after harvest. The technique of pre-cooling was developed to fill this need by cooling produce soon after harvesting down to a temperature appropriate to that product.

3. Uninterrupted cooling: Refrigeration should be applied from the point of harvest through to the point of consumption and where maximum post-harvest life with high product quality is justified. This is the "cold chain".

Refrigerated stores are important components of the marketing process for fresh fruits and vegetables. They also demand careful planning in their design, construction, management and day-to-day operation if the substantial capital invested in them is to be protected and if they are to serve their function in marketing.

When designing and constructing a cold store it is important to determine both the requirements of the cold store and the prevailing environmental conditions. The products to be stored, their types, quantities and periods of production also have to be weighed against the storage conditions demanded by the produce and the market place. Inherent factors, such as the availability of labour and its skills and experiences also have to be considered.

The size of the store will be determined by economic and technical factors. Small rooms are more expensive per unit volume for building and operation than large ones, but stock control and management of large cold stores is more complex and difficult. The volume of the cold store will depend upon the stacking patterns necessary for air circulation and heat dissipation, and the height of the rooms will depend on the handling and stacking methods to be used, 2.5 to 3 meters for manual handling, and 6 or even 9 meters if mechanical handling and pallet boxes are used.

Once all the above factors are accounted for then calculation of the refrigeration load can be made and hence the required refrigeration capacity and room insulation determined. These calculations are based on assessment of:

- The heat gain/loss through the walls
- The heat gain/loss by air removal and replacement
- The heat of respiration of the products
- The rate of refrigeration/removal of field heat;
- The heat gain from electric fans, lights, labour, etc.

Finally, the type of refrigeration machinery, with a power rating sufficient for all refrigeration needs plus a safety margin, can be selected. The usual frigorific power for long-term cold storage, as opposed to pre-cooling, of fruit and vegetables is of the order of 30 to 50 watts per cubic metre.

The elements of refrigeration capacity and insulation of the storeroom can have considerable bearing on its construction and operating costs. Specialists will have to be consulted It is recommended that an expert in refrigeration of fruits and vegetables before investment in such facilities begins.

Good management of cold stores needs knowledge and experience of:

- The storage conditions of the commodities
- Directions for loading of the rooms and maintaining a clean and hygienic state
- Management, control and maintenance of refrigeration equipment
- Staff training in store operation

The loading of a room should be as rapid as possible if there is no pre-cooling process but should be monitored carefully so as not to over-load the refrigeration plant, otherwise the cooling of the produce will take much longer and lead to reduced storage life.

The stacking of produce must allow for quick removal of some products, and especially with mixed commodity storage, and also not impede air circulation. Opening of doors is an important heat leakage point and must be controlled by disciplined management. If doors need to be be kept open for extended periods, doorways can be fitted with a curtain of wide transparent plastic strips to prevent excessive heat leakage. Storerooms need regular disinfecting to prevent contamination and spoilage of healthy produce and this needs to be properly supervised.

When loaded, the store room temperature must be checked daily and the thermostat regularly examined to ensure that it has not been tampered with. Recording thermometers should be used in large commercial cold stores. The relative humidity of the storeroom should also be checked regularly to prevent undue water loss by the produce. Evaporator coils should be checked daily for icing and defrosted when necessary. Maintenance and repair of refrigeration equipment should be carried out by specialised and well-trained technicians.

One of the most important aspects of store management is the careful and accurate keeping of records. Records of produce type and volume, daily temperatures and humidities, produce losses during storage and when they were first observed and removed, are all essential historical documents assisting in overall store management and auditing of operating costs and profits, but they are also frequently the first indicators of faults and trouble.

TABLE: **Generalised storage advice for fresh produce**

Advice	Reason
Harvest produce at the proper maturity stage	Immature produce has thinner skin resulting in faster evaporation
Keep produce in shade	Water losses are four times quicker in sunlight
Store only crops which are clean	Diseased products may infect sound crops. Damaged produce is easily infected and loses water. Dirt is a source of disease
Remove leaves attached to fruit and root crops	Leaves lose water rapidly
Apply approved sprout suppressant to potatoes, onions, garlic and ginger	Helps reduce sprouting during storage
Wash fruit in chlorinated water (200 ppm), fungicide for about half a minute, rinse and dry	Controls fungus disease
A thin coating of petroleum jelly will reduce shrivelling	Water loss is reduced
Line baskets with paper or leaves, and containers with polythene film with some ventilation holes	All act as barriers to high moisture loss
Store as soon as possible	The quicker produce is cooled, the slower the water evaporates and microbial action is reduced
Storage rooms and containers should be clean	Reduces the chance of infection from the previous crop
Allow air circulation	Removes heat and ethylene given off by produce
Separate ripe from unripe fruit	Ripening gives off ethylene which hastens the healing of wounds
Avoid mixing produce in the same storeroom	Odours and gases given off can damage other crops
Store leafy vegetable at a high relative humidity	Dry air rapidly draws water out of leaves
Cool moist conditions can be created by dripping water through jute sacks which serve as the wall covering of the cooler	The latent heat of evaporation cools the air. The high humidities lessen water loss

Keep root crops in moist and slightly warm environments for 10 days before storage	This is called curing and hastens the healing of wounds
Bulb crops should be dried or cured until the neck is tight and the outer scales rustle	Diseases, particularly neck rot, are controlled and moisture loss is reduced
Store roots and bulbs in drier atmosphere than other produce	Root crops sprout easily under moist conditions
Store temperate crops at below 10C	
Use containers which can withstand stacking	Optimises the volume of the store without injuring produce
Maintain high humidities in cold stores by preventing entry of warm air through using plastic strip curtains, keeping doors closed and wetting floors	High humidities for most crops reduce shrinkage and weight loss
Do not store onions in sacks piled to more than six high	To minimise compression damage
Keep potatoes stored in the dark	In sunlight they become green and poisonous
Small produce grown without irrigation tends to store best	Small cell size and high solid matter content restrict water loss
Clean, moist sawdust can be used to store fruit like tomatoes	High humidities are maintained. Sawdust should be dried before re-use

CASE STUDY

Agrinova

Agrinova is a company with the aim of "linking up all the separate parts of the supply chain and providing a central data management resource". The company believe that the fresh fruit and vegetable industry does not need a separate on-line system for every trader and aim to develop a central information database for the industry.

The system is under development but is already working well in the fishing industry where the information available has been consolidated. Fish volumes are captured by satellite from the boats, ports are linked and commercial transactions electronically recorded. In Iceland more than 25 ports are connected on a joint database from which fish auctions are carried out by buyers sitting in their own offices.

Agrinova are aiming to use this experience to bring together shared information from fruit and vegetable traders. The company also believe that no one today simply trades fresh produce but what customers are increasingly demanding is an assured supply chain online. Each retailer nowadays has a minimal number of approved suppliers whom they know well and an information system should aim to allow exchange of information between them so growers know when to plant a crop and of which variety and volumes and the specifications and protocols they need to follow.

The logistical exercise of bringing a product of the right quality to the consumer requires a lot of information to change hands. Every member of the chain has information and exchanges by word of mouth or on paper are not efficient. The Agrinova vision is to bring these people together on a standard Internet based system that will allow exchange of information and traceability by capturing data locally and storing it centrally and so improving the overall efficiency of the distribution system secured by password security systems.