Chapter 2
Factors Affecting Postharvest Quality of Fresh Fruits

Introduction

From many studies and field observations over the past 40 years, it has been reported that 40–50 % of horticultural crops produced in developing countries are lost before they can be consumed, mainly because of high rates of bruising, water loss, and subsequent decay during postharvest handling (Kitinoja 2002; Ray and Ravi 2005). Nutritional loss (loss of vitamins, antioxidant, and health-promoting substances) or decreased market value is another important loss that occurs in fresh produce. Quality of fresh produce is governed by many factors. The combined effect of all decides the rate of deterioration and spoilage (Siddiqui et al. 2015; Barman et al. 2015; Nayyer et al. 2015). These factors, if not controlled properly, lead to postharvest losses on large scale. According to Kader (2002), approximately one third of all fresh fruits and vegetables are lost before it reaches to the consumers. Another estimate suggests that about 30–40 % of total fruits and vegetables production is lost in between harvest and final consumption (Salami et al. 2010). Quality deterioration starts as soon as it is harvested and continued till consumed or finally spoiled if not consumed or preserved. The success or failure of any business plan related to fresh produce is totally dependent on the management of factors affecting the quality. This is obvious because fresh fruits and vegetables are living in nature, complete remaining life cycle after harvest, and then naturally spoil. This character puts fresh fruits and vegetables in the category of highly perishable commodities. Developed countries are in a very good position as they have developed good systems of postharvest management and infrastructure for quality maintenance. At the same time, developing countries are far behind in the same business, i.e., lacking in good postharvest practices and supporting infrastructure for quality maintenance. The outcome of this lacuna is considerably very high in developing countries. This is one of the reasons that postharvest losses in fresh fruits and vegetables are estimated about 5–35 % in developed countries and 20–50 % in developing countries (Kader 2002). In another report, it is reported that

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40–50 % of horticultural crops produced in developing countries are lost before they can be consumed, mainly because of high rates of bruising, water loss, and subsequent decay during postharvest handling (Kitinoja 2002; Ray and Ravi 2005). In both fruits and vegetables, many more additional changes take place after harvesting. Changes are noticed more in climacteric fruits and vegetables than non-climacteric. Some changes are desirable from consumer point of view, but most of them are undesirable. Development of sweetness, color, and flavor are best examples of desirable changes. These desirable changes persist for few days only. This is the stage liked by almost all consumers. At the same time, shelf life decreases and many undesirable changes take place such as water loss, shrinkage, shriveling, cell wall degradation, softening, physiological disorder, overripening, disease attack, rotting, and many more. All these changes, if not governed, ultimately affect the quality. These changes in fresh produce cannot be stopped, but these can be slowed down within certain limits if factors responsible for such deterioration can be minimized. This is important because it increases shelf life and marketing period of fresh produce and maintains their quality during postharvest handling. There are few proven methods and technologies used to slow down the undesirable changes for extended availability such as control of optimum low temperature and humidity during storage, suitable packaging, transportation, and maintenance of storage atmosphere.

Preharvest Factors Influencing Postharvest Quality of Fresh Produce

Postharvest management starts with preharvest managements. Once the fruits are harvested, the overall quality of fresh fruits can hardly be improved but it can be maintained. The final market value of the produce and acceptance by the consumers depends upon the grower's ability to apply best available preharvest technology followed by harvesting and then to apply best available postharvest handling practices. The preharvest factors influencing postharvest quality are frequency of irrigation, use of fertilizers, pest control, growth regulators, climatic conditions like wet and windy weather, natural climates such as hailing, high wind velocity, heavy rainfall, and tree conditions (age, training pruning, light penetration, etc), which influences overall fruit quality and suitability for storage by modifying physiology, chemical composition, and morphology of fruits. One such preharvest factor is spray of Gibberellic acid (10 ppm), if applied at color break stage, results in delay in color development and maintains firmness. This is important because it in extending harvesting period. Similarly, the use of calcium solution as foliar sprays increases firmness of fruits as well as extends the shelf life.

Postharvest Factors Influencing Postharvest Quality of Fresh Produce

There are many postharvest factors that affect quality of fresh produce as mentioned below:

1. Maturity stage
2. Methods of harvesting
3. Tools for harvesting and assembling
4. Time of harvesting
5. Precooling
6. Sorting and grading
7. Packaging, packaging materials, and pallatization
8. Use of cushioning materials in the package (foam net, paper cutting, rice straw, etc.)
9. Storage
10. Types of storage
11. Temperature during storage and transportation
12. RH during storage and transportation
13. Transportation
14. Road condition
15. Pattern of loading and unloading
16. Exposure to packed and unpacked boxes to sunlight

Maturity Stage

This is the starting point of postharvest quality management. Therefore, it must be ensured that properly matured fruits should be harvested. It must be harvested when it attains the appropriate stage of development based on physiological and horticultural maturity. Harvest maturity varies in accordance with the crop concerned. Fresh produce is ready for harvest when it has developed to the ideal condition for consumption (FAO 1989). Immature or overmatured fruits are inferior in quality and spoil more quickly even if other factors are favorable. The maturity of harvested fruits has an important role on shelf life, quality, and market price. Hence, certain standards of maturity must be kept in mind while harvesting the fruits.

At which stage of maturity, a fruit should be harvested is crucial to its subsequent storage, marketable life, and quality. Maturity always has a considerable influence on the quality of fresh produce as well as the storage potential and occurrence of many storage disorders (Siddiqui and Dhua 2010). There are mainly three stages in the life span of fruits and vegetables: maturation, ripening, and senescence. For climacteric fruits, maturation is indicative of the fruit being ready for harvest. At this point, the edible part of the fruit or vegetable is fully developed in size, although it may not be ready for immediate consumption. Ripening follows or overlaps

Table 2.1 Example of few climacteric and non-climacteric fruits

Climacteric fruits	Non-climacteric fruits
Mango, Banana, Papaya, Sapota, Apple, Custard Apple, Kiwi fruit, Peach, Jack Fruit, Guava, etc.	Grape, Kinnow Mandarin, Sweet Orange (all citrus fruits), Litchi, Pomegranate, Pineapple, etc.

