**DEBRE MARKOS UNIVERSITY COLLEGE OF AGRICULTURE AND NATURAL**

**RESOURCES MANAGEMENT**

**DEPARTMENT OF HORTICULTURE**

**LECTURE HANDOUT**

# ADVANCED POSTHARVEST PHYSIOLOGY AMD TECHNOLOGY OF HORTICULTURAL CROPS

**COMPILED BY**

**ABAYNEH MELKE (PhD)**

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**POSTHARVEST PHYSIOLOGY AND TECHNOLOGY OF HORTICULTURAL CROPS**

# Chapter One: Introduction

## 1.1. Postharvest handling from global perspectives

Today, one of the main global challenges is how to ensure food security for a world growing population whilst ensuring long-term sustainable development. According to the FAO, food production will need to grow by 70% to feed world population which will reach 9 billion by 2050. Further trends like increasing urban population, shift of lifestyle and diet patterns of the rising middle class in emerging economies along with climate change put considerable pressure strain on the planet's resources: declining freshwater resources and biodiversity, loss of fertile land, etc. Consequently, there is a need for an integrated and innovative approach to the global effort of ensuring sustainable food production and consumption (Nellemann et al., 2009; World Economic Forum 2009; FAO/OECD, 2011; Foresight, 2011; EU ERA-NET SUSFOOD 2012-2014).

In the meantime, while the number of food insecure population remains unacceptably high (FAO, 2010; IFAD, WFP and FAO, 2012), each year and worldwide, massive quantities of food are lost due to spoilage and infestations on the journey to consumers (FAO, 2011; Stuart, 2009; FAO, 2002). In some African, Caribbean and Pacific ACP countries, where tropical weather and poorly developed infrastructure contribute to the problem, wastage can regularly be as high as 40-50% (SPORE, 2011). Obviously, one of the major ways of strengthening food security is by reducing these losses.

The term "**postharvest loss**" - refers to measurable quantitative and qualitative food loss in the postharvest system (de Lucia and Assennato, 1994). This system comprises interconnected activities from the time of harvest through crop processing, marketing and food preparation, to the final decision by the consumer to eat or discard the food.

Nowadays, interventions in postharvest loss reduction are seen as an important component of the efforts of many agencies to reduce food insecurity. Postharvest loss is increasingly recognized as part of an integrated approach to realizing agriculture's full potential to meet the world's increasing food and energy needs. Therefore, reducing Postharvest loss along with making more effective uses of today's crops, improving productivity on existing farmland, and sustainably bringing additional acreage into production is critical to facing the challenge of feeding and increased world population.

**Postharvest loss** can be defined as the degradation in both quantity and quality of a food production from harvest to consumption. Quality losses include those that affect the nutrient/caloric composition, the acceptability, and the edibility of a given product. These losses are generally more common in developed countries (Kader, 2002). **Quantity losses** refer to those that result in the loss of the amount of a product. Loss of quantity is more common in developing countries (Kitinoja and Gorny, 2010). A recent FAO report indicates that at global level, volumes of lost and wasted food in high income regions are higher in downstream phases of the food chain, but just the opposite in low-income regions where more food is lost and wasted in upstream phases (FAO, 2013).

***Agricultural crops losses defined***

Losses are a measurable reduction in foodstuffs and may affect either quantity or quality (Tyler and Gilman, 1979). They arise from the fact that freshly harvested agricultural produce is a living thing that breathes and undergoes changes during postharvest handling. Loss should not be confused with damage, which is the visible sign of deterioration, for example, chewed grain and can only be partial. Damage restricts the use of a product, whereas loss makes its use impossible. Losses of quantity (weight or volume) and quality (altered physical condition or characteristics) can occur at any stage in the postharvest chain (Fig 1).

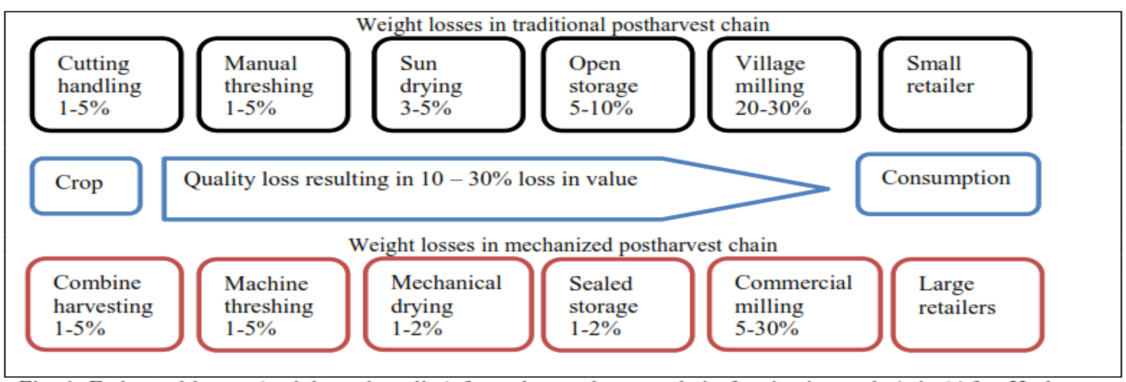


Fig. 1. Estimated losses (weight and quality) from the postharvest chain for rice in south Asia (After Hodges et al. 2011)

Economic loss can also occur if the produce is subsequently restricted to a lower value market. Here, food loss is a subset of PHL and represents the part of the edible share of food that is available for consumption at either the retail or consumer levels but not consumed for any reason.

***Food Losses and Food Waste around the world***

**Food losses** refer to the decrease in edible food mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption (FAO, 2013). Food losses take place at production, postharvest and processing stages in the food supply chain (Parfitt et al., 2010). Food losses are mainly due to poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack to markets.

**Food waste** refers to food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Food waste occurs at the food chain (retail and final consumption) and relates to retailers' and consumers' behavior. Food wastage also refers to any food lost by deterioration or waste. The term "wastage" includes both food loss and food waste

**Food waste or loss** is measured only for products that are directed to human consumption, excluding feed and parts of products which are not edible. As defined by Hodges et al., (2011), *"food waste is the subset of food loss that is potentially recoverable for human consumption"*. Therefore, food that was originally meant to human consumption but which fortuity gets out the human food chain is considered as food loss or waste even it is then directed to a non-food use (feed, bioenergy, etc.). This approach distinguishes "planned non-food uses and "unplanned" non-food uses, which are hereby accounted under losses (FAO, 2011).

Table 1: Generic food supply chain and examples of food waste (Parfitt et al., 2010)

| Stage | Examples of waste |
|---|---|
| 1. Harvesting, handling at harvesting | *Edible crops left in field, ploughed into soil, eaten by pests; timing of harvest not optimal; crop damaged during harvesting* |
| 2. Threshing | *Loss due to poor technique* |
| 3. Drying, transport and distribution | *Quality and quantity loss of during drying, poor transport infrastructure; loss owning to spoiling/bruising* |
| 4. Storage | *Pests and disease attacks, spillage, contamination; natural drying out of food* |
| 5. Primary processing, cleaning, classification, hulling, pounding, grinding, packaging, soaking, winnowing, drying, sieving, milling | *Process losses; contamination in process causing loss of quality.* |
| 6. Secondary processing, mixing, cooking, frying, molding, cutting, extrusion | *Process losses; contamination in process causing loss of quality* |
| 7. Product evaluation and quality control | *Product disregarded /out-grades in supply chain* |
| 8. Packaging | *Inappropriate packaging damages produces; grain spillage from sacks; attack by pests* |
| 9. Marketing, selling, distribution | *Damage during transport; spoilage; poor handling; losses caused by poor storage* |
| 10. Post-consumer | *Poor storage/stock management; discarded before serving; poor food preparation; expiration* |

| | |
|---|---|
| 11. End of life disposal of food waste/loss at different stages in supply chain. | *Food waste discarded may be separately treated, fed to animals, mixed with other wastes/landfilled* |

Key facts and figures on food waste and losses per continent are described below (Nellemann et al., 2009):

**Australia**: In a survey of more than 1,600 households in Australia in 2004 on behalf of the Australia Institute, it was concluded that on a country-wide basis, $10.5 billion was spent on items that were never used or thrown away. This amounts to more than $5,000/ capita/year.

**Asia**: Losses for cereals and oil seeds are lower, about 10-12%, according to the Food Corporation of India. Some 23 million tonnes of food cereals, 12 million tonnes of fruits and 21 million tonnes of vegetables are lost each year, with a total estimated value of 240 billion Rupees. A recent estimate by the Ministry of Food Processing is that agricultural produce worth 580 billion Rupees is wasted in India each year (Lundqvist et al., 2008).

**Africa**: In many African countries, the post-harvest losses of food cereals are estimated at 25% of the total crop harvested. For some crops such as fruits, vegetables and root crops, being less hardy than cereals, post-harvest losses can reach 50% (Voices Newsletter, 2006). In East Africa and the Near East, economic losses in the dairy sector due to spoilage and waste could average as much as US$90 million/year (FAO, 2004). In Kenya, each year around 95 million litres of milk, wortharound US$22.4 million, are lost. Cumulative losses in Tanzania amount to about 59.5 million litres of milk each year, over 16% of total dairy production during the dry season and 25% in the wet season. In Uganda, approximately 27% of all milk produced is lost, equivalent to US$23 million/year (FAO, 2004).

**Europe**: United Kingdom households waste an estimated 6.7 million tonnes of food every year, around one third of the 21.7 million tonnes purchased. This means that approximately 32% of all food purchased per year is not eaten. Most of this (5.9 million tonnes or 88%) is currently collected by local authorities. Most of the food waste (4.1 million tonnes or 61%) is avoidable and could have been eaten had it been better managed (WRAP, 2008; Knight and Davis, 2007).

**United States of America**: In the United States 30% of all food, worth US$48.3 billion (€32.5 billion), is thrown away each year. It is estimated that about half of the water used to produce this food also goes to waste, since agriculture is the largest human use of water. Losses at the farm level are probably about 15-35%, depending on the industry. The retail sector has comparatively high rates of loss of about 26%, while supermarkets, surprisingly, only lose about 1%. Overall, losses amount to around US$90 billion-US$100 billion a year (Lundqvist et al., 2008).

### 1.2. Main elements of the postharvest system <case of nonperishable food crops>

***Harvesting***

The time of harvesting is determined by the degree of maturity. With cereals and pulses, a distinction should be made between maturity of stalks (straw), ears or seedpods and seeds, for all that affects successive operations, particularly storage and preservation.

***Pre-harvest drying (mainly for cereals and pulses)***

Extended pre-harvest field drying ensures good preservation but also increases the risk of loss due to attacks by pests (birds, rodents, and insects) and moulds not to mention theft. On the other hand, harvesting before maturity entails the risk of loss through mould development leading to the decay of seeds.

***Transport***

Much care is needed in transporting a really mature harvest, in order to prevent detached grain from falling on the road before reaching the storage or threshing place. Collection and initial transport of the harvest thus depend on the place and conditions where it is to be stored, especially with a view to threshing.

***Post-Harvest drying***

The length of time needed for full drying of ears and grains depends considerably on weather and atmospheric conditions. In structures for lengthy drying such as cribs, or even unroofed threshing floors or terraces, the harvest is exposed to wandering livestock and the depredations of birds, rodents or small ruminants. Apart from the actual wastage, the droppings left by these „ marauders' often result in higher losses than what they actually eat. On the other hand, if grain is not dry enough, it becomes vulnerable to mould and can rot during storage.

Moreover, if grain is too dry it becomes brittle and can crack after threshing, during hulling or milling, especially for rice if milling takes place longer time (two to three months) after the grain has matured, thus causing heavy losses. During winnowing, broken grain can be removed with the husks and is also more susceptible to certain insects (e.g. flour beetles and weevils). Lastly, if grain is too dry, this means a loss of weight and hence a loss of money at the time of sale.

***Threshing***

If a harvest is threshed before it is dry enough, this operation will most probably be incomplete. Furthermore, if grain is threshed when it is too damp and then immediately heaped up or stored (in a granary or bags), it will be much more susceptible to attack by micro-organisms, thus limiting its conservation.

***Storage***

Storage is the art of keeping the quality of agricultural materials and preventing them from deterioration for specific period of time, beyond their normal shelf life. Different crops are harvested and stored by various means depending on the end utilization. Whether the seed will be used for new plantings the following year, for forage being processed into livestock feed, or even for crops to be developed for a special use, the grower must be aware of harvesting and storage requirements toward a quality product. After determining the prescribed use for the crop, timing for harvest and storage is of important consideration. Along with an assessment of when to harvest, the farmer needs to determine the method of harvesting.

There are a wide range of storage structures used throughout the world to successfully store horticultural produce. In general the structure needs to be kept cool (refrigerated, or at least ventilated and shaded) and the produce put into storage must be of high initial quality.

**Storage is essential for the following reasons:**

- ✓ Perishable nature of agric. & bio-materials
- ✓ Provision of food materials all year round
- ✓ Pilling/ provision for large scale processing
- ✓ Preservation of nutritional quality
- ✓ Price control and regulation
- ✓ Optimization of farmers' gain / financial empowerment of farmers
- ✓ Opportunity for export market, etc

***Processing***

Excessive hulling or threshing can also result in grain losses, particularly in the case of rice (hulling) which can suffer cracks and lesions. The grain is then not only worth less, but also becomes vulnerable to insects such as the rice moth (*Corcyra cephalonica*).

***Marketing***

Marketing is the final and decisive element in the post-harvest system, although it can occur at various points in the agro-food chain, particularly at some stage in processing. Moreover, it cannot be separated from transport, which is an essential link in the system.

Table 2: Comparison between properties of non-perishable (mainly cereals) and perishable (roots and tubers) regarding their storage capacity (Source: FAO, 1984, quoted by Knoth, J., 1993).

| Non-perishable food crops | Perishable food crops |
|---|---|
| Harvest manly seasonal, need for storage of long duration | Possibility of permanent or semi-permanent production, needs for short-term storage |
| Preliminary treatment (except threshing) of the crop before storage exceptional | Processing in dried products as an alternative of the shortage of fresh products |
| Products with low level of moisture content (10-15 percent or even less) | Products with high level of moisture in general between 50-80 percent |
| Small "fruits" of less than 1 g | Voluminous and heavy fruits from 5 g to 5 kg or even more |
| Respiratory activity very low of the stored product, heat limited | High or even very high respiratory activity of stored products inducing a heat emission in particular in tropical climates |
| Hard tissues, good protection against injuries | Soft tissues, highly vulnerable |
| Good natural disposition for storage even for several years | Products easily perishable, natural disposition for storage between some weeks up to several months (strong influence of the varieties) |
| Losses during storage mainly due to exogenous factors (moisture, insects or rodents) | Losses due partly to endogenous factors (respiration, transpiration, germination) and partly to exogenous factors (rot, insects) |

### 1.3. Critical factors contributing to postharvest loss

Postharvest losses vary greatly among commodities and production areas and seasons:

As a product moves in the postharvest chain, PHLs may occur from a number of causes, such as improper handling or bio deterioration by microorganisms, insects, rodents or birds. An important factor in developed countries is that a large amount of the food produced is not eaten but discarded, for reasons such as it was left on the plate after a meal or it passed its expiry date. In contrast, failure to consume available food in Less Developed Countries (LDCs) is not a reported concern; instead the low-quality food remaining in markets at the end of the day is sustenance for the very poor. The issue in LDCs is inefficient postharvest agricultural systems that lead to a loss of food that people would otherwise eat, sell or barter to improve their livelihoods (Hodges et al., 2010). There are internal and external factors contributing to postharvest loss.

#### 1.3.1. Internal Factors

The following sections describe PHL occurring at all stages in the food supply chain from the moment of harvesting, to handling, storage, processing and marketing.

***Harvesting***

The time of harvesting is determined by degree of crop maturity and weather conditions.

Primary causes of losses at the harvest stage include:

- Absence of establishing maturity index for some commodities, and/or lack of maturity index for local export markets.
- Low adoption of established indices, as price and distance to market influence adoption.
- Poor weather at harvesting time which affects the operations and functionality of harvesting machines or human labor and usually increases the moisture content of the harvested products.

**NB.** Loss is also caused by employment of improper harvesting methods such as: Rough handling; untimely harvesting; lack of appropriate and/or poorly-designed harvesting tools, equipment, and harvesting containers.

***Pre-cooling***

Loss at this stage is primarily due to the high cost and lack of availability of pre-cooling facilities, inadequate training on pre-cooling technology at the commercial scale, and lack of information on cost benefits of pre-cooling technology.

***Transportation***

Primary challenges in the transportation stage of the supply chain include poor infrastructure (roads, bridges, etc.), lack of appropriate transport systems, and a lack of refrigerated transport. In most developing countries, roads are not adequate for proper transport of horticultural crops. Also, transport vehicles and other modes of transport, especially those suitable for perishable crops, are not widely available. This is true both for local marketing and export to other countries. Most producers have small holdings and cannot afford to purchase their transport vehicles. In a few cases, marketing organizations and cooperatives have been able to acquire transport vehicles but cannot alleviate poor road conditions (Kader, 2002).

***Storage***

Facilities, hygiene, and monitoring must all be adequate for effective, long-term storage. In closed structures (granaries, warehouses, hermetic bins, silos), control of cleanliness, temperature, and humidity is particularly important. It also very important to manage pests and diseases since damage caused by pests (insects, rodents) and molds can lead to deterioration of facilities (e.g. mites in wooden posts) and result in losses in quality and food value as well as quantity.

***Grading***

Proper packing and packaging technologies are critical in order to minimize mechanical injury during the transit of produce from rural to urban areas. Causes of PHL in the grading stages are: lack of national standards and poor enforcement of standards, lack of skill, awareness, and financial resources.

***Packaging and labelling***

After harvest, fresh fruits and vegetables are generally transported from the farm to either a packing house or distribution centre. Farmers sell their produce in fresh markets or in wholesale markets. At the retail level, fresh produce is sold in an unpackaged form or is tied in bundles. This type of market handling of fresh produce greatly reduces its shelf life if it is not sold quickly.

***Secondary processing***

Causes of post-harvest loss in this stage include limited availability of suitable varieties for processing, lack of appropriate processing technologies, inadequate commercialization of newtechnologies and lack of basic infrastructure, inadequate facilities and infrastructure, and insufficient promotion of processed products.