maturation, rendering the produce edible, as indicated by texture, taste, color, and flavor. Senescence is the last stage, characterized by natural degradation of the fruit or vegetable, as in loss of texture, flavor, etc. (senescence ends with the death of the tissue of the fruit). Here, ripening treatment is an important operation in many climacteric fruits before retailing. This gives an opportunity for uniform ripening and availability based on market demand. Few examples of climacteric fruits are mango, banana, sapota, apple, custard apple, etc. For non-climacteric fruits, development of eating quality before harvesting is indicative of the fruit being ready for harvest. Therefore, non-climacteric fruits should be harvested after attaining proper development of eating quality (ripening) while still attached to the mother plant. In this case, ripening treatment is not given before retailing. Few examples of non-climacteric fruits are oranges, grape, litchi, etc. Climacteric fruits are harvested at full matured stage (before onset of ripening). Here, ripening treatment is given in few fruits before retailing. Examples of climacteric and non-climacteric fruits are listed in Table 2.1. It is important to note that each fruit has a set of maturity standards (physical as well as chemical) and growers are capable of identifying it easily. Only few chemical analyses are difficult to perform. For example, the most commonly used measure to access maturity for harvesting of Mandarin oranges is peel color (physical). Fruits are considered mature, if they have a yellow orange color on 25 % or more of the fruit surface. Chemical measure, however, includes TSS (total soluble solids contents) and acidity of the juice. The juice should have a TSS of 8.5 % or higher. TSS content is determined by squeezing a few drops of juice on a hand-held refractometer.

Skin/Peel Color

This factor is commonly used for the fruits, where skin color changes as fruit ripens or matures and thus it is regarded as a quality index. Huybrechts et al. (2003) reported peel color also acts as a maturity index for some cultivars of apple, which can be used to determine the maturity of the fruit. Peel color is also used for grading in many countries before storage or marketing (Watkins 2003). This is also true that few cultivars exhibit no perceptible color change during maturation (stay green character). Assessment of harvest maturity by skin color depends on the judgment and experience of the harvester. Now color charts are also available for cultivars, such as apples, tomatoes, peaches, banana, and peppers. One more reliable method to measure skin color is optical method. Here, light transmission properties can be used to measure the degree of maturity of fruits in terms of chlorophyll degradation

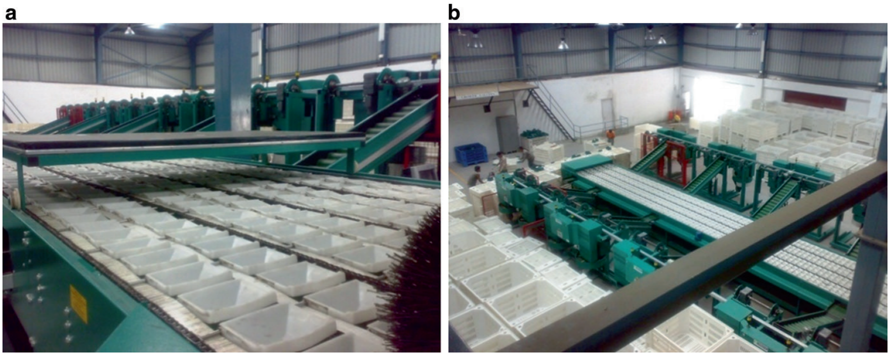

Fig 2.1 (**a**) GREEFA (*close up*); (**b**) GREEFA (*upper view*)

or development of color pigments. This method is based on the principle of reduction in chlorophyll content during maturation and ripening and development of color pigments at harvest maturity. Practically, fruits are allowed to pass through a camera unit, where camera takes 27–50 snaps of individual fruits, process it through CPU, and then put in a color range say above 70 % color, 60–70 % color, etc. One such grader based on optical method is GREEFA (Fig. 2.1a, b) widely used for apple grading all over the world.

Shape

In many fruits and vegetables, shape changes during maturation and thus gives an idea to determine harvest maturity. For instance, a banana fruit becomes more rounded in cross-sections and less angular as it matures on the plant. It is the stage when harvesting of banana is recommended. Mangoes also change shape during maturation. This is evident by comparing the relationship between the shoulders of the fruit and the point at which the stalk is attached changes. The shoulders of immature mangoes slope away from the fruit stalk, but as maturity advances, the shoulders become level with the point of attachment, and with final maturity, the shoulders may be raised above this point (Fig. 2.2a–c). This stage gives maximum yield and better quality attributes upon ripening.

Size

Change in the size of any fruit or vegetable crop while growing is frequently used to determine harvest maturity and quality. It is one of the oldest methods of maturity determination. Size increases as any fresh produce approaches towards maturity. For example, the size of a cauliflower curd or cabbage head increases up to full maturity with compactness in nature. This gives an idea for harvesting a quality curd or head.

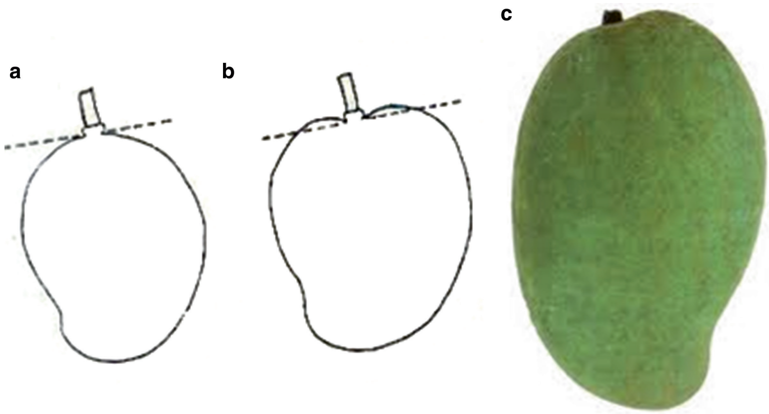

Fig 2.2 (**a**) Immature stage; (**b**) mature stage; (**c**) ideal mature mango

Aroma (Flavor)

Most fruits synthesize volatile compounds as they ripen. Such chemicals give fruit its characteristic odor and can be used to determine whether it is a good quality ripened fruit or not. For example in many instances, consumers bring ripe mango fruit near to nose in order to detect characteristic flavor of mango. This flavor may only be detectable by humans when a fruit is completely ripened, and therefore, this method has limited use in commercial situations.

Leaf/Flowers/Inflorescence Condition Changes

In many cases, leaf quality often determines when fruits and vegetables should be harvested. In root crops, the condition of the leaves can indicate the condition of the crop below the ground. For example, if potatoes are to be harvested for storage, then the optimum harvest time (optimum maturity) is soon after the leaves and stems started drying and most leaves have dried. If harvested earlier, (before yellowing of leaves) the skins will be less resistant to harvesting and handling damages and more prone to storage diseases. The same is true for onion and garlic. In case of banana, dryness of inflorescence at the tip of fingers and disappearance of angularity of fingers are often taken as a maturity index (Fig. 2.3).