***Biological***

Biological causes of deterioration include respiration rate, ethylene production and action, rates of compositional changes (associated with color, texture, flavour, and nutritive value), mechanical injuries, water stress, sprouting and rooting, physiological disorders, and pathological breakdown. The rate of biological deterioration depends on several environmental factors, including temperature, relative humidity, air velocity, and atmospheric composition (concentration of oxygen, carbon dioxide, and ethylene), and sanitation procedures. All these factors have been discussed by numerous authors (Kitimoja and Gorny, 1999; Kader, 2002; Gross et al, 2002).

***Microbiological***

Micro-organisms cause damage to stored foods (e.g., fungi and bacteria). Usually, microorganisms affect directly small amount of the food but they damage the food to the point that it becomes unacceptable. Toxic substances elaborated by molds (known as mycotoxins) cause loss in food quality and nutritional value.

***Chemical***

Many of the chemical constituents naturally present in stored foods spontaneously react causing loses of colour, flavour, texture and nutritional value. One such reaction is the "*maillard relation'* that causes browning and decolouration in dried fruits and other product. There can also be harmful chemicals such as pesticides or obnoxious chemical such as lubricating oil (Atanda et al., 2011).

**1.3.2. External Factors**

Factors outside of the food supply chain can cause significant postharvest loss. These factors can be grouped into two primary categories: environmental factors ic and socio-economic patterns and trends.

***Environmental factors:***

Climatic conditions, including wind, humidity, rainfall, and temperature influence both the quantity and quality of a harvest (Grolleaud 2002).

***Temperature***

In general, the higher the temperature the shorter the storage life of horticultural products and the greater the amount of loss within a given time, as most factors that destroy the produce or lower its quality occur at a faster rate as the temperature increases (Atanda et al. 2011).

***Humidity***

There is movement of water vapour between stored food and its surrounding atmosphere until equilibrium of water activity in the food and the atmosphere. A moist food will give up moisture to the air while a dry food will absorb moisture from the air. Fresh horticultural products have high moisture content and need to be stored under conditions of high relative moisture loss and wilting (except for onions and garlic). Dried or dehydrated products need to be stored underconditions of low relative humidity in order to avoid adsorbing moisture to the point where mold growth occurs (Atanda et al. 2011).

***Altitude***

Within a given latitude the prevailing temperature is dependent upon the elevation when other factors are equal. There is on the average a drop in temperature of 6.5°C (Atanda et al. 2011) for each kilometre increase in elevation above sea level. Storing food at high altitudes will therefore tend to increase the storage life and decrease the losses in food provided it is kept out of direct rays of the sun (FAO, 1983).

*Time*

The longer the time the food is stored the greater is the deterioration in quality and the greater is the chance of damage and loss. Hence, storage time is a critical factor in loss of foods especially for those that have a short natural shelf life.

### 1.3.3. Socio-economic factors

Social trend such as urbanization has driven more and more people from rural area to large cities, resulting in a high demand for food products at urban centres, increasing the need for more efficient and extended food supply chains (Parfitt et al. 2010).Other socio-economic factors are linked with grain importation which can introduce new insect species, hence posing a very significant problem. Not only is the imported grain at risk, but the native grain as well. For example, in 1980, the introduction of a new insect species to Africa along with grain importation created weight losses of up to 30% in just 3-6 months of storage (Boxall 2001).

## 1.4 Critical factors governing postharvest and waste in developed and less developed countries

***Developed countries:*** Developed countries have extensive and effective cold chain systems ensuring prolonged product shelf-life. Additionally, more sophisticated management and new technologies continue to improve the efficiency with which food is brought into stores, displayed and sold. A key factor in PHL is growing consumer intolerance of substandard foods (e.g. too small) or cosmetic defects such as blemishes and misshapen produce, and this has increased the rejection rate. For example, grading to satisfy the demand for greater product specifications has led to waste for some products (Hodges et al., 2010).

***Less developed countries:*** In Less Developed Countries (LDCs), the main cause of loss is biological spoilage. Livestock products, fish, fruit and vegetables lose value very quickly without refrigeration. In contrast, roots, tubers and grain products are less perishable as they have lower moisture contents, but poor post-harvest handling can lead to both weight and quality losses. Cereal grain products are least susceptible to postharvest loss, but grain may be scattered, dispersed or crushed during handling. They may also be subject to biodeterioration (Grolleaud 1997; Boxall 2002) that may start as cereal crops reach physiological maturity. Weather is a key issue at harvest. In developing countries with hot climates, most small-holder farmers rely on sun drying to ensure that crops are well dried before storage. If unfavorable weather conditions prevent crops from drying sufficiently, then losses will be high.

The causes of food losses and waste in low-income countries are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. Given that many smallholder farmers in developing countries live on the margins of food insecurity, a reduction in food losses could have an immediate and significant impact on their livelihoods.

### 1.5. Technologies and practices to reduce post-harvest losses

There are many examples of promising practices. These range from training in improved handling and storage hygiene to the use of hermetically sealed bags and household metallic silos, and are supported by enhancing the technical capabilities of local tinsmiths in silo construction. (The World Bank et al., 2011).

The choice of technology package depends on circumstances, such as the scale of production, crop type, prevailing climatic conditions, and the farmers' affordability and willingness to pay (which are linked to social, cultural and economic implications of adoption).

#### 1.5.1. Some strategies for reducing postharvest losses are listed below:

1. Simple and basic strategy of reducing post-harvest food losses for any type of commodity.

A systematic analysis of each commodity production and handling system is the logical first step in identifying an appropriate strategy for reducing postharvest losses (Bell et al., 1999; Kitinoja and Gorny, 1999).

Table: Strategies of reducing post-harvest food losses in cereal grains

| Stage in the food system | **Description and strategy** |
|---|---|
| Harvesting | In tropical countries in general, most grains have a single annual harvesting season, although in bimodal rainfall areas there may be two harvests (e.g., Ghana and Uganda). African producers harvest grain crops once the grain reaches physiological maturity (moisture content is 20-30%) (FAO, World Bank, 2011). At this stage the grain is very susceptible to pest attacks. Poor farmers sometimes harvest crops too early due to food deficiency or the desperate need for cash. In this way, the food incurs a loss in nutritional and economic value, and may get wasted if it is not suitable for consumption. Quality cannot be improved after harvest, only maintained; therefore, it is important to harvest at the proper maturity stage and at peak quality. |
| Drying | Most farmers in Africa, both small and large, rely almost exclusively on natural drying of crops by combining sunshine and movement of atmospheric air through the product; consequently, damp weather at harvest time can be a serious cause of postharvest losses (De Lima, 1982). Grains should be dried in such a manner that damage to the grain is minimized and moisture levels are lower than those required to support mold growth during storage (usually below 13-15%). This is necessary to prevent further growth of fungal species that may be present on fresh grains. The harvested crop may be dried in the yard or in a crib as indicated in figures A and B. |
| Threshing/shelling | For some grains, particularly millet and sorghum, threshing may be delayed for several months after harvest and the unthreshed crop stored in open cribs. In the case of maize, the grain may be stored on the cob with or without sheathing leaves for some months, or the cobs may be shelled and grain stored. Some machinery suitable for small small-scale operation exists such as: maize shellers; Rice mechanical threshers which are actively being promoted by the International Rice Research Institute (IRRI). See figure C. |
| Winnow/cleaning | Usually done prior to storage or marketing if the grain is to be sold directly. For the majority of the smallholder , this process is done manually. It is relatively ineffective from a commercial perspective, since grain purchased from smallholders frequently requires screening to remove stones, sand, and extraneous organic matter. There is little incentive for smallholders to provide well-cleaned grain for marketing; as a result profits from sales are limited. See figure D. |

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|---|---|
| On-farm storage | Post-harvest losses at storage are associated with both poor storage conditions and lack of storage capacity. It is important that stores be constructed in such a way as to provide: -dry, well-vented conditions allowing further drying in case of limited opportunities for complete drying prior to storage; -protection from rain and drainage of ground water; and -protection from entry of rodents and birds and minimum temperature fluctuations. |

### 1.5.2. Strategies of reducing post-harvest food losses in perishable crops (roots and tubers)

Root and tuber crops are still living organisms after they have been harvested and losses that occur during storage arise mainly from their physical and physiological condition. The main causes of loss are associated with mechanical damage, physiological condition (maturity, respiration, water loss, sprouting), diseases and pests. To ensure effective storage of root and tuber crops, these major causative factors need to be properly understood and, where appropriate, be properly controlled, taking into account the socio-economic factors which prevail in the areas of production and marketing (FAO, 1985).

| Stage in the food system | **Description and strategy** |
|---|---|
| Harvesting | It is the most important phase.. Unless this operation is carried out with maximum efficiency, later prevention of food loss activities may be a waste of time. If, for example, roots and tubers are bruised or otherwise damaged during harvesting, consideration of improved handling or packaging is not likely to be worthwhile, since an early infestation with moulds and virus will occur and rotting will have started. If harvesting operations are correctly undertaken there is greater scope for later introduction of improved methods. Provision of the proper tools and equipment for harvesting and training workers in their correct use should be a priority prevention of food loss activity. |
| Handling | The skin of roots and tubers is an effective barrier to most of the opportunistic bacteria and fungi that cause rotting of the tissues. Breaking of the skin also stimulates physiological deterioration and dehydration. Careful digging and movement of roots and tubers significantly reduces post harvest losses. |
| Packing | Packing of the roots is usually done in the field. Farmers commonly pack the roots and strategically place the large roots |

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|---|---|
| | at the top on the bag to quickly attract the buyer on first sight. Packing should minimize deterioration of the roots within the container and cushion against impact and compression. During packing in the field care must be taken to minimise physical damage that results from impact bruises due to stacking and overfilling of bags, abrasion or vibration bruises due to root movement against each other. Therefore packages should be neither loose (to avoid vibration bruising during transport) nor overfilled, and should provide good aeration. |
| Transportation | Temperature management is critical during long distance transport, so loads must be stacked to enable proper air circulation to carry away heat from the produce itself as well as incoming heat from the atmosphere and off the road. In many developing countries traditional baskets and various types of trays or buckets are used for transporting produce to the house or to village markets. These are usually of low cost, made from readily available material and serve the purpose for transport over short distances. But, they have many disadvantages in large loads carried over long distances (i.e. they are difficult to clean when contaminated with decay organisms).<br>However, packaging can be a major item of expense in produce marketing, especially in developing countries where packaging industries are not well developed. The selection of suitable containers for commercial scale marketing requires very careful consideration. Among the various types of packaging material that are available: natural and synthetic fibre sacks and bags as well as moulded plastic boxes seem to be more suitable and have greater promise for packaging roots and tubers and for their transport to distant markets. |
| Storage | The following three things must be done to ensure successful storage of fresh roots and tubers. i) Carefully select only top quality roots and tubers without any signs of handling or pest or disease damage for storage; ii) keep them in specially designed stores and iii) check the stores at regular intervals. Many farmers do not routinely store fresh roots and tubers, but leave them in the ground until required. It is possible to store fresh roots successfully in specially constructed pits or in mounds, or clamp stores. For example, when storing potatoes, a field storage clamp is a low cost technology that can be designed using locally available materials for ventilation and insulation. |
| Processing | Root and tuber crops (cassava, sweet potato, yam etc...) are both important household food security and income generating crops in many developing countries. Overcoming the perishability of the crops, improving marketing, enhancing nutritional value and adding economic value through processing are the main strategic areas in for reducing postharvest losses. The various processing techniques are listed below: peeling and washing, grating, pressing/fermentation, |

| | |
|---|---|
| | sieving, frying/drying. All these techniques can be divided into:<br><br>Traditional methods such as drying (production of dehydrated chips); processing into „gari' and farinha de mandioca; production of bread; production of „attieke'.<br><br>Improved methods of production of dehydrated chips such as: simple processing machinery developed by the International Potato Center "CIP" (washer, peeler, slicer and dryer).<br><br>An important aspect of processing is that it is often intended to prolong the preservation period of a product under ambient conditions.<br>The most appropriate products in this respect are dehydrated root and tubers products such as: potato products (starch and flakes).<br><br>Besides permitting better preservation, the drying and processing of root and tubers into dried chips and flour offers other advantages such as:<br><br>-facilitating transport and increased shelf life<br>-creating new opportunities for the farmer such as new markets and new sources of income.<br><br>Metal storage bins or water tanks made from smooth or corrugated galvanised metal sheets are used for storing dried products.<br><br>Dehydration or sun drying is the simplest and lowest cost method of preservation and should be more widely promoted and used in developing countries because it converts a perishable commodity into a stable item with long storage life. |

http://www.ghananewsagency.org/details/Science/Post-harvest-losses-in-root-and-tuber-production-to-be-reversed/?ci=8&ai=45284

### 1.5.3. Strategies of reducing post-harvest food losses in perishable crops (fruits and vegetables)

It is important to highlight that; some varieties of the same crop store better than others. Therefore, to reduce food loss and to achieve maximum shelf-life, only varieties known to store well should be stored.

| Stage in the food system | **Description and strategy** |
| --- | --- |
| Harvesting | Harvesting should be carried out as carefully as possible to minimize mechanical injury such as scratches, punctures and bruises to the crop. The time of the day when harvesting is done also affects produce quality and shelf-life. In general, harvesting during the coolest time of the day (early morning) is desirable; the produce is not exposed to the heat of the sun and the work efficiency of the harvesters is higher. If harvesting during the hotter part of the day cannot be avoided, the produce should be kept shaded in the field to minimize product weight loss and wilting. |

| | |
|---|---|
| Handling | Mechanical injury provides sites for pest attack and increases physiological losses. Therefore, avoid mechanical injury to the crop while handling. Because of their soft texture, all horticultural products (fruits and vegetables) should be handled gently to minimize bruising and breaking of the skin. The skin of horticultural products is an effective barrier to most of the opportunistic bacteria and fungi that cause rotting of the tissues. Breaking of the skin also stimulates physiological deterioration and dehydration. Reducing the number of times the commodity is handled reduces the extent of mechanical damage. |

| | |
|---|---|
| Sorting and cleaning | Systematic sorting or grading coupled with appropriate packaging and storage, will extend shelf life, maintain wholesomeness, freshness, and quality, and substantially reduce losses and marketing costs. Sorting is done to separate poor produce from good produce, and further classify the good produce based on other quality parameters like size (Bautista and Acedo, 1987). |
| Packaging | Proper packing is essential to maintain the freshness of leafy vegetable. Packaging should be designed to prevent premature deterioration in product quality, in addition to serving as a handling unit (Bautista and Acedo, 1987). Use clean, smooth and ventilated containers for packaging. This is a very important factor in cutting down losses in these crops during harvesting, transportation, marketing and storage. Use containers that are appropriate for the crop. Examples of packaging containers can be found in Figure F. |
| Transportation | Minimizing losses during transport necessitates special attention to vehicles, equipment, infrastructure, and handling. Load and unload transport vehicles carefully. Use clean, well- ventilated vehicle covered at the top for transportation. Transport crops during the cool part of the day by driving carefully over smooth roads to minimize damage to crop. Fresh produce must not be watered prior to loading, as this will lead to decay, rotting, and extensive losses. Major causes of losses are improper handling during loading and unloading. |
| Storage | Only crops with high initial quality can be stored successfully; it is therefore essential to ensure that only crops of the highest quality (mature, undamaged) are stored. Shelf life can be extended by maintaining a commodity at its optimal temperature, relative humidity and environmental conditions. |

| | |
|---|---|
| Processing | Processing is an important value-added activity that stabilizes and diversifies food supplies and creates employment and income opportunities. It can minimize the high perishability problem of leafy vegetables. Processed products are also more stable, have improved digestibility, and permit a better diet diversity, giving consumers access to a wider choice of products and a wider range of vitamins and minerals. Few processing technologies are listed: **Drying, salting, fermenting, and pickling.** |

## 1.5.4. Strategies of reducing post-harvest food losses in cereal grains

| Stage in the food system | **Description and strategy** |
|---|---|
| Harvesting | In tropical countries in general, most grains have a single annual harvesting season, although in bimodal rainfall areas there may be two harvests (e.g., Ghana and Uganda). African producers harvest grain crops once the grain reaches physiological maturity (moisture content is 20-30%) (FAO, World Bank, 2011). At this stage the grain is very susceptible to pest attacks. Poor farmers sometimes harvest crops too early due to food deficiency or the desperate need for cash. In this way, the food incurs a loss in nutritional and economic value, and may get wasted if it is not suitable for consumption. Quality cannot be improved after harvest, only maintained; therefore, it is important to harvest at the proper maturity stage and at peak quality. |
| Drying | Most farmers in Africa, both small and large, rely almost exclusively on natural drying of crops by combining sunshine and movement of atmospheric air through the product; consequently, damp weather at harvest time can be a serious cause of postharvest losses (De Lima, 1982). Grains should be dried in such a manner that damage to the grain is minimized and moisture levels are lower than those required to support mold growth during storage (usually below 13-15%). This is necessary to prevent further growth of fungal species that may be present on fresh grains. The harvested crop may be dried in the yard or in a crib as indicated in figures A and B. |
| Threshing/shelling | For some grains, particularly millet and sorghum, threshing may be delayed for several months after harvest and the unthreshed crop stored in open cribs. In the case of maize, the grain may be stored on the cob with or without sheathing leaves for some months, or the cobs may be shelled and grain stored. Some machinery suitable for small small-scale operation exists such as: maize shellers; Rice mechanical threshers which are actively being promoted by the International Rice Research Institute (IRRI). See figure C. |

| | |
|---|---|
| Winnow/cleaning | Usually done prior to storage or marketing if the grain is to be sold directly. For the majority of the smallholder , this process is done manually. It is relatively ineffective from a commercial perspective, since grain purchased from smallholders frequently requires screening to remove stones, sand, and extraneous organic matter. There is little incentive for smallholders to provide well-cleaned grain for marketing; as a result profits from sales are limited. |
| On-farm storage | Post-harvest losses at storage are associated with both poor storage conditions and lack of storage capacity. It is important that stores be constructed in such a way as to provide: -dry, well-vented conditions allowing further drying in case of limited opportunities for complete drying prior to storage; -protection from rain and drainage of ground water; and -protection from entry of rodents and birds and minimum temperature fluctuations. |

# Chapter Two

## 2.1. Importance of Postharvest Technology in Horticultural Crops

Fresh fruits and vegetables have been part of human diet since the dawn of the history. The systematic nutritional value of some fruits and vegetables was recognized in the early 17$^{th}$ century in England. One example is the ability of the citrus fruit to cure scurvy, a diseases wide spread among naval personnel. An example of the importance of the field to post-harvest handling is the discovery that ripening of fruit can be delayed, and thus their storage prolonged, by preventing fruit tissue respiration. The knowledge of the fundamental principles and mechanisms of respiration, leading to post- harvest storage techniques such as cold storage, gaseous storage, and waxy skin coatings. Another well-known example is the finding that ripening may be brought on by treatment with ethylene.