Development of Abscission Layer

As part of the natural development of a fruit, an abscission layer is formed in the fruit stalk. For example, in melons, harvesting is done after development of abscission layer. Harvesting before the abscission layer has fully developed results in inferior quality fruit, compared to those left on the vine till abscission layer is developed.

Fig 2.3 Observe dried flowers at the tip of each fingers and disappearance of angularity

Firmness (Flesh Firmness)

The texture or firmness of any fruit changes during ripening and maturation. This is more prominent towards ripening when it losses texture more rapidly. Excessive loss of moisture may also affect the texture of the crops. These textural changes are detected by touch, and the harvester presses the fruits or vegetables gently and can judge whether the crop is ready for harvest or not. This method is widely used in Indian fruit markets for apple. They also judge storable quality by simply pressing with thumb and fingers. This is an experience gained over years by producers, traders, and buyers. Today, sophisticated devices have been developed to measure texture in fruits and vegetables. For example, texture analyzers and pressure testers; they are currently available for fruits and vegetables in various forms. A force is applied on the surface of the fruit (after peeling), allowing the probe of the Penetrometer to penetrate the fruit flesh, which then gives a reading on firmness. Hand-held pressure testers are widely used in apple and pears world over. However, in some cases it could give variable results because the basis on which they are used to measure firmness is affected by the angle at which the force is applied and support to the hand holding the fruit. Table top pressure tester is used in order to minimize the error. Two commonly used pressure testers to measure the firmness of fruits and vegetables are the Magness-Taylor and UC Fruit Firmness. One more instrument is used for this purpose and is called Instron Universal Testing Machine. It is not portable and mainly used in laboratories. Flesh firmness (FF) is the most important quality measurement of apples and pear that has been used to determine optimal storage maturity by private companies. Flesh firmness varies among the cultivars (Watkins 2003).

Juice Content

The juice content of many fruits increases as fruit matures on the tree. To measure the juice content of a fruit, a representative sample of fruit is taken and then the juice is extracted in a standard and specified manner. The juice volume is related to the original mass of juice, which is proportional to its maturity. This method is mostly used in citrus fruits.

Sugars

In climacteric fruits, carbohydrates accumulate during maturation in the form of starch. As the fruit ripens, starch is broken down into sugars. In non-climacteric fruits, sugar tends to accumulate during maturation. A quick method to measure the amount of sugar present in fruits is with a brix hydrometer or a refractometer. A drop of fruit juice is placed in the prism of the refractometer and a reading taken; this is equivalent to the total amount of soluble solids or sugar content in the fruit juice. This method is widely used in grapes in many parts of the world to specify maturity.

Starch Content

Measurement of starch content is a reliable technique used to determine maturity in apple and pear cultivars. The method involves cutting the fruit in two and dipping the cut pieces into a solution containing 4 % potassium iodide and 1 % iodine (Potassium iodide solution). The cut surfaces stain to a blue-black color in places where starch is present. Starch converts into sugar as maturity advances. Harvest should be at the stage when the samples show that 65–70 % of the cut surfaces have turned blue-black leaving only the core (middle) part unstained.

Brix:Acid Ratio

In many fruits, the acidity changes during maturation and ripening, and in the case of citrus and other fruits, acidity reduces progressively as the fruit matures on the tree. Normally, acidity is not taken as a measurement of fruit maturity by itself but in relation to soluble solids, giving what is termed the brix:acid ratio.

Specific Gravity

Specific gravity is the relative gravity, or weight of solids or liquids, compared to pure distilled water at 62 °F (16.7 °C), which is considered unity. Specific gravity is obtained by comparing the weights of equal bulks of other bodies with the weight of water. In practice, the fruit or vegetable is weighed in air, then in pure water. The weight in air divided by the weight in water gives the specific gravity. This will ensure a reliable measure of fruit maturity. As a fruit matures, its specific gravity increases. This parameter is rarely used in practice to determine time of harvest, but could be used in cases where development of a suitable sampling technique is possible. It is used, however, to grade crops according to different maturities at postharvest. This is done by placing the fruit in a tank of water, wherein those that float are less mature than those that sink.

Methods of Harvesting

There are basically three methods most commonly used for harvesting any fruits or vegetables.

(a) Harvesting individual fruits/vegetables with hand by pulling or twisting the fruit pedicel
(b) Harvesting individual fruits or fruit bunch/vegetables or vegetable bunch with the help of fruit clippers/secateurs/scissors
(c) With harvester specially designed for harvesting

Harvesting Individual Fruits/Vegetables with Hand by Pulling or Twisting the Fruit Pedicel

This is simple and most commonly used method of harvesting. Harvester can easily pick the optimum mature fruits. One important demerit of this method is pulling little peel along with pedicel end renders the fruits for quick spoilage.

Harvesting Individual Fruits, Fruit Bunch/Vegetables, or Vegetable Bunch with the Help of Fruit Clippers/Secateurs/Scissors

This method is an advance form of hand pulling and twisting method. Here, fruit stalk is cut close to the point of attachment of fruit, leaving a very small portion of pedicel attached with fruits. This is highly accepted and widely used in almost all citrus fruits. Postharvest quality is found better in this method compared to any others. One important precaution should be in cutting fruit stalk close to the fruit; otherwise, the part of pedicel attached with fruit may puncture other healthy fruits during subsequent handling and marketing. Fruits born in bunch like grapes are harvested with scissors or secateurs.

Mechanical Harvesting

This method is used on commercial scale and specially designed machines are only used. Fruits and vegetables get more damage with harvester and quality deteriorates rapidly. Therefore, it is advisable to use harvester where harvested produce are intended to use for processing. This is most economic method of harvesting for processing grade fruits and vegetables.

Tools for Harvesting and Assembling

Postharvest quality also depends on the tools used for harvesting fresh produce. It is because faulty tools also affect quality. Depending on the type of fruits or vegetables, several tools are employed to harvest the produce. Commonly used tools for harvesting of fruit and vegetable are secateurs, scissors, fruit clippers, knives, and hand-held or pole-mounted picking shears. When fruits or vegetables are difficult to catch with hand, such as mangoes or avocados, a pole mounted with picking shear or scissors is used. Harvested fruits are collected in a bag attached with the pole itself. Where there is no provision of collecting in bags, fruits are allowed to fall on the ground directly or on a net above the ground or on a sheet of gunny bags or some cushioning material is placed on the ground just beneath the tree to prevent damage to the fruit while directly hitting the ground. Harvesting bags with shoulder or waist slings can also be used for fruits with firm skins, like citrus and avocados. They are easy to carry and leave both hands free for climbing, harvesting, and assembling. Harvested produce are assembled in a container before sorting, grading, and packing. These containers too influence the quality. Plastic containers such as crates, buckets, and bins are suitable containers for assembling harvested produce. These containers should be of enough strength and smooth without any sharp edges that could damage the produce. Additionally, cushioning materials should be used in order to reduce bruising. Commercial growers use plastic crates and bulk bins with varying capacities and crops such as apples and cabbages are placed and sent to packing houses for selection, grading, and packing or directly to market. Gunny bags, plastic bags, and Hessian bags are used for vegetables like potato, onion, garlic, etc.

Time of Harvesting

Harvesting time also affects quality. Fruits harvested before 10 AM in the morning and transported to pack house for sorting, grading, and packing yield better quality and lasts longer. Therefore, morning harvesting and within 10 AM transportation to destination pack house or market is always preferred in order to control damage due to high temperature. In case of grapes harvesting in India, it starts at 6 o'clock in the morning and harvested produce reach pack house by 10 AM. It facilitates faster precooling also and yield better quality.

Precooling

The quality of fresh fruits and vegetables largely depends on precooling before storage and marketing. This is a compulsory postharvest treatment followed in developed countries for almost all perishable commodities. The rapid cooling of fresh produce from field temperature (pulp temperature at the time of harvesting) to its best storage temperature is called precooling. It is an important postharvest operation recommended in almost all flowers, fruits, and few vegetables. The main objective of any precooling operation is to remove field temperature (field heat). This is important because it increases shell life of the produce. Removing field heat reduces rate of respiration and all biochemical reactions from newly harvested produce. Since fruits, vegetables, and flowers are still alive after harvest, the produce continues to respire. Respiration results in produce deterioration, including loss of nutritional value, changes in texture and flavor, and loss of weight. These processes cannot be stopped, but they can be slowed down significantly by precooling before storage or distribution. Generally, the higher the respiration rates of a fruit or vegetable, the greater the need for postharvest precooling. Precooling also reduces disease incidence. Wet or damp produce must be cooled, as warm, wet produce creates an environment that encourages the growth of decay organisms. Precooling facility is usually erected within pack house premises and it is the responsibility of grower-shipper or pack house owner. The four basic methods of precooling can be applied based on the texture and sale value of the product. These are forced air, hydro cooling, vacuum cooling, and icing. Each method was developed with specific crops in mind. For each crop, it is critical to know how to handle the produce at harvest, whether precooling is necessary, and which one is the best method of cooling. Forced air cooling is the most common and widely used method of precooling. Cost, easiness, and maintenance are also important considerations when you select a precooling method.

Forced Air

In this method, cool air with high speed moves over a product to remove the field heat. Both packed and unpacked fruits and vegetables can be precooled. Inside precooling chamber, fans pull hot air through the produce boxes and back into the cooling unit and this process continued till desired temperature is not achieved. During precooling, weight loss is expected. When a room is designed for pre cooling, it must be equipped with enough refrigeration capacity and proper humidity control. These steps can prevent excess weight loss. Forced air units are affordable for many small-scale growers and traders. An existing cold room can be augmented into precooling chamber by making use of portable fans, wooden or plastic pallets, and tarps. Line up two rows of produce and set up a fan to draw air down the aisle between the rows. Cover the aisle with a sturdy tarp to force the system to draw air through the boxes of produce. Forced air cools most commodities effectively, but those best adapted to this method include berries, stone fruits, and mushrooms.

Hydro Cooling

Hydro cooling cools produce with chilled water. Hence, packed fruits are difficult to cool by this method. The water usually is cooled by mechanical refrigeration, although cold well water and ice sometimes are used. The size of hydro cooling units varies depending on the size of the operation, but considerable refrigeration or large quantities of ice are required to keep the water at the desired temperature of 33–36 °F. The produce is cooled by a water bath or sprinkler system. The produce either is dumped in the bath or under the sprinkler or is left in bins or plastic crates. Small operations might have an ice-water tank in which to "stir" the vegetables for rapid cooling. Pay special attention to water quality. Unfiltered and unsanitized water can spread undesirable microorganisms.

Most vegetables and many fruits that can withstand wetting can be hydro cooled. Asparagus, celery, cantaloupes, green peas, leaf lettuce, peaches, radishes, and sweet corn can be cooled successfully with this method.

Vacuum Cooling

This method of precooling is based on the principle of "water evaporates at a very low temperature if pressure reduced" and maintained to a desired level. Vacuum cooling is one of the more rapid cooling systems and cooling is accomplished at very low pressures. At a normal pressure of 760 mmHg, water evaporates at 100 °C, but it evaporates at 1 °C if pressure is reduced to 5 mmHg. Produce is placed in sealed containers where vacuum cooling is performed. This system produces about 1 % product weight loss for each 5 °C of temperature reduction. Modern vacuum coolers add water as a fine spray in the form of pressure drops. Similar to the evaporation method, this system is in general used for leafy vegetables because of their high surface-to-mass ratio (Table 2.2). Produce is placed in a specially designed room, and air pressure is reduced. At lower atmospheric pressure, some water from the produce evaporates as the produce uses its own heat energy to convert water into water vapor. This lowers the temperature of products. Heat and moisture are removed from the vacuum tube by mechanical refrigeration. Commercial vacuum units usually cool the product to the proper storage temperature in less than 30 min. Units are available for cooling different amounts of product, from two pallets to a full truckload. Since initial investment and maintenance cost is high, this method is not commercialized on large scale.