Fruits and vegetables are being rich in vitamins and minerals, known as protective foods. Due to their high nutritive valve, ready availability, and being inexpensive they make significantly contributes to human well-being. Realizing the worth of fruits and vegetables in human health WHO recommend consumption of 120g of fruits and 280g of vegetables per capita per day.

- ✓ Fruits and vegetables are rich in ascorbic acid which have beneficial effects of wound healing and antioxidant. Dietary source of Vit. C is essential, since human beings lack the ability to synthesize it.
- ✓ Some fruits and vegetables are excellent source of beta -carotene (provitamin A) which is essential for the maintenance of eyes health; and folic acid which prevents anemia.
- ✓ These also prevent degenerative diseases which are prevalent in people with sedentary lifestyle. Concern about obesity and coronary heart diseases have led to reduced levels of fat
- ✓ intake. Antioxidants, phenolic compounds and dietary fiber are considered to be beneficial in reducing risk of various cancers.
- ✓ Many fruits and vegetables have neutraceuticals properties.

Fruits and vegetables provide variety in the diet through difference in color, shape, taste, aroma and texture that distinguish from the other major food groups of grains, meats and dairy products. Sensory appeal of fruits and vegetables is not confined to consumption but also has market value. Diversity in their color and shape is used by traders in arranging product displays to attract potential purchasers; and chefs have traditionally used fruits and vegetables to enhance the attractiveness of the prepared dishes or table presentations; to adorn meat displays and fruits and vegetables carvings have become an art.

The ornamental provides sensory pleasure and serenity, derived from the colors, shape and aroma of individual species. Garden plants, cut flowers, foliage and flowering plants are increasingly used in exterior and interior decoration. Considerable commercial opportunities arise from their role in social, religious and economic ceremonies and special greeting occasion such as festivals, Valentine"s day and others occasion.

***The need for Postharvest technology***

Fruits and vegetables and ornamentals are ideally harvested based on optimum eating or visual quality. However, since they are living biological entities, they will deteriorate after harvest. The rate of deterioration varies greatly among products depending on their overall rate of metabolism, but for many it can be rapid. For example, marketing chains where produce is transported from farm to end user with in a short time period, the rate of PH deterioration is of little consequences. However, with the increasing remoteness of production areas from population centers, the time lag from farm to market is considerable. The deliberate storage of certain produce to capture better return adds to this time delay between farm and end user, by extending the marketing periods into times of shorter supply. Thus a modern marketing chain puts increasing demands on produce and creates the need for the PH techniques that allows retention of quality over an increasingly longer period.

***Harvest****:* is a specific and single deliberate action to separates the food stuff with or without non edible portion from its growth medium.

Eg.

- ✓ Plucking of fruits and vegetables
- ✓ Reaping of cereals
- ✓ Lifting of fish from water
- ✓ lifting of tuber or roots from soil *etc*.

***Postharvest*** – all the succeeding action after harvest are defined as post-harvest technique. From this period of time all action is enters the process of preparation for final consumption.

Eg.

- ✓ pre cooling
- ✓ cleaning/washing
- ✓ trimming/sorting
- ✓ curing
- ✓ grading
- ✓ waxing
- ✓ chemical treatments
- ✓ packaging
- ✓ transportation
- ✓ storage, ripening and distribution

The extending the postharvest life of horticultural produce requires knowledge of all the factors that can lead to loss of quality or generation of unsalable material. The field of study that adds to and uses this knowledge in order to develop affordable and effective technologies that minimizes the rate of deterioration is known as Postharvest technology.

Postharvest technology is inter-disciplinary "science and technique" applied to horticultural/agriculture produce after harvest for its protection, conservation, processing, packaging, distribution, marketing, and utilization to meet the food and nutritional requirements of the people in relation to their needs. Hence thorough understanding of the structure, composition, biochemistry and physiology_of horticultural produce is essential for Postharvest technologist.

***Postharvest Shelf Life -*** Once harvested, produce is subject to the active process of senescence. Numerous biochemical processes continuously change the original composition of the produce until it becomes unmarketable. The period during which consumption is considered acceptable is defined as the time of "postharvest shelf life.

Post-harvest shelf life is typically determined by objective methods like:

- ✓ Overall appearance
- ✓ Taste, flavor, and texture of the commodity.

These methods usually include a combination of sensory, biochemical, mechanical, and colorimetric(optical) measurements.

***Postharvest Physiology -*** is the scientific study of the physiology of living plant tissues after they have been denied further nutrition by picking/harvest. It has direct applications to post harvest handling in establishing the storage and transport conditions that prolong shelf life.

***Preservation*** - the techniques of extending the storage life of the produce without deteriorating its edible quality for further use".

Horticultural produce is biological entity with various physiological activities like transpiration and respiration continuing even after harvesting. This process leads to the bio-chemical breakdown and cause spoilage of the produce. Spoilage is initiated by enzymes present inside the produce, involvement of microorganism, infestation of insect-pest and invasion of pathogens. By taking care of these factors, food products can be stored for longer period.

***Processing*** - the application of techniques to prevent losses through preservation, processing, packaging, storage and distribution.

The processed foods have now become more of a necessity than a luxury. It has an important role in the conservation and better utilization of fruits and vegetables. It is necessary in order to avoid glut and utilize the surplus during the peak seasons. It is employs modern methods to extend storage life for better distribution and also processing technique to preserve them for utilization in the off season.

Problems faced in establishment of processing unit are identified as follows.

- insufficient demand
- weak infrastructure
- poor transportation
- perishable nature of crops and
- grower sustains substantial losses

The market for many horticultural commodities has increased every time as being offered for sale in the markets and it demands innovation in the handling methods and study of their quality factors. The process which deals with handling of parts of the plants, such as fruits, vegetables, root crops, spices, foliage and flowers which are often collectively referred to as **perishable crops,** is called **postharvest management**. Perishables are botanically and physiologically very diverse and therefore behave in very different ways and require a variety of different treatments and conditions.

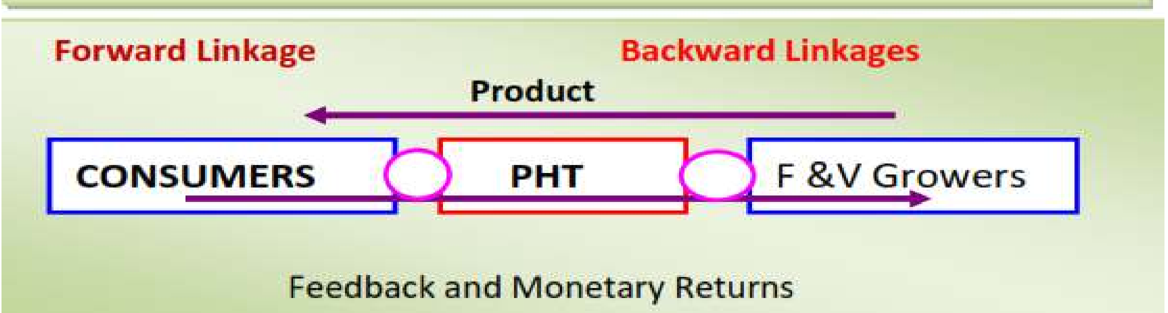
Postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Post-harvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product. Effective handling decreases postharvest losses.

The most important goals of post-harvest handling are:

- ✓ Keeping the product cool, to avoid moistre loss and slow down undesirable chemical changes
- ✓ Avoiding physical damage such as bruising, delay spoilage.

After the harvest, post-harvest processing is usually continued in a packing house. This can be a simple shed, providing shade and running water, or a large-scale, sophisticated, mechanized facility, with conveyor belts, automated sorting and packing stations, walk-in coolers. In mechanized harvesting, processing may also begin as part of the actual harvest process, with initial cleaning and sorting performed by the harvesting machinery. Implementing Good Agricultural Practices in production and harvest; Good Manufacturing Practices especially during post-harvest and Quality and Safety Assurance Systems, such as Hazard Analysis Critical Control Point, throughout the food chain to avoid and to control hazards are of the key factors for the flourishing nature of the postharvest industries.

**Fig 2.1. Postharvest technology and its sub - disciplines**


**Postharvest technology functioning chain**

Effective management during the postharvest period, rather than the level of sophistication of any given technology, is the key in reaching the desired objectives. Many simple practices have successfully been used to reduce losses and maintain produce quality of horticultural crops in various parts of the world for many years.

There are many interacting steps involved in any postharvest system. Produce is often handled by many different people, transported and stored repeatedly between harvest and consumption. While particular practices and the sequence of operations will vary for each crop, there is a general series of steps in postharvest handling systems that are often followed.

- ✓ Harvesting and preparation for market
- ✓ Curing root, tuber and bulb crops
- ✓ Packinghouse operations
- ✓ Packing and packaging materials
- ✓ Decay and insect control
- ✓ Temperature and relative humidity control
- ✓ Storage of horticultural crops
- ✓ Transportation of horticultural crops
- ✓ Handling at destination
- ✓ Packing and Packaging Practices

***Postharvest technology importance and role:***

- ✓ Postharvest reduction
- ✓ Value addition
- ✓ Contribution to the Economy
- ✓ Making availability of fruits and vegetables during off seasons
- ✓ Tools for export earnings
- ✓ Employment generation
- ✓ Adding variety in taste and nutrition
- ✓ Waste utilization
- ✓ Home scale preservation
- ✓ Supply of food to the defense forces
- ✓ Special canned fruits for infants & children"s
- ✓ Food supplier to the Astronauts

***Role of Postharvest Technologist:***

1. To provide quality, nutritious and safe food

2. To develop new product & technologies - **Discoveries -** The best example for the highest postharvest life in the nature is the Swiss Apple - *Uttwiler Spatlauber*, is well known for its excellent storability; it can stay fresh looking for up to four months after being harvested. However, it has not been widely cultivated because of its sour taste.

**Innovation** – biotechnology has been used to extend the storage life in tomato and developed variety called FLAVR SAVR - using technology to reduce the activity of the enzyme endopolygalcturonase, which involved in the cell wall breakdown during ripening and fruit will remain firmer during ripening on and off the plant.

3. To develop new equipment and determine their efficiency.

For these, there is a wide range of technologies available that, if adopted, would enable smallholders and larger producers to improve the quality and quantity of food/grains during postharvest handling and storage. The Postharvest loss strategy should be better integrated into agricultural programs to provide technical advice and affordable solutions to farmers. For smallholders with few options to invest in improved postharvest practices and technologies, the simplest option and one with only minor financial implications is improvement in basic storage hygiene and good storage management.

# Chapter –Three

**Basics of postharvest physiology and technology**

**3.1. Recent Advances in Postharvest Technologies for high-value perishables (Fruits & Vegetables)**

International trade in high-value perishables has grown enormously in the past few decades. In the developed world, consumers now expect to be able to eat perishable produce from all parts of the world, and in most cases throughout the year. This trade is an important source of income for many, and is becoming increasingly important as a source of revenue for many tropical developing countries. This trade is possible only through the development of technologies for extending the storage life of perishable plant products. Some of the most important technologies are summarized below.

***A. Development of the cold chain***

Temperature control is probably the single most important factor in the extension of storage life of perishable products. Generally, a decrease in temperature slows metabolism and development. However,for all commodities there is a temperature below which tissue damage occurs. This varies by commodity, from — 1°C for certain temperate commodities, such as pears, to 15°C for tropical products, such as bananas and sweet potato.  It is now appreciated that very significant quality improvements can be achieved by considering cooling immediately after harvest, and maintaining appropriate temperature through the whole handling chain. In developed countries this can extend even into the consumer's home, as the use of domestic refrigerators becomes more widespread. The control of temperature through the whole handling chain is often referred to as the cold ***chain.***

***B. Controlled atmosphere storage and modified atmosphere packaging***

As well as by lowering the temperature, metabolic processes and development of perishable plant produce can also be slowed down through modification of the storage environment, usually by decreasing oxygen concentration, sometimes with an associated increase in carbon dioxide concentration. In some cases, the atmospheric concentrations are closely controlled throughout the storage period *(controlled atmosphere storage),* and in other cases, after an initial modification period, the atmosphere may be allowed to alter through respiration of the commodity itself *(modified atmosphere storage).* Modified atmospheres may be used on a scale as large as a container or pallet (100s-1000s kg), or down to the scale of individual consumer packs (< 500 g). The technologies and how they are applied to a wide range of perishable plant products are thoroughly reviewed by Thompson (2010).

### *C. Ethylene control technologies*

The importance of ethylene control for maintenance of quality in perishable plant products is now widely recognized. Ethylene gas ($C_2H_4$) is produced naturally by most plant tissues, especially ripening fruit. It is a plant hormone that controls many biological processes. Ethylene is a gas at ambient temperatures, so that if one plant or plant organ starts to produce ethylene, nearby plant tissues are also affected. For plants many processes involving tissue death, such as leaf drop in deciduous trees, petal drop in flowers and over-ripening of fruit, are actively controlled as part of the natural life cycle, and are controlled or stimulated by ethylene. For this reason, during handling of fresh produce exposure to ethylene can speed up deterioration.

As it controls so many processes associated with the quality of fruit and vegetables, ethylene is an extremely important chemical for the fresh produce handling industry. On the one hand, it is used to trigger ripening in fruits. Thus bananas are transported green to the United Kingdom and are then stimulated to ripen by being fumigated with ethylene within warm ripening rooms. On the other hand, as set out above ethylene will stimulate deterioration and senescence. Ethylene control strategies are therefore key for maintenance of quality.

The concentrations at which ethylene can affect produce are very low. There is evidence that many products are sensitive to concentrations well below 100 parts per billion (ppb). In the United Kingdom, ethylene is known to build up in pack-houses to concentrations near 1000 ppb (= 1 part per million [ppm]), which is above the threshold of sensitivity of most produce. A study conducted on a range of perishable produce showed a 60% extension of post-harvest life when stored in <5 ppb compared with 100 ppb ethylene (Willset al. 1999).

Processes controlled by ethylene can be classified into two types: System 1 and System 2.

***System 1 ethylene stimulates the process:*** If ethylene concentrations are increased the process goes faster, and if ethylene concentrations are reduced or ethylene is removed completely then the process slows or stops. This is the case for ethylene stimulation of the deterioration or senescence of vegetables, the ripening of non-climacteric fruit, the over-ripening or senescence of fruit (both non-climacteric and climacteric), and the discoloration of cucumber and browning of broccoli.

***System 2 ethylene acts as a switch that cannot be stopped:*** If ethylene levels are reduced or ethylene is removed completely, then the process continues. This is the case for the initiation of ripening of climacteric fruit.

### *D. 1-Methylcyclopropene (*1-MCP)

An important development in the management of ethylene during post-harvest handling of fresh produce was the discovery of the chemical 1-methylcyclopropene (1-MCP). 1-MCP acts as an ethylene antagonist by binding ethylene receptors within the cells of the plant tissues and thereby blocking the ethylene response. Other ethylene antagonists such as silver thiosulphate and ethylene synthesis inhibitors such as amino-ethyoxy-vinyl-glycine (AVG) were already known. However, 1-MCP has turned out to be an extremely useful chemical both as a tool to investigate ethylene physiology and as a commercial post-harvest treatment to counteract ethylene effects and extend shelf life (Blankenship & Dole 2003). The use of 1-MCP for the handling of individual commodities is discussed in many chapters of this book.

## 3.2. Physiological and Biochemical aspects of Postharvest Handling

Perishable plant products, on the other hand, have high moisture content and tend to be softer so that they are more susceptible to physical damage. Perishable plant products include fleshy fruits (apples, tomatoes bananas, mangoes), root crops (potatoes, cassava, sweet potato, yam, onion), leafy vegetables (cabbage, spinach, lettuce), and vegetables arising from stems (celery). There is a wide range in storability among the perishables once they have been harvested. Root crops (storage roots and tubers) tend to be the least perishable. This is consistent with their physiological purpose to survive between growing seasons in order to produce a new plant. Fruits and flowers, on the other hand, are very perishable, often with a potential storage life of only a few days. As far as the plant is concerned, their physiological role is transient; once it is complete the tissues die, usually through the process of *senescence,* an active, programmed cell death. Leafy vegetables are very prone to water loss once they have been separated from the plant roots, which normally act as their source of water. When considering the main constraints to storage for durable and perishable plant products, pests and diseases are very important for durables, whereas maintenance of quality in perishable products is very dependent on the physiological health of the plant tissues.

### 3.2.1. Physiological classification of fruit based on their respiratory behavior

Physiologically fruits are classified as ***climacteric*** or ***non- climacteric*** according to their respiratory behavior and ethylene production rates during ripening. The volatile plant hormone, ethylene, stimulates a wide range of plant responses including fruit ripening (Oetiker & Yang 1995; Rees & Hammond 2002).

**Climacteric fruits** are those whose ripening is accompanied by a distinct increase in respiratory rate (climacteric rise) which is generally associated with elevated ethylene production just before the increase in respiration. After the climacteric rise, ethylene production declines significantly. Ethylene is necessary for the co-ordination and completion of ripening.

**Non-climacteric fruits** are those that do not exhibit increases in ethylene and respiration, but rather undergo a gradual decline in respiration during ripening. It is a general rule that climacteric fruit can be picked mature but unripe, and can then be ripened off the plant, whereas non-climacteric fruit will not ripen once picked. However, even in non-climacteric fruit the quality can change after harvest in such a way as to make the fruit more palatable. For example, pineapples will soften after harvest. Non-climacteric fruit such as pineapples and oranges can be artificially de-greened by the application of ethylene.