Table 2.2 Vegetables (leafy vegetables) suitable for vacuum cooling

Belgian endive	Chinese cabbage	Kohlrabi	Spinach
Broccoli	Carrot	Leek	Sweet corn
Brussels sprouts	Escarole	Parsley	Swiss chard
Cantaloupe	Green onions	Pea/snowpeas	Watercress

Source: Sargent et al. (2000), McGregor (1987)

Table 2.3 Fresh produce suitable for ice cooling

Belgian endive	Chinese cabbage	Kohlrabi	Spinach
Broccoli	Carrot	Leek	Sweet corn
Brussels sprouts	Escarole	Parsley	Swiss chard
Cantaloupe	Green onions	Pea/snowpeas	Watercress

Source: Sargent et al. (2000), McGregor (1987)

Icing

Crushed or slurry ice is placed directly into the produce box. This can be an effective way of precooling individual boxes of certain vegetables. The produce can be cooled in a short time and the temperature could be maintained in transit also. Fresh produce that can be ice are listed below in Table 2.3.

Sorting and Grading

This is one of the most important postharvest operations after harvesting. This is done primarily for quality packing and removal of diseased and defective produce from the lot. Proper sorting and grading gives assurance of quality produce. This is either done in the farmer's field or in the pack houses. Both manual and mechanical graders are used for grading. All round-shaped fruits and vegetables are easily graded by mechanical graders. Grading may be based on color, size, and extent of defects, while sorting is totally dependent on man power for removal of diseased, defected, and damaged fruits or vegetables. Grading is done by simple to highly sophisticated graders. Today, many sophisticated graders are in use for fresh produce such as *GREEFA*. Both size and color grading simultaneously is possible and is being used on commercial scale in apples.

Packaging, Packaging Materials, and Pallatization

Both packing and packaging materials play many important roles in quality maintenance of fresh produce. Packing starts with placing the produce in the box. While placing, care must be taken to place in line, pedicel end of all fruits should be in one direction, separation layers or trays must be used where it is necessary. The box should not be underfilled or overfilled. Overfilling is generally noticed in India where a farmer fills more in a box beyond the capacity of the box designed by the manufacturer. They do this primarily for two reasons: (a) *Demand by the commission agent* (*Traders*)—It was observed that those lots containing more weight in a box priced more.

In general, all apple boxes are designed for 20 kg but it contains 22–23 kg, and in many cases it is found 25–30 kg is found, where the capacity is only 20 kg (Ahmad et al. 2014). This results in heavy touching marks and bruising during handling; (b) *To save the cost of packing and transportation*—Farmers want to save something immediately and he/she calculates the cost of empty boxes, packing charges, handling and transport charges by saving number of boxes, and to do so they prefer overfilling. The practice results in damage and touching (pressure marks) in almost all fruits. The type of boxes and quality in terms of strength and ventilation of each boxes play very important role in maintaining quality of any fresh produce. A number of boxes are used for packing fresh produce such as bamboo baskets, wooden boxes, CFB boxes, and thermocol boxes. Among them, CFB boxes are most common and widely used all over the world. However, quality in terms of strengths, printability, and perforations varies from country to country and even region to region within the country.

In India, Himachal and J&K farmers use CFB boxes of very weak strength (3-ply) for packing apple, pear, and few stone fruits. These boxes generally become very loose or even torn during transportation from Himachal or Kashmir to various wholesale markets (APMC Azadpur, Delhi, Chandigarh, etc.) of India. Just to strengthen these boxes, buyers or forwarding agents prefer wrapping of boxes by thin plastic ropes. The idea is to give little strength to these boxes during further transportation.

Wooden boxes are the second most important packing boxes widely used in many countries including India. However, unavailability and cost of wooden box is a concern during peak season. Government regulations also discourage the use of wooden boxes for sake of trees. Bamboo baskets with gunny bags are also in use for less value crops. Repackaging of fruits and vegetables is common when the product has been packed in large containers, such as sacks, CFB boxes, and plastic containers. The repackaging process is often carried out by repackers, who open the box, regrade, and again pack in the same box. During repacking, any damaged or rotting fruit is found, it is thrown away. It gives the product an appearance more appealing to consumers.

Use of Cushioning Materials

Cushioning materials are used in many stages during postharvest handling operations. But there are three main stages, where it becomes compulsory in order to maintain postharvest quality. The first stage is putting harvested produce into plastic crates or any rigid container. All crates have hard surfaces and while keeping produce inside, there is a chance of dropping off from little height, causing impact bruising popularly called touching marks. The second stage is transportation from field to pack house. In general, plastic crates are used for transportation from field to pack house and the distance may vary from few kilometers to many kilometers.

Based on the condition of roads, there would be impact and vibration bruising; these bruising may not be visible immediately, but after few days, browning or blackening symptoms develop and finally produce starts rotting.

Cushioning materials if used in plastic crates reduce these bruising and touching marks drastically. The third stage is transportation of packed produce from pack house to destination markets. Loading, unloading, and transportation jerks causes bruising. Therefore, it is recommended to use cushioning material to preserve post-harvest quality of fresh produce. There may be many types of cushioning materials such as newspaper sheets, newspaper cuttings, rice straw, bubble sheet, specially designed foam nets, moulded trays, gunny bags, leaves, khaskhas, and other locally available material.

Storage

Almost all fruits are seasonal in nature. Every year, harvesting season falls during a fixed period, say 2–3 months. This period may differ from state to state for the same fruit and for different fruits also. For example, in India, apple harvesting season falls from July to October in Himachal Pradesh and from August to November in J&K every year. This may be little early or late due to prevailing weather conditions during growing periods. Demand for many fruits and vegetables are round the year. The demand of any fruit or vegetable beyond the harvesting season is called off-season demand. This demand can be fulfilled only if fruits are stored in the harvesting season and sold during off-season. The management of temperature, ventilation, and relative humidity are the three most important factors that effect postharvest quality and storage life of horticultural produce. There may be many objectives of storage but the main objectives are:

- To minimize glut and distress sale in the market, thus assuring good price to the farmers.
- To insure availability of food in off-season.
- Save horticultural produce from being spoiled.
- Storage in season when cost of produce is relatively low and marketing in off-season at a better price. This gives higher returns to growers and traders.
- To regulate the price of the commodity during season and also in off-season.
- Mostly apple, pear, grapes, potato, onion, and chilli are stored in large quantities to feed the market round the year.

Lowering the temperature to the lowest safe level is of paramount importance for enhancing the shelf life, reducing the losses, and maintaining fresh quality of fresh produce. For example, mango needs a temperature above 8 °C, banana above 12 °C, apple 1–2 °C, etc. The safe temperature of few important fruits and vegetables are mentioned in Table 2.4

Table 2.4 Optimum storage temperature of few important fruits and vegetables

Crop	Optimum temperature (0 °C)	Relative humidity (%)
Apple	1–4	90–95
Apricot	–0.5 to 0	90–95
Artichoke	0	95–100
Asian pear	1	90–95
Asparagus	0–2	95–100
Avocado	3–13	85–90
Banana	13–15	90–95
Broccoli	0	90–95
Brussels sprouts	0	90–95
Brinjal	8–12	90–95
Cabbage	0	98–100
Carrot	0	95–100
Cassava	0–5	85–96
Cashew apple	0–2	85–90
Cauliflower	0	95–98
Celery	0	98–100
Cherimoya	13	90–95
Cherries	−1 to 0.5	90–95
Coconut	0	80–85
Cucumber	5–10	90–95
Custard apple	5–7	85–90
Dates	−18 to 0	75
Fig	–0.5 to 0	85–90
Garlic	0	65–70
Ginger	13	65
Grape	–0.5 to 0	90–95
Grapefruit	10–15	85–90
Green onions	0	95–100
Guava	5–10	90
Jack fruit	13	85–90
Kale	0	95–100
Kiwi fruit	–0.5 to 0	90–95
Lemon	10–13	85–90
Lettuce	0–2	98–100
Lima bean	3–5	95
Lime	9–10	85–90
Longan	1–2	90–95
Loquat	0	90
Lychee	1–2	90–95
Mandarin	4–7	90–95
Mango	13	90–95
Mangosteen	13	85–90

(continued)

Table 2.4 (continued)

Crop	Optimum temperature (0 °C)	Relative humidity (%)
Melon (Others)	7–10	90–95
Mushrooms	0–1.5	95
Nectarine	–0.5 to 0	90–95
Okra	7–10	90–95
Onions (dry)	0	65–70
Olives, fresh	5–10	85–90
Orange	0–9	85–90
Papaya	7–13	85–90
Parsley	0	95–100
Parsnip	0	95–100
Passion fruit	7–10	85–90
Peach	–0.5 to 0	90–95
Pear	–1.5 to 0.5	90–95
Peas	0	95–100
Pepper (bell)	7–13	90–95
Persimmon	–1	90
Pineapple	7–13	85–90
Pitaya	6–8	85–95
Plum	–0.5 to 0	90–95
Pomegranate	5	90–95
Potato (early)	7–16	90–95
Potato (late)	4.5–13	90–95
Prickly pear	2–4	90–95
Pumpkins	10–15	50–70
Quince	–0.5 to 0	90
Radish	0	95–100
Rambutan	10–12	90–95
Raspberries	–0.5 to 0	90–95
Rhubarb	0	95–100
Sapodilla	15–20	85–90
Scorzonera	0	95–98
Snapbeans	4–7	95
Snowpeas	0–1	90–95
Spinach	0	95–100
Sprouts	0	95–100
Strawberry	0–0.5	90–95
Sweet corn	0–1.5	95–98
Sweet potato	15–20	85–90
Swiss chard	0	95–100
Summer squash	5–10	95
Tamarind	7	90–95
Taro	7–10	85–90

(continued)

Table 2.4 (continued)

Crop	Optimum temperature (0 °C)	Relative humidity (%)
Tart cherries	0	90–95
Tomato (MG)	12.5–15	90–95
Tomato (red)	8–10	90–95
Tree tomato	3–4	85–90
Turnip	0	90–95
Watermelon	10–15	90
White sapote	19–21	85–90
Yam	16	70–80
Yellow sapote	13–15	85–90

Source: Cantwell (1999), Sargent et al. (2000), McGregor (1987)

Special Treatments (Curing)

Most root crops don't need curing before being placed in the storage chamber. Therefore, these crops should not be exposed to sunlight. Potato, for example, turns green and become toxic if exposed to sun. However, few root crops require curing before storage for proper quality maintenance during storage and subsequent marketing. Potato also requires curing for peel hardening and wound healing (suberization) under shade. Onion and garlic require at least 1 week curing process to dry out outer scaly leaves and tightening of neck portion. Pumpkin and squash need about 2 weeks curing to harden their skin before storage. Don't skip curing where it is required as curing affects quality.

Do's and Don'ts for Storage of Fresh Produce

- Store only high-quality produce, free of damage, decay, and of proper maturity (not overripe or undermature).
- Know the requirements for the commodities you want to put into storage, and follow recommendations for proper temperature, relative humidity, and ventilation. Never store carrot with apple or any fruit that releases ethylene gas because carrot is very sensitive to ethylene and develops bitterness due to formation of a compound called Iso-coumarin.
- Avoid lower than recommended temperatures in storage, because many commodities are susceptible to low temperature injury called freezing or chilling.
- Do not overload storage rooms or stack boxes tightly; it will hinder air movement through all boxes. Air follows the same path or easiest path if not blocked.
- Boxes should be stored on perforated wooden racks specially designed for air movement.

- Provide adequate ventilation in the storage room by keeping little space between two stack lines. Boxes should not be stored on the passage kept for the movement of staffs and labors.
- Storage rooms should be protected from rodents by keeping the immediate outdoor area clean and free from trash and weeds.
- Containers/Boxes must be well-ventilated and strong enough to withstand stacking. Do not stack boxes beyond their stacking strength.
- Monitor temperature in the storage room by placing thermometers at different locations.
- Don't store onion or garlic in high humidity environments.
- Control Inspect/Pest/rodents population inside the store.
- Check your produce at regular intervals for any sign of damage due to insect/pest/water loss, ripening, shriveling, etc.
- Remove damaged or diseased produce to prevent the spread of pathogens.
- Always handle produce gently and never store produce unless it is of the best quality.
- Damaged produce will lose water faster and have higher decay rates in storage as compared to undamaged produce and must be removed.

It is advisable not to store different crops together in one room of any cold store. But practically, it is very difficult to maintain and in some cases it is unavoidable, particularly at distribution or retail levels. A strategy widely practiced is to set cold chambers at an average of around 2–5 °C and 90–95 % relative humidity, irrespective of specific requirement. Frequent opening and closing of cold store chamber for product loading and unloading causes an increase in temperature and decrease in relative humidity. Therefore, it is advisable for specific chambers for specific products.