In the case of some fruit, the classification as climacteric or non-climacteric is not straight forward, and is still a matter of debate. For example, muskmelon was originally thought to be climacteric, but is now considered by some scientists as non-climacteric (Obandoet al. 2007). Several scientific papers have been published on guava; some scientists conclude that it is non-climacteric, and others that it is climacteric, while a few scientists suggest that varieties may differ in their classification (Brown & Wills 1983; Reyes & Paull 1995).

In climacteric fruits such as *apple, pear, banana, tomato, and avocado*, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, microliter/L), whereas in non-climacteric fruits such as *orange, lemon, strawberry, and pineapple*, ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening. Climacteric fruits respond to external ethylene treatment by an early induction of the respiratory climacteric and accelerated ripening in a concentration-dependent manner. Non-climacteric fruits, on the other hand, show increased respiration in response to increased levels of ethylene concentration without showing acceleration in the time required for ripening. Vegetables produce very low amounts of ethylene most of them with less than 0.1 µL/(kg h), with slightly higher levels as in cassava (1.7 µL/kg h), breadfruit (1.2 µL/kg h), and cucumber (0.6 µL/kg h) when measured at 20–25◦C.

Table 3.1. Classification of Some Major Fruits into Climacteric and Non- climacteric

| **Climacteric fruit** | | **Non-climacteric fruit** | |
|---|---|---|---|
| Apple | Pear | Blackberry | Orange |
| Apricot | Pepper (chilli) | Cherry | Pepper (bell) |
| Avocado | Persimmon | Grape | Pineapple |
| Banana | Plum | Grapefruit | Pomegranate |
| Cherimoya | Quince | Lemon | Prickly pear |
| Kiwifruit | Sapodilla | Lime | Rambutan |
| Mango | Sapote | Longan | Strawberry |
| Nectarine | Tomato | Loquat | Tamarillo |
| Papaya | Passion fruit | Lychee | Watermelon |
| Peach | | Mandarin | Muskmelon |

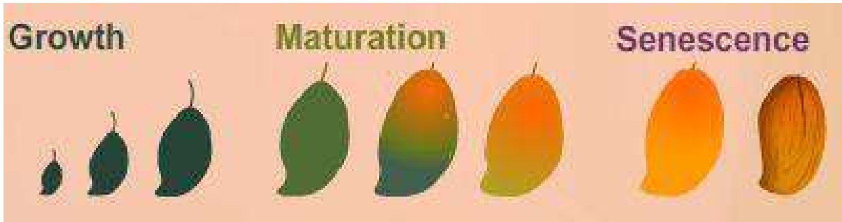
Source: UC Davis (2011)

### 3.2.2. Physiology of fruit and vegetables

Horticultural Produce respire by taking up $O_2$, giving off $CO_2$ and heat and also transpire. While attached to plants, losses due to transpiration and respiration are replaced by flow of sap, which contain water, photosynthates and minerals. These functions continue even after harvest, and since the produce is now removed from the its normal source of $H_2O$, photosynthates and minerals, the produce entirely depend on their own food reserves and moisture content. Therefore, losses of repairable substrates and moisture are not made up and deterioration has commenced hence, produce are perishable. Also, fruits and vegetables are living entities and diverse in structure, composition and physiology. They have the typical plant cell system.

The life of fruit and vegetables can be conveniently divided into three major physiological stages following germination.

These are: Growth → Maturation → Senescence




- ✓ ***Growth*** - involves cell division and subsequent cell enlargement, which accounts for the final size of the produce.
- ✓ ***Maturation*** **-** usually commences before growth ceases and includes different activities in different commodities. Growth and maturation are often collectively referred to as the development phase.
- ✓ ***Senescence*** - is defined as the period when synthetic (anabolic) biochemical process gives way to degradative (catabolic) process, leading to ageing and finally death of the tissue.
- ✓ ***Ripening*** - is a phase of qualitative change which occurs in fruits particularly, after completion of maturation, during which the fruit becomes acceptable for consumption in terms of taste and flavor. Ripening occur during the later stages of maturation and is the first stage of senescence.

Normally development and maturation processes are completed before harvest. The completion of this stage is referred to as 'maturity'. But depending upon the nature of produce and the desired characteristics in a particular fruit or vegetable, the stage of maturity differs. Sometimes in fruits like mango, it has to attain the full stage of maturation to develop the characteristic flavor and taste, while in vegetables like Okra/beans/drumstick it should not mature fully where it becomes fibrous and unpalatable. Similar terminology may be applied to the vegetables, ornamental and flowers, except that ripening stages does not occur. As consequence it is very difficult to delineate the changes from maturation to senescence in vegetables and ornamentals. Vegetables are harvested over a wide range of physiological ages, that is, from a time well before the commencement of maturation through to the commencement of senescence. Based on this requirement terms like 'physiological maturity' and 'harvest maturity' are used.

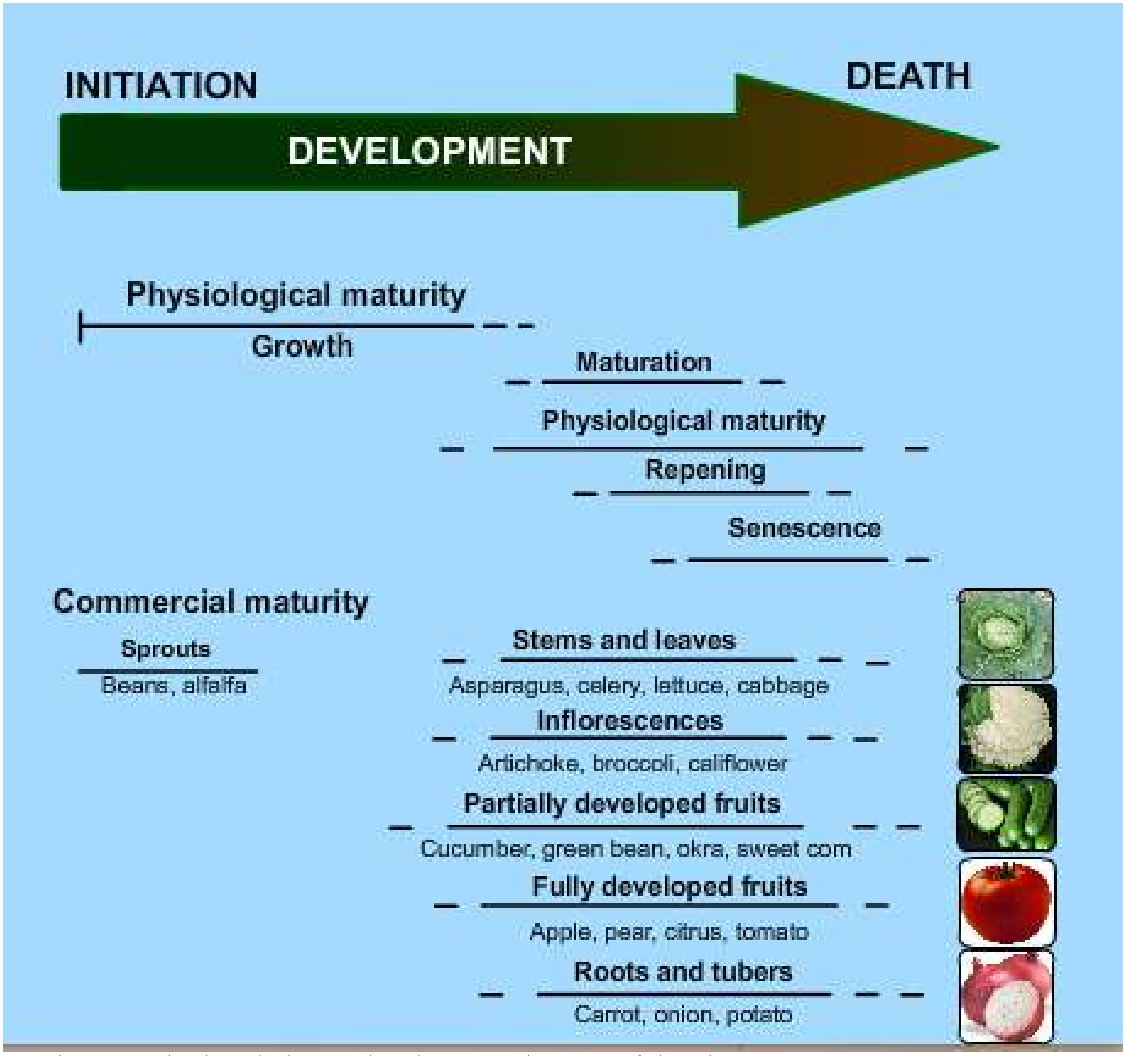
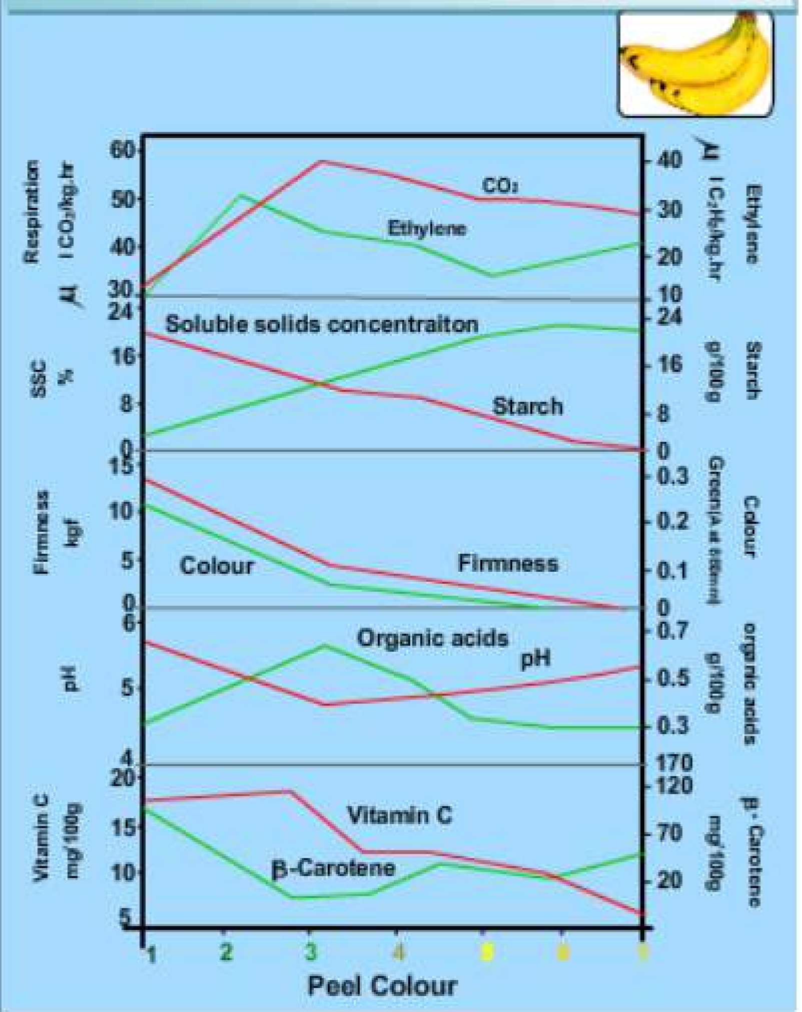


Fig. Maturity in relation to developmental stages of the plant

Fig. Physiological changes that occur during ripening of Cavendish banana (var. Williams). The peel colour stage indicate the change from green (stage 1) to full yellow (stage 6) and finally to stage skin pitting occur (stage 7) at $20^0C$



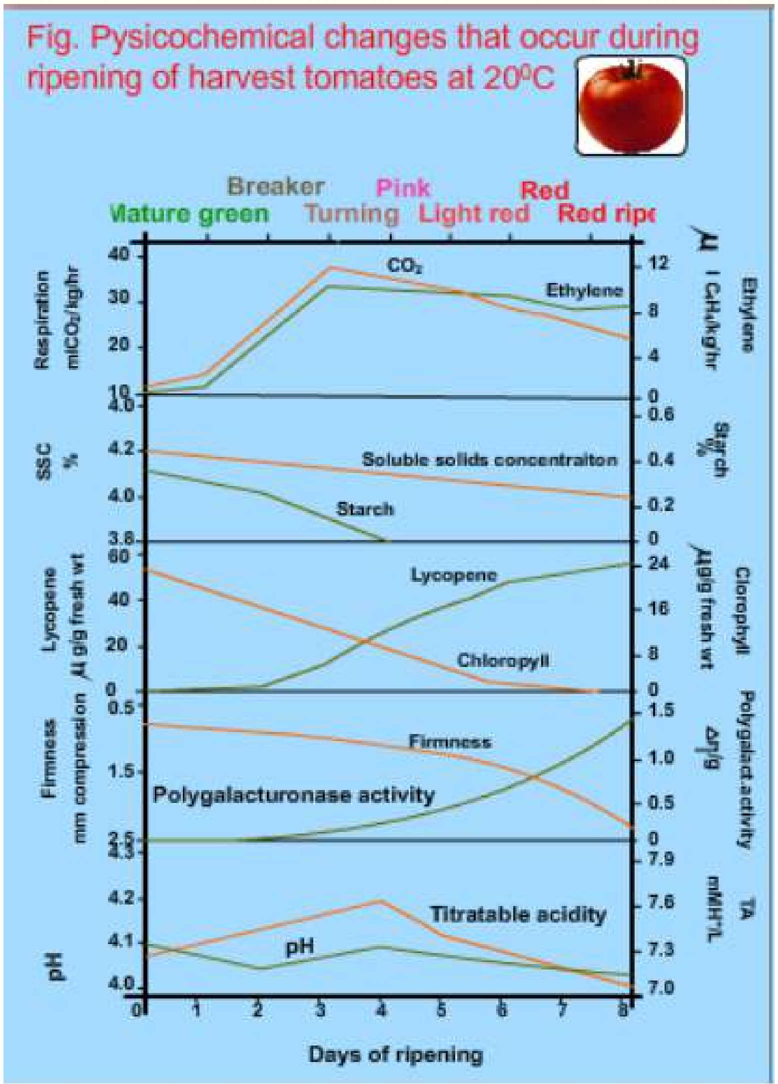



Fig. Pysicochemical changes that occur during ripening of harvest tomatoes at 20$^0$C

## *Respiration*

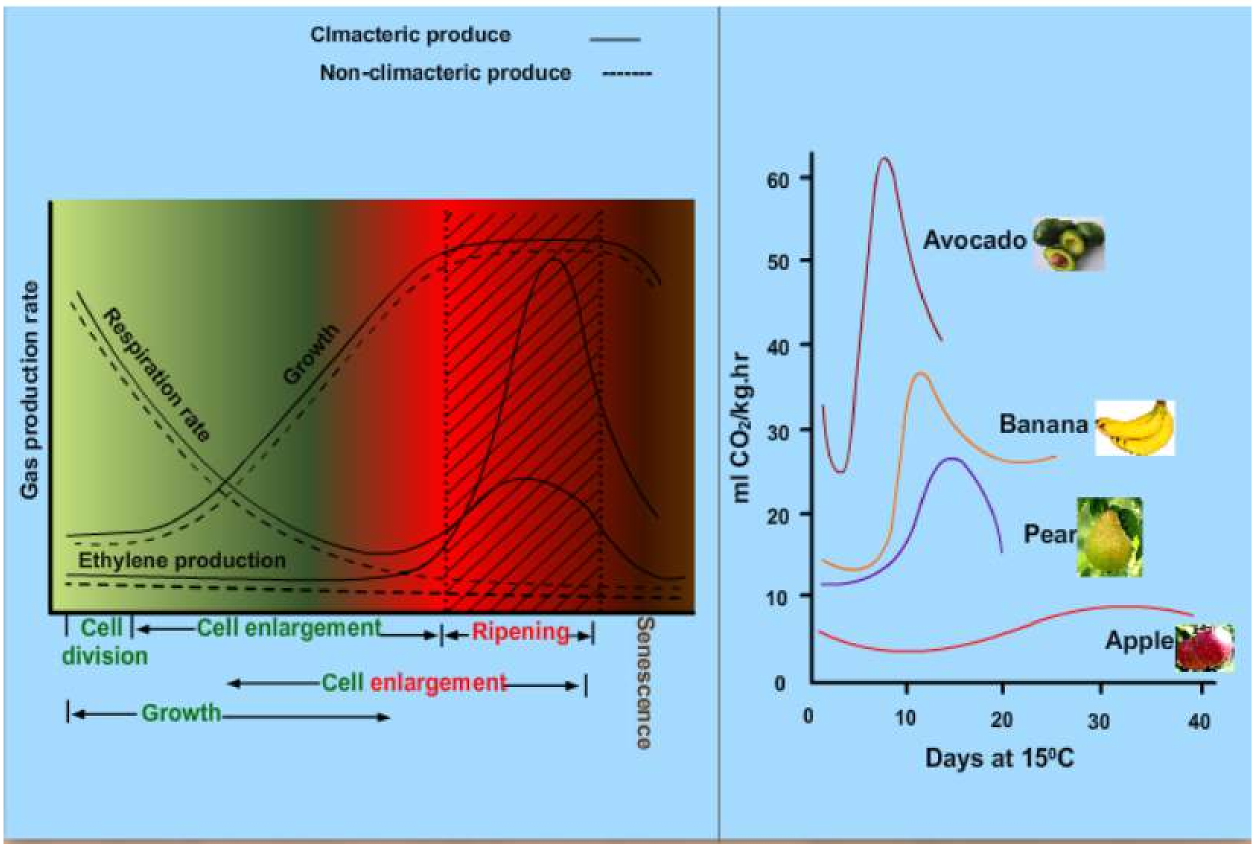
One of the major physiological and biochemical change which occur in fruits and vegetables is a change in the pattern of respiration. The respiration rate of produce is an excellent indicator of the metabolic activity of the tissue and thus is a useful guide to the potential storage life of the produce. If the respiration rate of a fruit or vegetable is measured as their $O_2$ consumed or $CO_2$ evolved during the course of the development, maturation, ripening and senescent period, a characteristic respiratory pattern is observed. The respiratory pattern also impacts the pattern of evolution of ethylene. Based on this pattern, fruits can be classified into ‘climacteric’ and ‘non-climacteric’.

Few fruits exhibit the pronounced increase in the respiration (increase in $CO_2$ and $C_2H_4$) coincident with the_ripening, such increase in the respiration is known as respiratory climacteric, and this group of fruits is called climacteric.