Thompson et al. (1999) recommended three combinations of temperature and relative humidity (RH): (1) 0–2 °C and 90–98 % RH for leafy vegetables, crucifers, temperate fruits, and berries; (2) 7–10 °C and 85–95 % RH for citrus, subtropical fruits, and fruit vegetables; (3) 13–18 °C and 85–95 % RH for tropical fruits, melons, pumpkins, and root vegetables. Storage of compatible groups of fruits and vegetables together (requires same temperature and RH) is advisable and necessary. Otherwise, quality of one produce affects the quality of other produce. Some fruits or vegetables can be stored together due to their common temperature and relative humidity requirements. At the same time, its reverse is also true. An overview of storage of compatible groups of fruits and vegetables is listed in Table 2.5.

Types of Storage

There are many types of storage system or structure, starting from as simple as field storage to as sophisticated as Controlled atmosphere and hypobaric storage. Among field storage, heap, cellar, underground tunnels or rooms, RCC rooms, and evaporative cool chamber or Zero Energy Cool Chamber (ZECC) systems are important.

Table 2.5 Compatibility groups of fruits and vegetables that can be stored together

Group	Temperature	Crops	Status of commodities
Group 1	0–2 °C and 90–95 % RH	Apple, Apricot, Asian Pear, Grapes, Litchis, Plum, Prunes, Pomegranate, Mushroom Turnip Peach	Produce ethylene
Group 2	0–2 °C and 90–95 % RH	Asparagus, Leafy greens, Broccoli, Peas, Spinach, Cabbage, Carrot, Cauliflower, Cherries	Sensitive to ethylene
Group 3	0–2 °C and 65–70 % RH	Garlic, Onions dry	Moisture will damage these crops

Source: Thompson et al. (1999)

ZECC is an important on-farm storage structure based on the principle of evaporative cooling for fresh produce for short-term storage (Roy and Khurdiya 1986; Pal et al. 1997). Among advanced and technologically superior, modern cold storage, Controlled Atmosphere storage and hypobaric storage are important. There are some basic requirements in all types of field storage which are summarized below.

Natural Ventilation

Among all field storage systems, natural ventilation is required. Due to this natural airflow around the product, heat is removed regularly. Produce is placed in heaps, bags, boxes, bins, pallets, etc. Problems of pest and rodents are severe in field storage. Therefore, there must be adequate provision to keep out animals, rodents, and pests. Another problem of field storage is development of hot and humid condition within the storage facility. This creates ideal conditions for the development of disease. It is possible to regulate temperature and relative humidity up to certain extent by opening and closing storage ventilation. At noon, ambient temperature increases and relative humidity decreases except rainy days. However, at night the opposite happens. To reduce the temperature of stored products, buildings ventilation should be left open at night when external air temperatures are lower.

Forced-Air Ventilation

Heat and gas exchange can be improved in a store room provided air is forced to pass through the stored produce. This system allows for more efficient cooling and control over temperature and relative humidity. Electric power facility is compulsory for forced air ventilation. As air follows the path of least resistance, loading patterns as well as fan capacity should be carefully calculated to ensure that there is uniform distribution of air throughout the stored produce. Inlet and exhaust fan can drag night cool air inside the chamber where difference in night and day temperature is more.

For modern cold stores, forced air ventilation is compulsory. This requirement is fulfilled by cooling fans. For smooth ventilation, perforated wooden floors for multi-storey cold stores and plastic or wooden plates for a single room are necessary. For Controlled Atmosphere Storage (CA) and hypobaric storage, fresh produce is stored in perforated plastic bins and crates and staked little away from the wall and door. This arrangement allows air movement through the produce.

Temperature and Relative Humidity

Since fruits, vegetables, and flowers are alive after harvest, all physiological processes continue after harvest such as respiration and transpiration (water loss), and supply of nutrient and water is not possible since produce is no more attached to the parent plant. Respiration results in produce deterioration, including loss of nutritional value, changes in texture and flavor, and loss of weight by transpiration. These processes cannot be stopped, but they can be reduced significantly by careful management of temperature and relative humidity during storage and transportation. Growth and multiplication of microorganism responsible for rotting and spoilage are also associated with low temperature. At sufficiently low temperature, many disease-causing microbes stop growth and multiplication. Respiration rates vary tremendously for different products. It can also be affected by environmental conditions, mostly by temperature. As a thumb rule, lower the temperature, the slower will be its respiration rate and the growth of decay organisms. According to Van't Hoff Quotation (Q10), the rate of deteriorative reactions doubles for each 10 °C rise in temperature. Generally, the higher the respiration rates of a fruit or vegetable, the greater the need for postharvest cooling.

Water is the main component found in fruits and vegetables. An important factor in maintaining postharvest quality is to ensure that there is adequate relative humidity inside the storage area. Water loss or dehydration means a loss in weight, which in turn affects the appearance, texture and, in some cases, the flavor also. Water loss also affects crispiness and firmness. Consumers tend to associate these qualities as poor with recently harvested fresh produce. For most fresh produce, relative humidity of about 90–95 % is recommended for storage and transportation. Since transportation period is only few hours to days, maintenance of RH is not of much importance except for leafy vegetables. But in storage, maintenance of RH is compulsory. In modern cold stores, humidifiers are used for humidity generation. The recommended temperature and humidity for fruits and vegetables are mentioned in Table 2.3.

Controlled atmosphere storage (CA) is a system of storage of fresh produce in an atmosphere that differs from normal atmosphere in respect to CO_2 and O_2 levels. At the time of loading in a CA chamber, levels of CO_2 and O_2 are similar to normal air. With the passage of time, the gas mixture will constantly change due respiring fruits and vegetables in the store. Leakage of gases through doors and walls is not allowed in any CA chamber. Once the predetermined levels of CO_2 and O_2 are achieved, it is constantly monitored. It is recommended that after loading, the chamber should be

Table 2.6 Examples of CO_2 injury in controlled atmosphere (CA) storage

Crop and cultivars	CO_2 injury level (%)	CO_2 injury symptoms	O_2 injury level	O_2 injury symptoms
Apple, red delicious	>3	Internal browning	<1 %	Alcoholic taste
Apple, Fuji	>5	CO_2 injury	<2 %	Alcoholic taint
Apple, Gala	>1.5	CO_2 injury	<1.5 %	Ribbon scald
Apricot	>5	Loss of flavor	<1 %	Off-flavor
Banana	>7	Green fruit softening	<1 %	Brown skin, discoloration
Green beans	>7	Off-flavor	<55	Off-flavor
Cabbage	>10	Discoloration of inner leaves	<25	Off-flavor
Cherry	>30	Brown, discoloration	<1 %	Skin pitting, off-flavor
Mango	>10	Softening	<2 %	Skin discoloration

Source: Thompson (1998)

closed and desired level of gas composition should be established within 48 h with the help of Nitrogen generator. The gases are then measured periodically and the levels maintained by introduction of fresh air or passing the store atmosphere through a chemical to remove excess build up of CO_2. Selection of the most suitable atmosphere depends on cultivars, stage of maturity, and environmental and cultivation parameters. No one atmosphere is best for all produce. If the level of CO_2 increases or O_2 decreases, an anaerobic condition may prevail with the formation of alcohol and physiological changes take place referred to as CA injury. Some examples of CA injury are mentioned in Table 2.6.