Table 3.2. Difference between climacteric and non-climacteric fruits

| | **Climacteric fruits** | **Non- Climacteric fruits** |
|---|---|---|
| 1 | Normally they ripen after harvest | Fruit that does not ripen after harvest. Ripen on the plant itself. |
| 2 | The quality of fruit changes drastically after harvest characterized by softening, change in colour and sweetness. (except in avocado, which will ripen only after detached from the plant) | The quality do not change significantly after harvest except little softening. Do not change to improve their eating characteristics |
| 3 | Exhibits a peak in respiration | Does not exhibit a peak |
| 4 | More ethylene is produced during ripening | Little / No ethylene production |
| 5 | Significant increase in $CO_2$ production | No significant increase in $CO_2$ production |
| 6 | Significant increase in $CO_2$ production | Slowly |
| 7 | Decrease in internal oxygen concentration | More |
| 8 | Low concentration of ethylene 0.1-1.0 µ L/L/day is sufficient to hasten ripening | Not much response is seen to exogenous application of ethylene. |
| 9 | Eg - Many except in the opposite column | Eg- Bell pepper, Blackberry, Blueberry, Cacao, Cashew apple, Cherry, Citrus sp.,Carambola, Cucumber, Eggplant, Grape, Litchi, Loquat, Okra, Olives, Pea, Pineapple, Pomegranate, Pumpkin, Raspberry, Strawberry, Summer squash, Tart cherries, Tree tomato and *rin* & *nor* tomato, Watermelon |

A B




| | |
|---|---|
| (A) growth, respiration and ethylene production patterns of climacteric and non-climacteric fruits | (B) respiratory patterns of harvested climacteric fruit |

## ***Respiration Processes***

Respiration is a process in which stored organic materials (carbohydrates, protein, and fat) are broken down into simple end products with release of energy. Oxygen is used in this process and carbon dioxide is produced.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy (686 k.cal)}$$

Oxidation of glucose generates an equal amount of $CO_2$ for the $O_2$ consumed, whereas oxidation of malate generate more $CO_2$ then the $O_2$ consumed. This ratio between the oxygen consumed and carbondioxide produced is called respiratory quotient. This relationship is important in measuring respiration by gas exchange. The $O_2$ concentration at which anaerobic respiration commences varies between tissues and is usually below 1 % V/V and off falvour may results from fermentation.

Respiration influences the product in following manner:

- ✓ Reduced food value (energy value) for the consumer
- ✓ Reduced flavor due to loss of volatiles
- ✓ Reduced sweetness
- ✓ Reduce weight
- ✓ Important for the commodities desire dehydration

The rate of deterioration of horticultural commodities is directly proportion to the respiration rate. On the basis of their respiration rate we can classify different fruit and vegetables in following way:

Table 3.3. Classification of horticultural commodities according to their respiration rate

| **CLASS** | **Range at $5^{o}$ C ($mg\ CO_2\ Kg^{-1}\ hr^{-1}$)** | **COMMODITIES** |
|---|---|---|
| Very low | < 5 | Dates, Dried fruit and vegetables, Nuts, *etc*. |
| Low | 5 - 10 | Apple, Beet, Celery, Citrus Fruits, Garlic, Grapes, Kiwi Fruit, Onion, Papaya, Pineapple, Potato (Mature), Sweet Potato, Watermelon *etc*. |
| Moderate | 10 - 20 | Apricot, Banana, Cabbage, Carrot (Topped ), Cherry, Fig, Lettuce (Head), Mango, Peach, Pear, Plum, Potato (Immature), Radish (Topped), Tomato, Summer squash |
| High | 20 - 40 | Avocado. Carrot (with tops), Cauliflower, Leeks, Lettuce (Leaf), Radish (with tops), Raspberry |
| Very high | 40 - 60 | Artichoke, Bean Sprouts, Broccoli, Brussels sprouts, Cut flowers, Green Onion, Okra |
| Extremely high | > 60 | Asparagus, Mushroom, Parsley, Peas, Spinach, Sweet corn |

**Factors responsible for the respiration (external and internal)**

- ✓ Temperature
- ✓ RH
- ✓ Gas composition in the ambient and within the cell
- ✓ Moisture content of the tissue
- ✓ Wounding or injury
- ✓ Type of the plant parts
- ✓ Stage of development of tissue
- ✓ Surface area to volume of the produce
- ✓ Pre-harvest treatments and PH methods employed
- ✓ Chemical composition of tissue
- ✓ Size of the produce
- ✓ Presence of natural coating on the surface

### 3.3. Ethylene – its role, biosynthesis and effects

Ethylene is a natural plant hormone released by all plant tissues and microorganisms. It is also called 'Ripening hormone', as it plays an important role in ripening process. Low concentration of 0.1-1.0 microlitres is sufficient to trigger the ripening process in climacteric fruits. It has autocatalytic activity because of which such small quantities can trigger further release of large quantities of ethylene by the fruit tissue. Very little response is only seen to exogenous application of ethylene in case of non-climacteric fruits. Production of ethylene results in premature ripening of certain horticultural produce.

All fruits produce minute quantity of ethylene during development, however, coincident with ripening, climacteric fruits produce much larger amount of ethylene than non-climacteric fruits

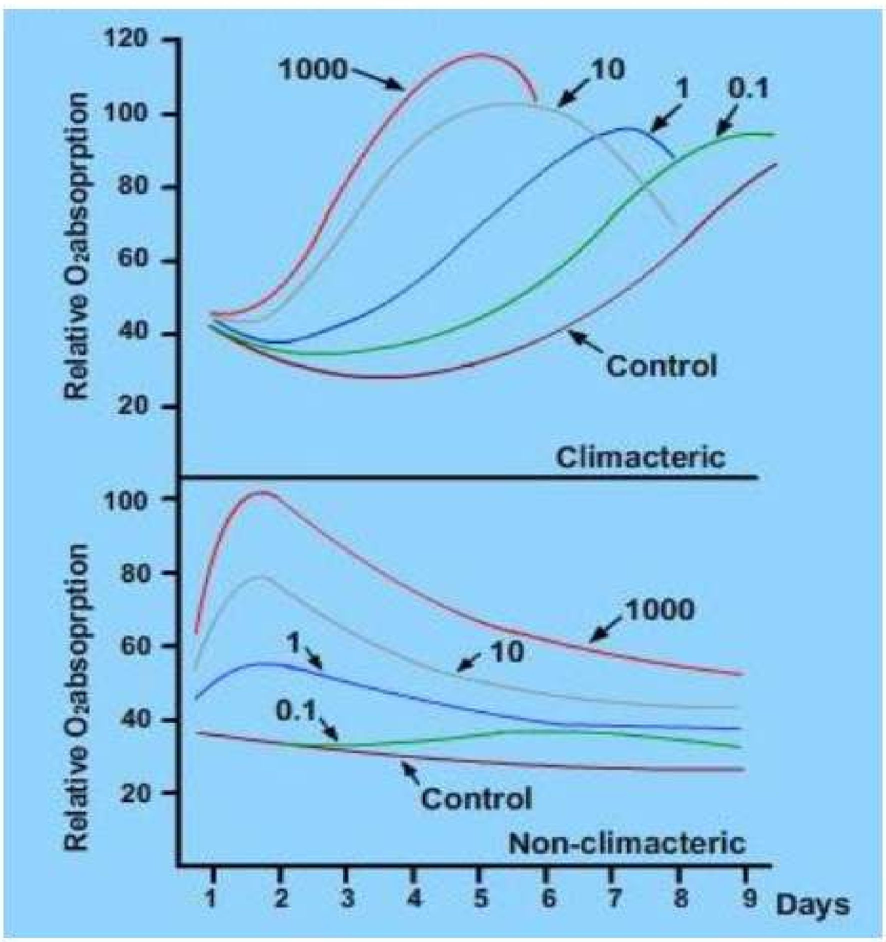
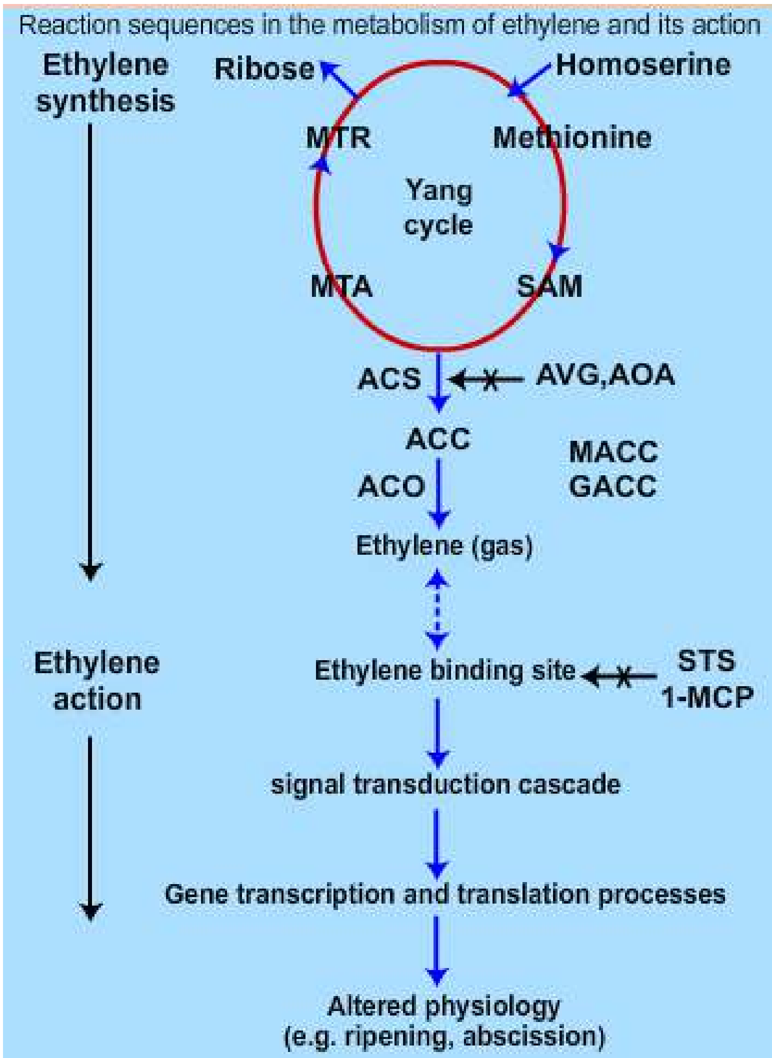



Fig. Effects of applied ethylene on respiration of climacteric and non-climacteric fruits

**Ethylene Biosynthesis**




Ethylene has been shown to be produced from methionine via a intermediates S-adenosyl-methionine (SAM) and 1-aminocyclopropane-1-carboxylic acid (ACC). The conversion of SAM to ACC by the enzymes ACC Synthase(ACS). In higher plants, ACC can be removed by conjugation to form malonyl ACC (MACC) or glutamyl ACC (GACC). Ethylene forming enzyme (EFE) or ACC oxidase (ACO) is required to convert ACC to ethylene. ACO is a liable enzyme and sensitive to oxygen and attached to outer layer of the plasmalemma. Factor that effect the activity of the ACS includes fruit ripening, senescence, auxin, physical injuries and chilling injury. This enzyme (ACS) is strongly inhibited by amino-oxy-acetic acid (AOA), rhizobitoxine and amino ethoxy vinayl glycine (AVG). ACO is inhibited by anaerobiosis, temperature above $35^0$C and cobalt ions.

The immediate precursor of ethylene is ACC, which undergoes oxidation by ACC oxidase to generate ethylene. Biochemical steps involving ACC synthase and ACC oxidase are the key regulatory points in the biosynthesis of ethylene. ACC synthase that is localized in the cytoplasm is a soluble enzyme with a relative molecular mass of 50 kDa (kilodalton). ACC synthase has several isoforms that are differentially expressed in response to wounding, other stress factors, and at the initiation of ripening.

ACC synthase is the rate-limiting enzyme of the ethylene biosynthetic pathway and requires pyridoxal-5-phosphate as a co-factor. ACC synthase is inhibited by pyridoxal phosphate inhibitors such as amino-ethoxy-vinyl-glycine and amino-oxy-acetic acid. Field application of amino-ethoxy-vinyl-glycine as a growth regulator is a practical method of delaying the ripening in fruits such as apples, peaches, and pears. As well, controlled atmosphere storage at very low oxygen levels (1–3%) is a common practice in commercial operations for long-term storage of fruits such as apples to reduce the production of ethylene, since oxygen is required for the conversion of ACC to ethylene.

Among various chemical used for extension of shelf life fruits 1-MCP has been found to be very effective. The 1-methyl cyclo propene (1-MCP) has been shown to be highly effective inhibitors of $C_2H_4$ action. 1–MCP binds irreversibly to the $C_2H_4$ receptors in sensitive plants tissues and a single treatment with low concentration for a few hours at ambient temperatures confers protection against $C_2H_4$ for several days. Many fruits respond to 1-MCP in extension of storage life by retarding the process of ripening.

The pattern of C2H4 production in tomato is it rises before the onset of ripening, where as in, apple and mango it does not rise before increase in reparation. Immature tomato fruit has high rate of C2H4 production and it extremely tolerance to C2H4 but banana and melons can readily ripened with C2H4 even when immature.

On the basis of ethylene production rate horticultural commodities are classified into following way:

| Class | Range at $20^0$ C ($\mu$ $C_2H_4$ release $kg^{-1}hr^{-1}$) | Commodities |
|---|---|---|
| Very low | < 0.1 | Artichoke, Asparagus, Cauliflower, Cherry, Citrus fruits, Grape, Cut Flowers, Leafy Vegetables, Pomegranate, Potato, Root Vegetables, Strawberry |
| Low | 0.1-1.0 | Brinjal, Chilli, Cucumber, Green Capsicum, Okra, Pine apple, Pumpkin, Water melon |
| Moderate | 1.0 -10 | Banana, Guava, Fig, Litchi, Melon, Mango, Tomato |
| High | 10-100 | Apple, Apricot, Avocado, Kiwi Fruit (ripe), Papaya, Peach, Plum, Pear |
| Very high | > 100 | Sapota, Passion Fruit |

**Ripening** is a catabolic process wherein the fruit undergoes a chain of biochemical reactions involving changes in colour, texture and taste.

**Table: Biochemical changes that occur during the ripening of fruit**

| | **Events** | **Quality Parameters** |
|---|---|---|
| 1 | Seed maturation | |
| 2 | **Change in pigmentation** | Colour |
| | ✓ Degradation of chlorophyll | |
| | ✓ Unmasking of existing pigments | |
| | ✓ Synthesis caroteniod | |
| | ✓ Synthesis anthocyanin | |
| 3 | **Softening** | Texture |
| | ✓ Change in pectin composition | |
| | ✓ Changes in other cell wall | |
| | ✓ Hydrolysis of storage materials | |
| 4 | **Change in carbohydrates composition** | Flavour |
| | ✓ Starch conversion to sugars | |
| | ✓ Sugar conversion to starch | |
| 5 | Production of aromatic volatiles | |
| 6 | Changes in organic acids | |
| 7 | Fruit abscission | Dropping |
| 8 | Change in repatriation rate | |
| 9 | Change in rate of $C_2H_4$ synthesis | Ripening |
| 10 | Change in tissue permeability | Softening |
| 11 | Change in proteins | |
| | ✓ Quantitative | |
| | ✓ Qualitative – enzymes synthesis | |
| 12 | Development of surface waxes | Shining |

***Color Development in fruit***

The change in color is either due to synthesis of plant pigments are due to unmasking of already existing color. Change in color is due to chlorophyll, which is magnesium organic complex. The loss of green color is due to degradation of chlorophyll structure. Change in color development is common except avocado, kiwi fruit and Granny Smith Apple. Chlorophyll degradation leads to development of yellow/orange/red/purple pigments.

The principle agents responsible for the degradation are

- ✓ change in pH,
- ✓ oxidation systems or
- ✓ enzymes chlorophyllases

Carotenoids are stable pigments and remain there till senescence. They are either synthesized during developmental process or they are masked by the presence of chlorophyll. This kind of change is seen in case of banana. While in tomato, the color pigment lycopene is developed simultaneously with degradation of chlorophyll. Other pigments found in fruits and vegetables are anthocyanins. They are red-purple or blue water soluble phenolic glucosides that are found in vacuoles like in beet root and epidermal cell of apple and grape. They produce strong color, which often mask carotenoids and chlorophyll. In acidic pH levels the anthocyanins are red in color and in alkaline pH they tend to become blue. This gives rise to a phenomenon in roses known as 'blueing', whereas shift from red to blue coloration occur with aging. This is due to depletion of CHO and release of free amino acids resulting in more alkaline pH in the cell sap.

### *Changes in texture and taste*

On ripening of fruits, breakdown of starch to sugars, which affects taste and texture of the produce as:

**a.** ***Textural Changes -*** The texture of the fruit softens with ripening. This is because of the action of enzymes like hydrolases (poly galacturonase, pectin methyl esterase and cellulases) which breakdown the pectins, cellulose and hemicellulose.

Propectin is insoluble form of pectic substances binds to calcium and sugars in the cell wall. On maturation and ripening, propectin gradually broken-down to lower molecular weight fraction which are more soluble in water. The rate of degradation of pectic substances is directly correlated with rate of softening of the fruit.

***b.*** ***Change in Taste -*** The primary change in taste is the development of sweetness in fruits after ripening. During ripening the starch break down into simple sugars like glucose, fructose and sucrose which are responsible for sweetness. This change is also mediated through the action of various enzymes like amylase, invertase, phosphorylase, *etc*.

### 3.4. Changes in Vegetables

***Seeds -*** are consumed as fresh vegetables, for eg. Sweet corn (baby corn), have high levels of metabolic activity, because they are harvested at immature stage. Eating quality is determined by falvor and texture, not by physiological age. Generally, seeds are sweeter and tender at an immature stage. With advancing maturity, the sugars are converted to starch, with a result of loss of sweetness: water content also decreases and amount of fiber material increases.

***Texture -*** in edible flower/buds/stems/leaves, textures is an often dominant character that determines the both harvest date and quality, as loss of turgor through water loss causes a loss of texture. The natural flavor is often less important than texture, as many of these vegetables are cooked and seasoned with salt and spices.

***Bulbs/roots/tuber -*** in these crops using appropriate storage condition their storage shelf life can be prolonged.

**Events of changes during maturation/ripening of Horticultural produce**

| Increase | Decrease |
|---|---|
| $CO_2$ | Starch |
| $C_2H_4$ | Chlorophyll |
| Colour pigments | Firmness |
| Polygalcturonase activity | Vit.C at the end |
| Acidity (marginal) | Texture |
| pH (marginal) | Water |
| Sugars | |
| Organic acids | |
| Aroma | |
| Sweetness | |
| Fibre at the end | |

## 3.5. Biochemical composition of fruits

**Water –** Most of the fruits and vegetables contain 70-80% moisture while some vegetables like leafy vegetables and melons contain almost 92-95% moisture. The tubers crop like cassava, yam and corms contain less moisture (around 50%) and are more starchy. Moisture plays an important role in fruits and vegetables because many of the nutrients exist in soluble state in them. The higher moisture content makes the fruits, vegetables and flowers perishable as it is easily vulnerable to attack by microorganisms. Further moisture is lost during the biological activity of these commodities which deteriorates its quality in terms of freshness. Therefore, retention of the moisture or prevention of loss of moisture is one of the important considerations in planning a storage technique or strategy for extension of shelf life. The actual water content is dependent on the availability of water to the tissue at the time of harvest. Water content of produce will vary during the day if there are fluctuations in temperature. For most produce, it is desirable to harvest when the maximum possible water content is present as these results in a crisp texture.

Examples of moisture content of some of fruits and vegetables

- ✓ 95% - cucumber, lettuce, melons
- ✓ >80% - many F&V
- ✓ 50% - starch tubers and seeds like –yam, cassava and corn

Fruits contain a large percentage of water that can often exceed 95% by fresh weight. During ripening, activation of several metabolic pathways often leads to drastic changes in the biochemical composition of fruits. Fruits such as banana store starch during development and hydrolyze the starch to sugars during ripening that also results in fruit softening. Most fruits are capable of photosynthesis, store starch, and convert them to sugars during ripening.

Fruits such as apple, tomato, and grape have a high percentage of organic acids, which decreases during ripening. Fruits contain large amounts of fibrous materials such as cellulose and pectin. The degradation of these polymers into smaller water-soluble units during ripening leads to fruit softening as exemplified by the breakdown of pectin in tomato and cellulose in avocado. Secondary plant products are major compositional ingredients in fruits. Anthocyanins are the major color components in grapes, blueberries, apples, and plums; carotenoids, specifically lycopene and carotene, are the major components that impart colorin tomatoes. Aroma is derived from several types of compounds that include monoterpenes (as in lime, orange), ester volatiles (ethyl, methyl butyrate in apple, iso-amyl acetate in banana), simple organic acids such as citric and malic acids (citrus fruits, apple), and small chain aldehydes such as hexenal and hexanal (cucumber). Fruits are also rich in vitamin C. Lipid content is quite low in fruits, the exceptions being avocado and olives, in which triacylglycerols (oils) form the major storage components. The amounts of proteins are usually low in most fruits.

### 3.5.1. Carbohydrates, Sugars and Fibers

***Carbohydrates*** **–** Carbohydrates are the major constituent after water, which account for 2-40% in tissues with lowest found in cucurbits and highest found in cassava. They occur mainly as starches and structural polysaccharides like pectins, celluloses, hemicelluloses. In many of the fruits and some vegetables the starches and few other polysaccharides undergo conversion into simple sugars like sucrose, glucose and fructose during ripening.  These are responsible for sweetness.  Small quantities of carbohydrates also occur as organic acids which are responsible for sourness or acidity. The major organic acids found in fruits and vegetable are citric, malic, tartaric, oxalic and pyruvic. Small quantities of bi- and tri-carboxylic acids also are present. In fruits and vegetables carbohydrates contribute mainly for its calorific value. Sugars constitutes major carbohydrates in fruits particularly after ripening.

As the name implies, carbohydrates are organic compounds containing carbon, hydrogen, and oxygen. Basically, all carbohydrates are derived by the photosynthetic reduction of CO2, and the hexoses (glucose, fructose) and pentoses (ribose, ribulose) that are intermediates in the pathway are further converted to several sugar monomers. Polymerization of several sugar derivatives leads to various storage (starch) and structural components (cellulose, pectin). During photosynthesis, the glucose formed is converted to starch and stored as starch granules. Glucose and its isomer fructose, along with phosphorylated forms (glucose-6-phosphate, glucose-1,6-diphosphate, fructose-6-phosphate, and fructose-1,6-diphosphate), can be considered to be the major metabolic hexose pool components that provide carbon skeleton for the synthesis of carbohydrate polymers. Starch is the major storage carbohydrate in fruits. There are two molecular forms of starch—amylose and amylopectin—and both components are present in the starch grain. Starch is synthesized from glucose phosphate by the activities of a number of enzymes designated as ADP-glucose pyrophosphorylase, starch synthase and a starch-branching enzyme. ADP-glucose pyrophosphorylase catalyzes the reaction between glucose-1-phosphate and ATP that generates ADP-glucose and pyrophosphate. ADP-glucose is used by starch synthase to add glucose molecules to amylose or amylopectin chain, thus increasing their degree of polymerization. In contrast to cellulose that is made up of glucose units in ß-1,4-glycosidic linkages, the starch molecule contains glucose linked by a-1,4-glycosidic linkages. The starch-branching enzyme introduces glucose molecules through a-1,6-linkages to a linear amylose molecule. These added glucose branch points serve as sites for further elongation by starch synthase, thus resulting in a branched starch molecule, also known as amylopectin.

Cell wall is a complex structure composed of cellulose and pectin, derived from hexoses such as glucose, galactose, rhamnose and mannose, and pentoses such as xylose and arabinose, as well as some of their derivatives such as glucuronic and galacturonic acids. Amodel proposed by Keegstra et al. (1993) describes the cell wall as a polymeric structure constituted by cellulose microfibrils and hemi-cellulose embedded in the apoplastic matrix in association with pectic components and proteins. In combination, these components provide the structural rigidity that is characteristic to the plant cell. Most of the pectin is localized in the middle lamella. Cellulose is biosynthesized by the action of ß-1,4-glucan synthase enzyme complexes that are localized on the plasma membrane. The enzyme uses uridine diphosphate glucose (UDPG) as a substrate and, by adding UDPG units to small cellulose units, extends the length and polymerization of the cellulose chain. In addition to cellulose, there are polymers made of different hexoses and pentoses known as hemicelluloses, and based on their composition, they are categorized as xyloglucans, glucomannans, and galacto-glucomannans. The cellulose chains assemble into microfibrils through hydrogen bonds to form crystalline structures. In a similar manner, pectin is biosynthesized from UDPgalacturonic acid (galacturonic acid is derived from galactose, a six-carbon sugar) as well as other sugars and derivatives and includes galacturonans and rhamno-galacturonans that form the acidic fraction of pectin. As the name implies, rhamno-galacturonans are synthesized primarily from galacturonic acid and rhamnose. The carboxylic acid groups complex with calcium, which provide the rigidity to the cell wall and the fruit. The neutral fraction of the pectin comprises polymers such as arabinans (polymers of arabinose), galactans (polymers of galactose), or arabinogalactans (containing both arabinose and galactose). All these polymeric components form a complex three-dimensional network stabilized by hydrogen bonds, ionic interactions involving calcium, phenolic components such as diferulic acid and hydroxyl-proline-rich glycoproteins (Fry, 1986). It is also important to visualize that these structures are not static and the components of cell wall are constantly being turned over in response to growth conditions.

***Sugars –*** Many tropical and sub-tropical fruits contain highest level of sugars. Glucose and fructose are the major sugars in all fruits and often present in similar level, while sucrose is only present in about $2/3^{rd}$ of the produce. It helps in imparting colour, flavour, appearance and texture to the fruits. Flavour is fundamentally the balance between sugar and acids ratios. Sugar is the primary substrate for respiration and energy. The glycaemic index (GI) of fruits and vegetables varies from 22 (cherries) -97 (parsnip). Potato and sweet potato – 55 – 60; Bread- 70

***Fiber –*** Most of the fiber components are cellulose, hemicelluloses, lignin and pectic substances

### 3.5.2. Lipids and bio membranes

***Lipids*** – Lipids are not more than 1% in majority of fruits and vegetables except some like avocado (20%) and olive (15%). In most of them it is present as protective cuticle layer on surface. However, nuts contain considerable amount of fats. Generally low fat levels seen in fruits and vegetables make it healthier foods to combat heart related diseases and disorders like hyperlipidaemia.

By structure, lipids can form both structural and storage components. The major forms of lipids include fatty acids, diacyl and triacylglycerols, phospholipids, sterols, and waxes that provide an external barrier to the fruits. Fruits, in general, are not rich in lipids with the exception of avocado and olives that store large amounts of triacylglycerols or oil. As generally observed in plants, the major fatty acids in fruits include palmitic (16:0), stearic (18:0), oleic (18:1), linoleic (18:2), and linolenic (18:3) acids. Among these, oleic, linoleic, and linolenic acids possess an increasing degree of unsaturation. Olive oil is rich in triacylglycerols containing the monounsaturated oleic acid and is considered as a healthy ingredient for human consumption.

Compartmentalization of cellular ingredients and ions is an essential characteristic of all life forms. The compartmentalization is achieved by biomembranes, formed by the assembly of phospholipids and several neutral lipids that include diacylglycerols and sterols, the major constituents of the biomembranes. Virtually, all cellular structures include or are enclosed by biomembranes. The cytoplasm is surrounded by the plasma membrane, the biosynthetic, and the transport compartments such as the endoplasmic reticulum and golgi bodies forman integral network of membranes within the cell. Photosynthetic activity, which converts light energy into chemical energy, and respiration, which further converts chemical energy into more usable forms, occur on the thylakoid membrane matrix in the chloroplast and the cristae of mitochondria, respectively. All these membranes have their characteristic composition and enzyme complexes to perform their designated function.

The major phospholipids that constitute the biomembranes include phosphatidylcholine, phosphatidyl-ethanolamine, phosphatidyl-glycerol, and phosphatidylin-ositol. Their relative proportion may vary from tissue to tissue. In addition, metabolic intermediates of phospholipids such as phosphatidic acid, diacylglycerols, and free fatty acids are also present in the membrane in lower amounts. Phospholipids are integral functional components of hormonal and environmental signal transduction processes in the cell. Phosphorylated forms of phosphatidylinositol such as phosphatidylinositol-4-phosphate and phosphatidylinositol 4,5-bisphosphate are formed during signal transduction events, though their amounts can be very low. The membrane also contains sterols such as sitosterol, campesterol, and stigmasterol, as well as their glucosides, and they are extremely important for the regulation of membrane fluidity and function.

***Biomembranes -*** bilamellar layers of phospholipids. The amphipathic nature of phospholipids having hydrophilic head groups (choline, ethanolamine, etc.) and hydrophobic fatty acyl chains thermodynamically favor their assembly into bilamellar or micellar structures when exposed to an aqueous environment. In a biomembrane, the hydrophilic head groups are exposed to the external aqueous environment. The phospholipid composition between various fruits may differ, and within the same fruit, the inner and outer lamella of the membrane may have a different phospholipid composition. Such differences may cause changes in polarity between the outer and inner lamellae of the membrane and lead to the generation of a voltage across the membrane. These differences usually become operational during signal transduction events. An essential characteristic of the membrane is its fluidity. The fluid-mosaic model of the membrane (Singer and Nicholson, 1972) depicts the membrane as a planar matrix composed of phospholipids and proteins. The proteins are embedded in the membrane bilayer (integral proteins) or are bound to the periphery (peripheral proteins).

The nature of this interaction stems from the structure of the proteins. If the proteins have a much larger proportion of hydrophobic amino acids, they would tend to become embedded in the membrane bilayer. If the protein contains more hydrophilic amino acids, it may tend to prefer a more aqueous environment and thus remain as a peripheral protein. In addition, proteins may be covalently attached to phospholipids such as phosphatidyl inositol. Proteins that remain in the cytosol may also become attached to the membrane in response to an increase in cytosolic calcium levels. The membrane is a highly dynamic entity. The semi-fluid nature of the membrane allows for the movement of phospholipids in the plane of the membrane and between the bilayers of the membrane. The proteins are also mobile within the plane of the membrane. However, this process is not always random and is regulated by the functional assembly of proteins into metabolons (photosynthetic units in thylakoid membrane, respiratory complexes in the mitochondria, cellulose synthase on plasma membrane, etc.), their interactions with the underlying cytoskeletal system (network of proteins such as actin and tubulin), and the fluidity of the membrane.

The maintenance of homeostasis (life processes) requires the maintenance of the integrity and function of discrete membrane compartments. This is essential for the compartmentalization of ions and metabolites, which may otherwise destroy the cell. For instance, calcium ions are highly compartmentalized within the cell. The concentration of calcium is maintained at the millimolar levels within the cell wall compartment (apoplast), endoplasmic reticulum, and the tonoplast (vacuole). This is achieved by energy-dependent extrusion of calcium from the cytoplasm into these compartments by ATPases. As a result, the cytosolic calcium levels are maintained at low micromolar ($<1$ μM) levels. Maintenance of this concentration gradient across the membrane is a key requirement for the signal transduction events, as regulated entry of calcium into the cytosol can be achieved simply by opening calcium channels. Calcium can then activate several cellular biochemical reactions that mediate the response to the signal. Calcium is pumped back into the storage compartments when the signal diminishes in intensity. In a similar manner, cytosolic pH is highly regulated by the activity of proton ATPases.

The pH of the apoplast and the vacuole is maintained near 4, whereas the pH of the cytosol is maintained in the range of 6–6.5. The pH gradient across the membrane is a key feature that regulates the absorption or extrusion of other ions and metabolites such as sugars. The cell could undergo senescence if this compartmentalization is lost. There are several factors that affect the fluidity of the membrane. The major factor that affects the fluidity is the type and proportion of acyl chain fatty acids of the phospholipids.

At a given temperature, a higher proportion of unsaturated fatty acyl chains (oleic, linoleic, linolenic) in the phospholipids can increase the fluidity of the membrane. An increase in saturated fatty acids such as palmitic and stearic acids can decrease the fluidity. Other membrane components such as sterols and degradation products of fatty acids such as fatty aldehydes and alkanes can also decrease the fluidity. Based on the physiological status of the tissue, the membranes can exist in either a liquid crystalline state (where the phospholipids and their acyl chains are mobile) or a gel state where they are packed as rigid-ordered structures and their movements are much restricted. The membrane usually has coexisting domains of liquid crystalline and gel-phase lipids depending on growth conditions, temperature, ion concentration near the membrane surface. The tissue has the ability to adjust the fluidity of the membrane by altering the acyl lipid composition of the phospholipids.

For instance, an increase in the gel-phase lipid domains resulting from exposure to cold temperature could be counteracted by increasing the proportion of fatty acyl chains having a higher degree of unsaturation and therefore a lower melting point. Thus, the membrane will tend to remain fluid even at a lower temperature. An increase in gel-phase lipid domains can result in the loss of compartmentalization. The differences in the mobility properties of phospholipid acyl chains can cause packing imperfections at the interface between gel and liquid crystalline phases, and these regions can become leaky to calcium ions and protons that are highly compartmentalized. The membrane proteins are also excluded from the gel phase into the liquid crystalline phase. Thus, during examinations of membrane structure by freeze fracture electron microscopy, the gel-phase domains can appear as regions devoid of proteins (Paliyath and Thompson, 1990).

### 3.5.3 Proteins

***Protein*** – Fruits and vegetables are not an important source of proteins. Though some vegetables like brassica group contains 3-5% of proteins and legumes (5g), majority of fruits and vegetables contain no more than 1-2%. These proteins are present mainly as enzymes.

Fruits, in general, are not very rich sources of proteins. During the early growth phase of fruits, the chloroplasts and mitochondria are the major organelles that contain structural proteins. The structural proteins include the light-harvesting complexes in chloroplast or the respiratory enzyme/protein complexes in mitochondria. Ribulose-bis-phosphate carboxylase/ oxygenase (Rubisco) is the most abundant enzyme in photosynthetic tissues. Fruits do not store proteins as an energy source. The green fruits such as bell peppers and tomato have a higher level of chloroplast proteins.

***Minerals*** - Fruits and vegetables are good sources of minerals. Minerals are essential for growth and development of body right from birth to old age. Calcium is present in several fruits as calcium pectate in cell walls. Calcium appears to be linked to control of enzyme activities, respiration and ethylene production. Some fruits like bananas are rich in potassium.

***Vitamins*** – Generally fruits and vegetables are rich vitamins but their quantity is varied among them. Fat- soluble vitamins A, D, E and K and water-soluble vitamins C and B group are found in F&V. These are needed for growth, normal function of the body.

**Vitamins and their sources**

| | |
|---|---|
| Vitamin A | Leafy vegetables, radish tops, mango, papaya, carrots *etc*. |
| Thiamine ($B_1$) | Fresh peas & beans, cabbage, bael, pomegranate, jamum, *etc*. |
| Riboflavin($B_2$) | Banana, litchi, papaya, radish top, pineapple, cowpea *etc*. |
| Niacin($B_3$) | Banana, strawberry, peach, cherry, green vegetables *etc*. |
| Vitamin C | Anola, guava, citrus fruits, cashew apple, leafy vegetables, |
| Vitamin D | Cabbage, carrot |
| Pyridoxine ($B_6$) | Vegetables |
| Folic acid ($B_9$) | Fresh GLV, lady's finger, cluster beans |

**3.5.3. Anthocyanin and its biosynthesis**

The development of color is a characteristic feature of the ripening process, and in several fruits, the color components are anthocyanins biosynthesized from metabolic precursors. The anthocyanins accumulate in the vacuole of the cell and are often abundant in the cells closer to the surface of the fruit. Anthocyanin biosynthesis starts by the condensation of three molecules of malonyl CoA with *p*-coumaroyl CoA to form tetrahydroxy-chalcone, mediated by the enzyme chalcone synthase (Fig. 3.8). Tetrahydroxychalcone has the basic flavonoid structure C6–C3–C6, with two phenyl groups separated by a three-carbon link. Chalcone isomerase enables the ring closure of chalcone leading to the formation of the flavanone naringenin that possesses a flavonoid structure having two phenyl groups linked together by a heterocyclic ring (Fig. 3.9). The phenyl groups are designated as A and B, and the heterocyclic ring is designated as ring C. Subsequent conversions of naringenin by flavonol hydroxylases result in the formation of dihydrokaempferol, dihydromyricetin, and dihydroquercetin, which differ in their number of hydroxyl moieties. Dihydroflavonol reductase converts the dihydroflavonols into the colorless thocyanidin compounds leucocyanidin, leucopelargonidin, and leucodelphinidin. Removal of hydrogens and the induction of unsaturation of the C ring at C2 and C3, mediated by anthocyanin synthase, results in the formation of cyanidin, pelargonidin, and delphinidin, the colored compounds.