Several refinements in CA storage have been made in recent years to improve quality maintenance. These refinements include creating nitrogen by separation from compressed air using molecular sieve beds or membrane systems, rapid CA (rapid establishment of optimal levels of O_2 and CO_2), etc. All these refinements are for quality maintenance and to increase the length of storage period. Application of CA to all fresh produce is not found cost-effective, and therefore, commercially not exploited. Commercial use of CA storage is maximum on apples and pears worldwide and less on cabbages, sweet onions, kiwi fruits, avocados, persimmons, pomegranates, and nuts and dried fruits and vegetables (Kader 1986). Classification of fresh produce according to their CA storage potential at optimum temperatures and RH is mentioned in Table 2.7

Transportation and Transport Vehicle

Transportation may be a connecting link between producers and consumers. It holds key factor in postharvest quality maintenance of all fresh produce. Most fresh produce in India and other countries of the world is transported from farmers' field to

Table 2.7 Shelf life of few important fruits and vegetables in controlled atmosphere storage (CA)

S. no.	Storage duration (months)	Crops
	>12	Almond, Brazil nut, cashew, filbert, macadamia, pecan, pistachio, walnut, dried fruits, and vegetables
	6–12	Some cultivars of apples and European pears
	3–6	Cabbage, Chinese cabbage, kiwi fruit, persimmon, pomegranate, some cultivars of Asian pears
	1–3	Avocado, banana, cherry, grape (no SO_2), mango, olive, onion (sweet cultivars), some cultivars of nectarine, peach and plum, tomato (mature-green)
	<1	Asparagus, broccoli, cane berries, fig, lettuce, muskmelons, papaya, pineapple, strawberry, sweet corn; fresh-cut fruits and vegetables; some cut flowers

Source: Kader (1986)

nearby market or wholesale market and from wholesale market to terminal market up to final retailers’ shops in open and non-refrigerated vehicles. Only few reputed firms use refrigerated vehicles for transportation and distribution in summer months only, starting from March to May/June in India. It is mainly due to the increased cost of transportation by reefer van. In open truck vehicles (Non-reefer), produce is always susceptible to a loss of quality. Ambient temperature alone spoils the produce. Other means of transport include rail transport (A/C and non A/C), air, and ship. All imported fruits are transported in A/C containers by ships only. In every country, a dedicated port is assigned for receiving and dispatch of fresh produce containers. In India, a large number of fresh produce containers are received at Mumbai and Chennai port.

After harvest, a number of vehicles (trucks, tractors, trains, boats, ships, utility vehicles, etc.) are used to transport the product from field to either packing houses or whole sale or retail markets. These vehicles are not equipped with refrigeration units and thus the produce decays faster, compared to that in refrigerated vehicles. If the produce is treated with edible wax or chemicals or additives after harvest, it can withstand little longer distances in open vehicles (non-reefer), without much damage. Refrigerated vehicles (trucks, trains, ships, airplanes, etc.) contain installed refrigeration units with sufficiently low temperatures to maintain freshness in fresh produce. These types of vehicles are sealed with insulation material inside the walls of the container, which maintains the inside container temperature at desired level and thus preserves maximum quality.

Fruits and vegetables must be classified in order to separate those susceptible to cold temperatures (mango, banana, tomato, etc.) and those not (apple, pear, cauliflower, peppers, etc.). This eliminates the possibility of product damage (chilling and freezing injury) when cooling at low temperatures during transport. Refrigeration temperatures can vary from 0 °C (32 °F) to 13 °C (55.4 °F) and RH from 70 to 95 %. Reefer van transport is an example of temporary refrigerated storage. Mixed loads cause incompatibility problems in transport also because packaging dimensions are different for different produce and it is not fully stackable. It is therefore not advisable to transport mixed lots for long distance. However, for short distance, there may not be any problem.

There is usually little or no humidity control available during transport and marketing. Thus, the packaging must be designed to provide a partial barrier against movement of water vapor from the product. Plastic liners designed with small perforations to allow some gas exchange may be an option.

Road Condition and Duration of Transportation

Both road condition and duration of transportation affect quality of fresh produce. In hilly tracks and rough road surface, more touching and bruising take place as compared to smooth surface. Longer duration during transportation also affects quality. Reefer van should not be hold unnecessary. It not only increases the cost of produce, but also affects quality.

Pattern of Loading

Pattern of loading also plays crucial role in maintaining quality of fresh produce. Here pattern of loading means number of packed boxes in one layer (stacking height). In case of fresh produce, stacking height depends on extent of perishable nature of packed commodities and strength of packing materials. If produce are more perishable or box strength is weak, stacking height is kept low and vice versa.

For example, height of grape boxes is kept low or it is packed in five ply corrugated boxes or thermocol boxes. This precaution must be taken to preserve postharvest quality of this highly perishable commodity. While loading, another important criteria is interlocking between the boxes. Loading and unloading fruits and vegetables directly affect quality of fresh produce. It can be done either by hand or with the aid of a forklift. Forklift is used for palletized boxes and shipping containers only. Generally, fruits and vegetables are stacked on pallets to ease the loading and unloading process and to prevent damage to the product and packages. Export/Import commodities arrive at the port in containers and are unloaded directly into the vehicle with the aid of conveyor belts connected from the vehicle to the container (Fig. 2.4a–c).

Another important consideration while loading as discussed above is interlocking systems of loading. In this system, a little space is left in each layer on alternate basis (once in left side and once in right side). This facilitates air movement through the produce and provides strength to the boxes during transportation. Exposure to sun while awaiting loading at local mandis or transport can reduce quality drastically. The exposed portion turns black or brown and starts decaying. It is advised for non-reefer transport to move continuously while under sunlight and stop and park your vehicle under a tree shade, especially during sunny days.

Fig 2.4 (**a**) Reefer container; (**b**) inside view of a reefer container; (**c**) ship loaded

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