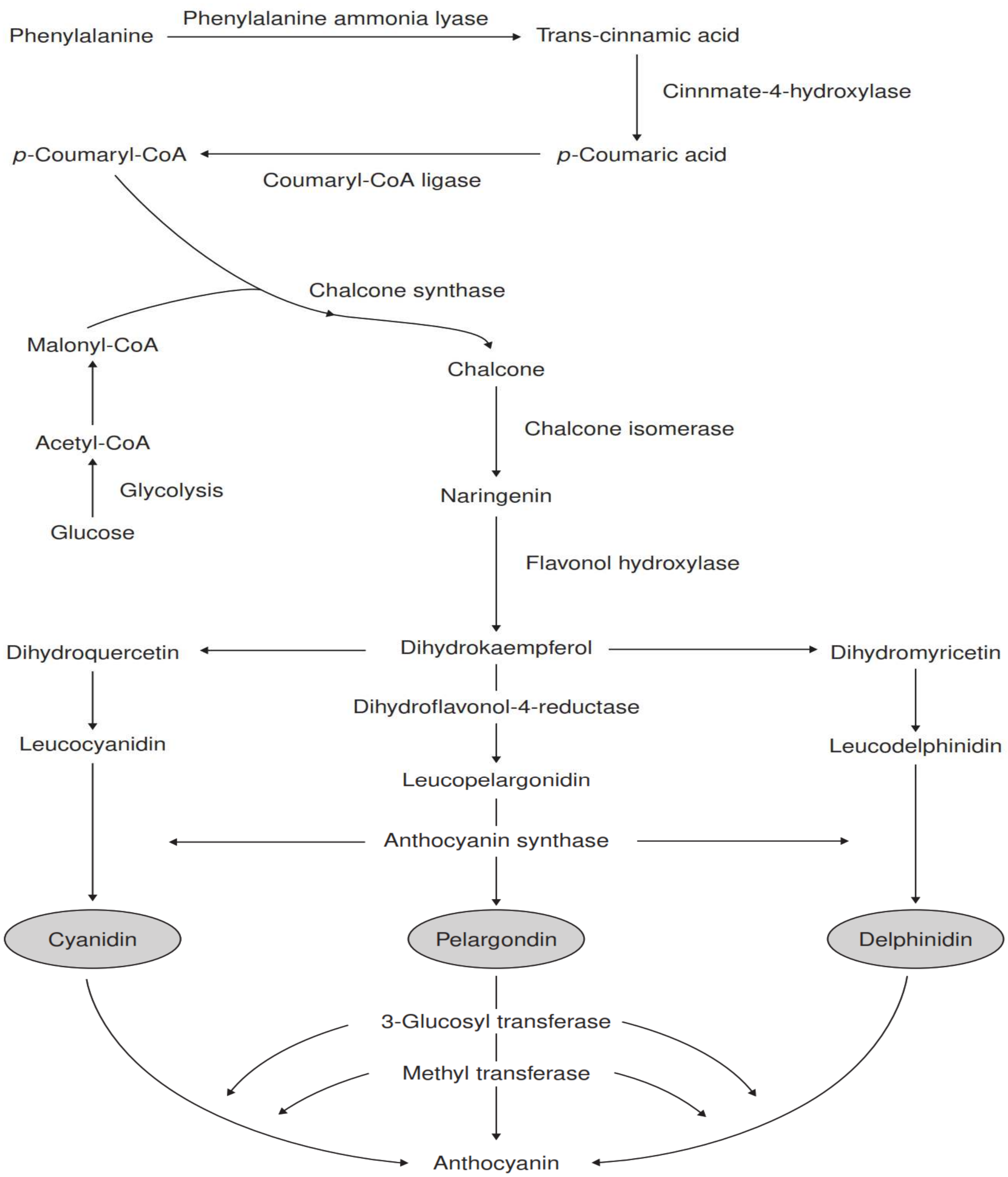



**Fig.** Anthocyanin biosynthetic pathway in plants.

Glycosylation, methylation, coumaroylation, and a variety of other additions of the anthocyanidins result in color stabilization of the diverse types of anthocyanins seen in fruits. Pelargonidins give orange, pink, and red color, cyanidins provide magenta and crimson coloration, and delphinidins provide the purple, mauve, and blue color characteristic to several fruits. The color characteristics of fruits may result from a combination of several forms of anthocyanins existing together, as well as the conditions of pH and ions present in the vacuole.

Anthocyanin pigments cause the diverse coloration of grape cultivars resulting in skin colors varying from translucent, red, and black. All the forms of anthocyanins, along with those with modifications of the hydroxyl groups, are routinely present in the red and dark varieties of grapes. A glucose moiety is attached at the 3 and 5 positions or at both in most grape anthocyanins. The glycosylation pattern can vary between the European (*Vitis vinifera*) and North American (*Vitis labrusca*) grape varieties. Anthocyanin accumulation occurs toward the end of ripening, and is highly influenced by sugar levels, light, temperature, ethylene, and increased metabolite translocation from leaves to fruits.

All these factors positively influence the anthocyanin levels. Most of the anthocyanin accumulation may be limited to epidermal cell layers and a few of the subepidermal cells. In certain high-anthocyanin-containing varieties, even the interior cells of the fruit may possess high levels of anthocyanins. In the red wine varieties such as merlot, pinot noir, and cabernet sauvignon, anthocyanin content may vary between 1,500 and 3,000 mg/kg fresh weight.

In some high-anthocyanin-containing varieties such as Vincent, Lomanto, and Colobel, the anthocyanin levels can exceed 9,000 mg/kg fresh weight. Anthocyanins are very strong antioxidants and are known to provide protection from the development of cardiovascular diseases and cancer. Many fruits have a tart taste during early stage of development, which is termed as astringency, and is characteristic to fruits such as banana, kiwi, and grape. The astringency is due to the presence of tannins and several other phenolic components in fruits. Tannins are polymers of flavonoids such as catechin and epicatechin, phenolic acids (caffeoyl tartaric acid, coumaroyl tartaric acid, etc.). The contents of tannins decrease during ripening, making the fruit palatable.

### 3.5.4. Ester volatile biosynthesis

The sweet aroma characteristic to several ripe fruits are due to the evolution of several types of volatile components that include monoterpenes, esters, organic acids, aldehydes, ketones, alkanes, etc. Some of these ingredients specifically provide the aroma characteristic to fruits and are referred to as character impact compounds. For instance, the banana flavor is predominantly from isoamyl acetate, apple flavor from ethyl-2-methyl butyrate, and the flavor of lime is primarily due to the monoterpene limonene. As the name implies, ester volatiles are formed from an alcohol and an organic acid through the formation of an ester linkage. The alcohols and acids are, in general, products of lipid catabolism. Several volatiles are esterified with ethanol giving rise to ethyl derivatives of aliphatic acids (ethyl acetate, ethyl butyrate, etc.).

The ester volatiles are formed by the activity of the enzyme acyl CoA: alcohol acyltransferase or generally called as alcoholacyltransferase. In apple fruits, the major aroma components are ester volatiles (Paliyath et al., 1997). The alcohol can vary from ethanol, propanol, butanol, pentanol, hexanol, etc. The organic acid moiety containing the CoA group can vary in chain length from C2 (acetyl) to C12 (dodecanoyl). Alcoholacyltrans- ferase activity has been identified in several fruits that include banana, strawberry, melon, apple, etc. In banana, esters are the predominant volatiles enriched with esters such as acetates and butyrates.

The flavor may result from the combined perception of amyl esters and butyl esters. Volatile production increases during ripening. The components for volatile biosynthesis may arise from amino acids and fatty acids. In melons, the volatile components comprise esters, aldehydes, alcohols, terpenes, and lactones. Hexyl acetate, isoamyl acetate, and octyl acetate are the major aliphatic esters. Benzyl acetate, phenyl propyl acetate, and phenyl ethyl acetate are also observed. The aldehydes, alcohols, terpenes, and lactones are minor components in melons. In mango fruits, the characteristic aroma of each variety is based on the composition of volatiles. The variety "Baladi" is characterized by the presence of high levels of limonene, other monoterpenes and sesquiterpenes, and ethyl esters of even numbered fatty acids. By contrast, the variety "Alphonso" is characterized by high levels of C6 aldehydes and alcohols (hexanal, hexanol) that may indicate a high level of fatty acid peroxidation in ripe fruits. C6 aldehydes are major flavor components of tomato fruits as well.

In genetically transformed tomatoes (antisense phospholipase D), the evolution of pentanal and hexenal/hexanal was much higher after blending, suggesting the preservation of fatty acids in ripe fruits. Preserving the integrity of the membrane during ripening could help preserve the fatty acids that contribute to the flavor profile of the fruits, and this feature may provide a better flavor profile for fruits.

### 3.5.5. Pigments, Phenolics and Antioxidants

***Pigments -*** The attractive colour of the many fruit is due to sugar derivates of anthocynidins. At the time of ripening, loss of chlorophyll and accompanied by synthesis of anthocyanins or carotenoids which present in vacuole and chloroplast respectively. anthocyanins – gives colour from red to blue; carotenoids - are synthesized in green tissue eg. beta-carotene and lycopene.

***Phenolics and antioxidants*** – major class of plant compounds, it comprising of anthocyanins, leucoanthocyanins, anthoxanthins, hydroxybenzoic acids, glycosides, sugar esters of quinic and shikimic acids, esters of hydroxycinnamic acids and coumarin derivatives.

The **phenols** are impotent in determining the colour and flavour of the fruit. **Phenols** are by products of the metabolism of the amino acids and contribute the sensory qualities of the fruits (colour, astringency, bitterness and aroma) and play the vital role in the resistance to attack of pathogen and stress. It is known for its antioxidant activities.

***Volatiles (Flavour) compounds*** – Important in producing characteristic flavor and aroma (mol.wt <250 possess volatile nature) and Concentration – 10 mg $100^{-1}$g. These compounds are – esters, alcohols, acids, ldehydes and ketones. **Ethanol** is common to all fruits and vegetables, whereas others are specific. **Esters** are present in ripe fruits; while Sulphur in Brassica sp. and tomato.

### 3.6. Organic acids

***Organic acids*** – imparts taste and flavour. The major acids are malic (apple), citric (citrus), tartaric (grape), quinic, succinic and shikimic acids.

Organic acids play important role in:

- ✓ Photosynthesis and respiration
- ✓ Synthesis of phenolic compounds, lipids and volatiles aroma

Organic acids are major components of fruits. The acidity of fruits arises from the organic acids that are stored in the vacuole, and their composition can vary depending on the type of fruit. In general, young fruits contain more acids that may decline during maturation and ripening due to their conversion to sugars (gluconeogenesis). Some fruit families are characterized by the presence of certain organic acids. For example, fruits of Oxalidaceae members (eg. Star fruit, *Averrhoa* *carambola*) contain oxalic acid, and fruits of the citrus family, Rutaceae, are rich in citric acid. Apples contain malic acid and grapes are characterized by the presence of tartaric acid. In general, citric and malic acids are the major organic acids of fruits. Grapes contain tartaric acid as the major organic acid. During ripening, these acids can enter the citric acid cycle and undergo further metabolic conversions.

L- (+) tartaric acid is the optically active form of tartaric acid in grape berries. A peak in acid content is observed before the initiation of ripening, and the acid content declines on a fresh weight basis during ripening. Tartaric acid can be biosynthesized from carbohydrates and other organic acids. Radiolabeled glucose, glycolate, and ascorbate were all converted to tartarate in grape berries. Malate can be derived from the citric acid cycle or through carbon dioxide fixation of pyruvate by the malic enzyme (nicotinamide adenine dinucleotide phosphate (NADPH)-dependent malate dehydrogenase). Malic acid, as the name implies, is also the major organic acid in apples.

### 3.7. Fruit ripening and softening

Fruit ripening is the physiological repercussion of very complex and interrelated bio-chemical changes that occur in the fruits. Ripening is the ultimate stage of the development of the fruit, which entails the development of ideal organoleptic characters such as taste, color, and aroma that are important features of attraction for the vectors (animals, birds, etc.) responsible for the dispersal of the fruit, and thus the seeds, in the ecosystem. Human beings have developed an agronomic system of cultivation, harvest, and storage of fruits with ideal food qualities. In most cases, the ripening process is very fast, and the fruits undergo senescence resulting in the loss of desirable qualities. An understanding of the biochemistry and molecular biology of the fruit ripening process has resulted in developing biotechnological strategies for the preservation of postharvest shelf life and quality of fruits. In response to the initiation of ripening, several biochemical changes are induced in the fruit, which ultimately results in the development of ideal texture, taste, color, and flavor. Several biochemical pathways are involved in these processes as described next.

#### 3.7.1. Carbohydrate metabolism in response to fruit ripening

***Cell wall degradation***

Cell wall degradation is the major factor that causes softening of several fruits. This involves the degradation of cellulose components, pectin components, or both. Cellulose is degraded by the enzyme cellulase or ß-1,4-glucanase. Pectin degradation involves the enzymes pectin-ethyle-sterase, polygalacuronase (pectinase), and ß-galactosidase. The degradation of cell wall can be reduced by the application of calcium as a spray or drench in apple fruits. Calcium binds and cross-links the free carboxylic groups of polygalacturonic acid components in pectin. Calcium treatment therefore also enhances the firmness of the fruits.

The activities of both cellulase and pectinase have been observed to increase during ripening of avocado fruits and result in their softening. Cellulase is an enzyme with a relative molecular mass of 54.2 kDa and formed by extensive post-translational processing of a native 54-kDa protein involving proteolytic cleavage of the signal peptide and glycosylation (Bennet and Christofferson, 1986).

***Starch degradation response***

Starch is the major storage form of carbohydrates. During ripening, starch is catabolized into glucose and fructose, which enters the metabolic pool where they are used as respiratory substrates or further converted to other metabolites (Fig. 3.2). In fruits such as banana, the breakdown of starch into simple sugars is associated with fruit softening. There are several enzymes involved in the catabolism of starch. a-Amylase hydrolyzes amylose molecules by cleaving the a-1,4-linkages between sugars, providing smaller chains of amylose termedas dextrins. ß-Amylase is another enzyme that acts on the glucan chain, releasing maltose,which is a diglucoside. The dextrins as well as maltose can be further catabolized to simpleglucose units by the action of glucosidases. Starch phosphorylase is another enzyme, whichmediates the phosphorolytic cleavage of terminal glucose units at the nonreducing end ofthe starch molecule using inorganic phosphate, thus releasing glucose-1-phosphate. Theamylopectin molecule is also degraded in a similar manner to amylose, but also involvesthe action of debranching enzymes, which cleaves the a-1,6-linkages in amylopectin andreleases linear units of the glucan chain.

In general, starch is confined to the plastid compartments of fruit cells, where it exists as granules made up of both amylose and amylopectin molecules. The enzymes that catabolize starch are also found in this compartment and their activities increase during ripening. Theglucose-1-phosphate generated by starch degradation is mobilized into the cytoplasm where it can enter into various metabolic pools such as that of glycolysis (respiration), pentose phosphate pathway, or for turnover reactions that replenish lost or damaged cellular structures (cell wall components).

It is important to visualize that the cell always tries to extend its life under regular developmental conditions (the exceptions being programmed cell death that occurs during hypersensitive response to kill invading pathogens, thus killing both the pathogen and the cell/tissue, formation of xylem vessels, secondary xylem tissues,etc.), and the turnover reactions are a part of maintaining the homeostasis. The cell ultimately succumbs to the catabolic reactions during senescence. The compartmentalization and storage of chemical energy in the form of metabolizable macromolecules are all theinherent properties of life, which is defined as a struggle against increasing entropy.

The biosynthesis and catabolism of sucrose is an important part of carbohydrate metabolism. Sucrose is the major form of transport sugar and is translocated through thephloem tissues to other parts of the plant. It is conceivable that photosynthetically fixed carbon from leaf tissues may be transported to the fruits as sucrose during fruit development. Sucrose is biosynthesized from glucose-1-phosphate by three major steps (see figure below).

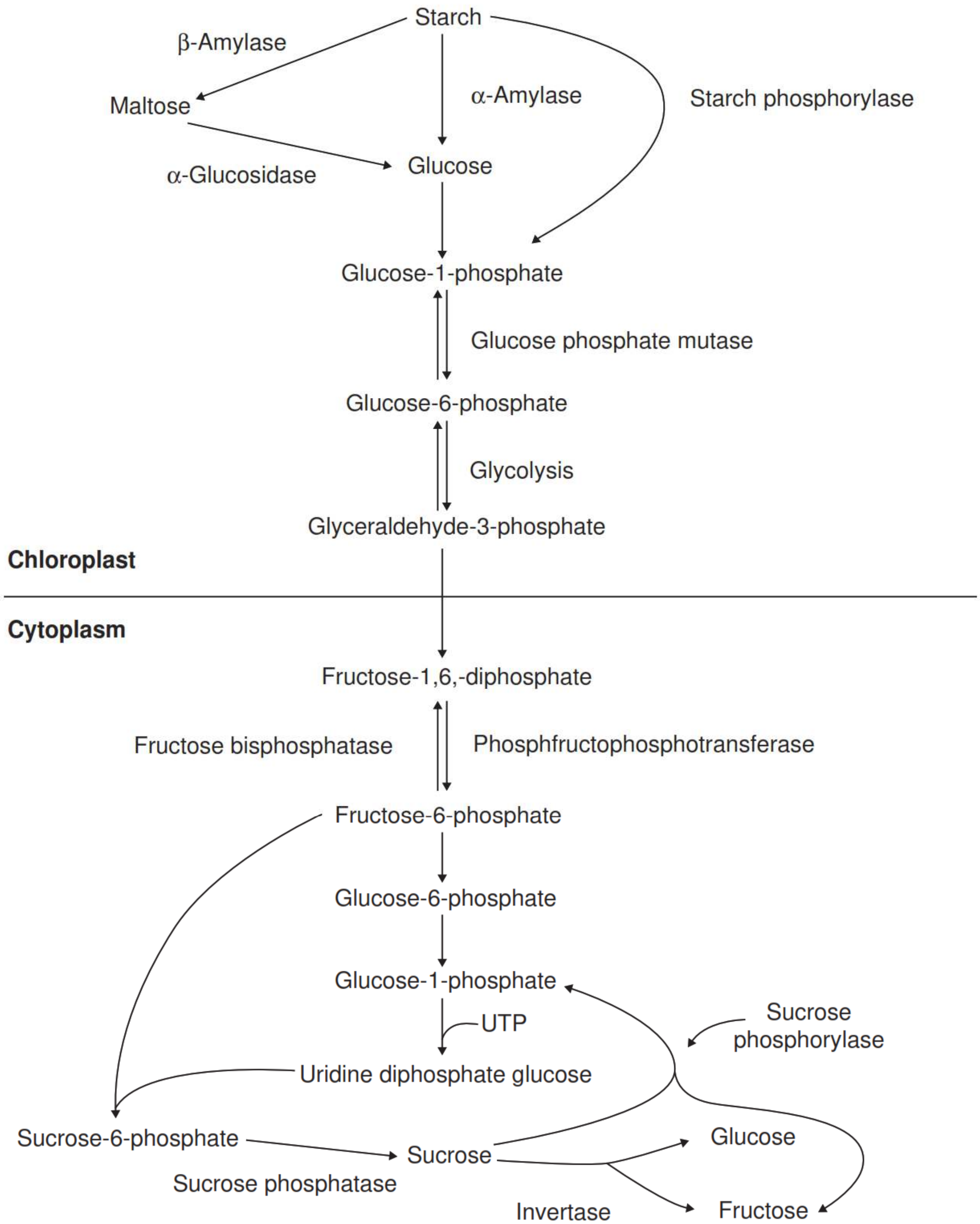



**Fig.** Starch–sugar inter-conversions in plants and metabolite transfer from chloroplast to the cytoplasm.

The first reaction involves the conversion of glucose-1-phosphate to UDP-glucose, by UDP-glucose pyrophosphorylase in the presence of UTP (uridine triphosphate). UDP-glucose is also animportant substrate for the biosynthesis of cell wall components such as cellulose. UDP-glucose is converted to sucrose-6-phosphate by the enzyme sucrose phosphate synthase, which utilizes fructose-6-phosphate during this reaction. Finally, sucrose is formed fromsucrose-6-phosphate by the action of phosphatase with the liberation of the inorganic phosphate. Even though sucrose biosynthesis is an integral part of starch metabolism, sucrose often is not the predominant sugar that accumulates in fruits.

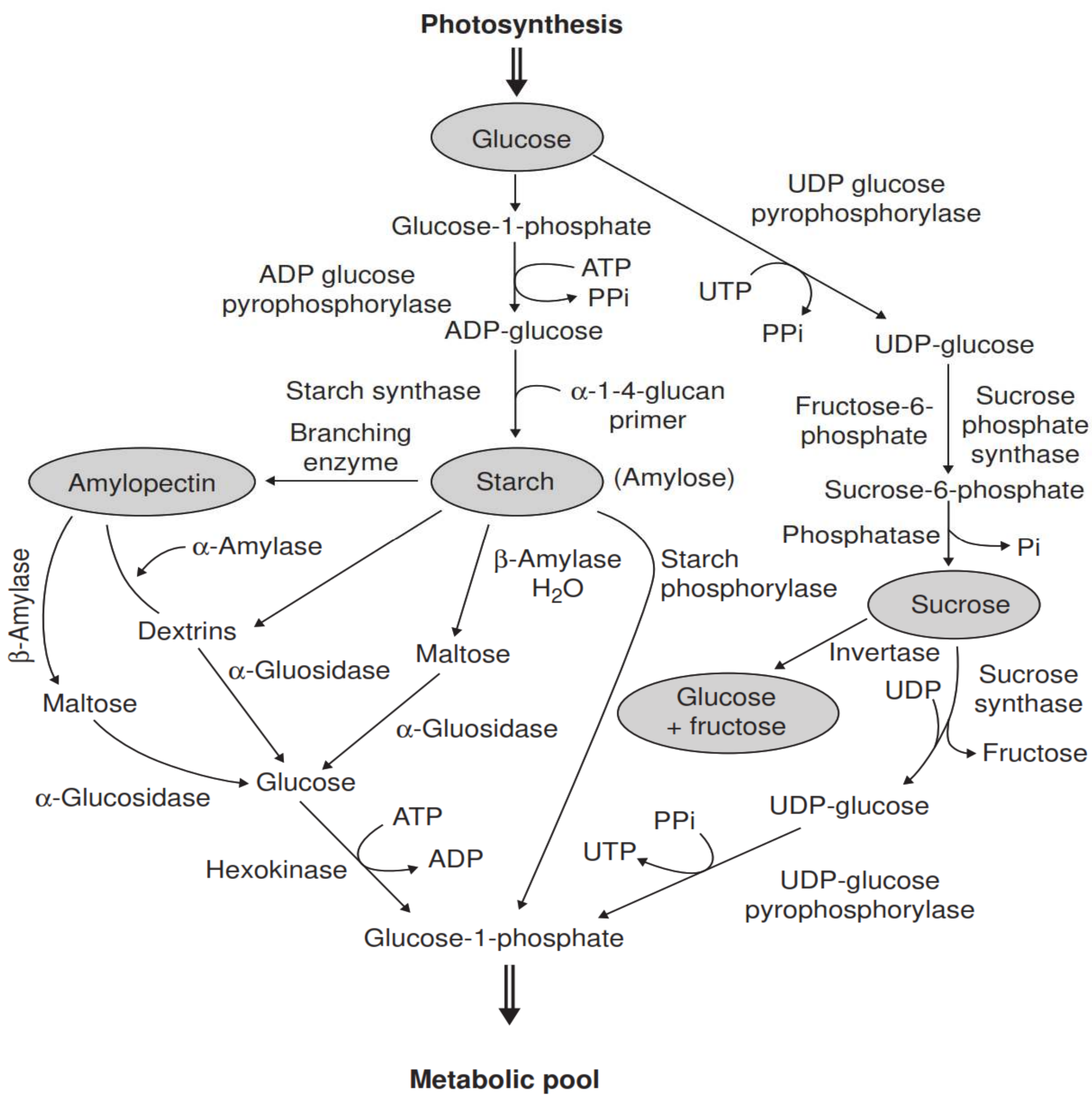



**Fig.** Carbohydrate metabolism in fruits.

Sucrose is further converted into glucose and fructose by the action of invertase, which is characteristic to many ripe fruits. Or, by the actions of sucrose synthase and UDP-glucose pyrophosphorylase, glucose-1- phosphate can be regenerated from sucrose. As well, sugar alcohols such as sorbitol and mannitol are major transport and storage components in apple and olive, respectively. Biosynthesis and catabolism of starch has been extensively studied in banana, where prior to ripening, it can account for 20–25% by fresh weight of the pulp tissue. All the starch degrading enzymes—a-amylase, ß-amylase, a-glucosidase, and starch phosphorylase—have been isolated from banana pulp. The activities of these enzymes increase during ripening. Concomitant with the catabolism of starch, there is an accumulation of the sugars, primarily, sucrose, glucose, and fructose.

At the initiation of ripening, sucrose appears to be the major sugar component, which declines during the advancement of ripening with a simultaneous increase in glucose and fructose through the action of invertase (Beaudry, et al., 1989). Mango is another fruit that stores large amounts of starch. The starch is degraded by the activities of amylases during the ripening process. In mango, glucose, fructose, and sucrose are the major forms of simple sugars (Selvaraj et al., 1989). The sugar content is generally very high in ripe mangoes and can reach levels in excess of 90% of the total soluble solids content. Fructose is the predominant sugar in mangoes. In contrast to the bananas, the sucrose levels increase with the advancement of ripening in mangoes, potentially due to gluconeogenesis from organic acids (Kumar and Selvaraj, 1990). As well, the levels of pentose sugars increase during ripening, and could be related to an increase in the activity of the pentose phosphate pathway.

***Glycolysis***

The conversion of starch to sugars and their subsequent metabolism occur in different compartments. During the development of fruits, photosynthetically fixed carbon is utilized for both respiration and biosynthesis. During this phase, the biosynthetic processes dominate. As the fruit matures and begin to ripen, the pattern of sugar utilization changes. Ripening is a highly energy-intensive process. And this is reflected in the burst in respiratory carbondioxide evolution during ripening. As mentioned earlier, the respiratory burst is characteristic of some fruits that are designated as climacteric fruits. The postharvest shelf life of fruits can depend on their intensity of respiration. Fruits such as mango and banana possess high level of respiratory activity and are highly perishable. The application of controlled atmosphere conditions having low oxygen levels and low temperature have thus become a routine technology for the long-term preservation of fruits.

The sugars and sugar phosphates generated during the catabolism of starch are metabolized through the glycolysis and citric acid cycle. Sugar phosphates can also be channeled through the pentose phosphate pathway, which is a major metabolic cycle that provides reducing power for biosynthetic reactions in the form of NADPH, as well as supplying carbon skeletons for the biosynthesis of several secondary plant products. The organic acids stored in the vacuole are metabolized through the functional reversal of respiratory pathway, which is termed as gluconeogenesis. Altogether, sugar metabolism is a key biochemical characteristic of the fruits.

In the glycolytic steps of reactions, glucose-6-phosphate is isomerized tofructose-6-phosphate by the enzyme hexose phosphate isomerase. Glucose-6-phosphate is derived from glucose-1-phosphate by the action of glucose phosphate mutase. Fructose-6-phosphate is phosphorylated at the C1 position yielding fructose-1,6-bisphosphate. This reaction is catalyzed by the enzyme phosphofructokinase in the presence of ATP. Fructose1,6-bisphosphateis further cleaved into two three-carbon intermediates, di-hydroxy-acetone-phosphate and glyceraldehyde-3-phosphate, catalyzed by the enzyme aldolase.

These two compounds are inter-convertible through an isomerization reaction mediated by triose-phosphate isomerase. Glyceraldehyde-3-phosphate is subsequently phosphorylated at the C1 position using orthophosphate, as well as oxidized using nicotin-amide adenine- dinucleotide (NAD), to generate 1,3-diphosphoglycerate and nicotinamide adenine dinucleotide plus hydrogen (NADH). In the next reaction, 1,3-diphosphoglycerate is dephosphorylated by glycerate-3-phosphate kinase in the presence of ADP, along with the formation of ATP. Glycerate-3-phosphate formed during this reaction is further isomerized to 2-phosphoglycerate in the presence of phosphoglycerate mutase. In the presence of the enzyme enolase, 2-phosphoglycerate is converted to phosphoenol pyruvate (PEP). Dephosphorylation of phosphoenolpyruvate in the presence of ADP by pyruvate kinase yields pyruvate and ATP. Metabolic fate of pyruvate is highly regulated. Under normal conditions, it is converted to acetyl coA, which then enters the citric acid cycle.

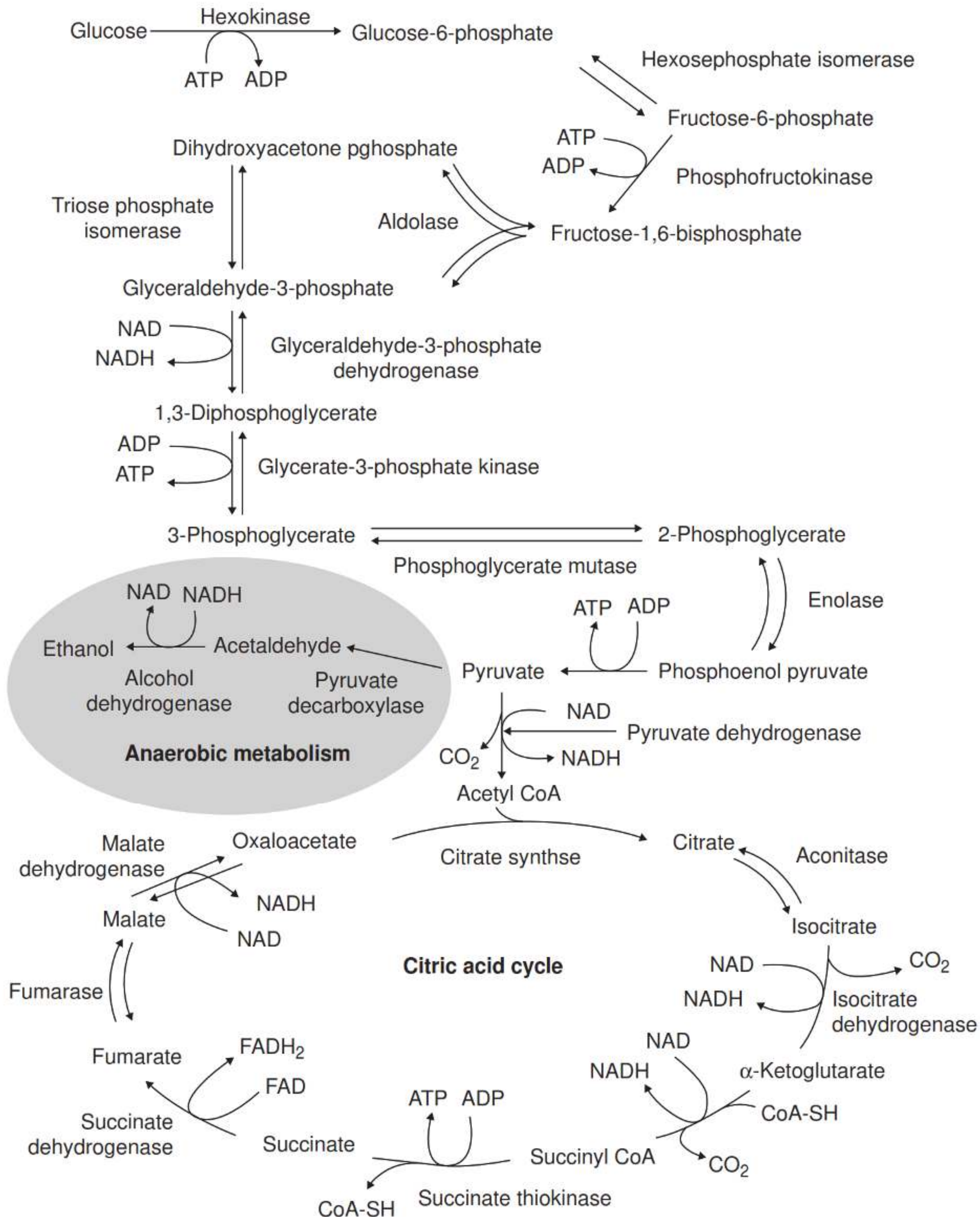



**Fig.** Catabolism of sugars through glycolytic pathway and citric acid cycle.

Under anaerobic conditions, pyruvate can be metabolized to ethanol, which is a byproduct in several ripening fruits.There are two key regulatory steps in glycolysis: one mediated by phosphofructokinase (PFK) and the other by pyruvate kinase.

In addition, there are other types of modulation involving cofactors and enzyme structural changes reported to be involved in glycolytic control. ATP levels increase during ripening. However, in fruits, this does not cause a feedback inhibition of phosphofructokinase as observed in animal systems. There are two isozymes of PFK in plants: one localized in plastids and the other localized in the cytoplasm.

These isozymes regulate the flow of carbon from the hexose phosphate pool to the pentose phosphate pool. PFK isozymes are strongly inhibited by phosphoenol pyruvate. Thus, any conditions that may cause the accumulation of phosphoenol pyruvate will tend to reduce the carbon flow through glycolysis. By contrast, inorganic phosphate is a strong activator of PFK. Thus, the ratio of PEP to inorganic phosphate would appear to be the major factor that regulates the activity of PFK and carbon flux through glycolysis. Structural alteration of phosphofructokinase, which increases the efficiency of utilization of fructose-6-phosphate, is another means of regulation that can activate the carbon flow through the glycolytic pathway.

Other enzymes of the glycolytic pathway are involved in the regulation of starch/sucrose biosynthesis. Fructose-1,6-bisphosphate is converted back to fructose-6phosphate by the enzyme fructose-1,6-bisphosphatase, also releasing inorganic phosphate. This enzyme is localized in the cytosol and chloroplast. Fructose-6-phosphate is converted to fructose-2,6-bisphosphate by fructose-6-phosphate 2-kinase, which can be dephosphorylated at the 2-position by fructose-2,6-bisphosphatase. Fructose-6-phosphate is an intermediary in sucrose biosynthesis. Sucrose phosphate synthase (SPS) is regulated by reversible phosphorylation (a form of posttranslational modification that involves addition of a phosphate moiety from ATP to an OH amino acid residue in the protein, such as serine or threonine, mediated by a kinase, and dephosphorylation mediated by a phosphatase) by SPS kinase and SPS phosphatase. Phosphorylation of the enzyme makes it less active. Glucose6-phosphate is an allosteric activator (a molecule that can bind to an enzyme and increase its activity through enzyme subunit association) of the active form of SPS (dephosphorylated).

Glucose-6-phosphate is an inhibitor of SPS kinase, and inorganic phosphate is an inhibitor of SPS phosphatase. Thus, under conditions when glucose-6-phosphate/inorganic phosphate ratio is high, the active form of SPS will dominate, favoring sucrose phosphate biosynthesis. These regulations are highly complex and may be regulated by the flux of other sugars in several pathways. The conversion of PEP to pyruvate mediated by pyruvate kinase is another key metabolic step in the glycolytic pathway and is irreversible.

Pyruvate is used in several metabolic reactions. During respiration, pyruvate is further converted to acetyl coenzyme A (acetyl CoA), which enters the citric acid cycle through which it is completely oxidized to carbon dioxide (Fig. 3.3). The conversion of pyruvate to acetyl CoA is mediated by the enzyme complex pyruvate dehydrogenase and is an oxidative step that involves the formation of NADH from NAD. Acetyl CoA is a key metabolite and starting point for several biosynthetic reactions (fatty acids, isoprenoids, phenylpropanoids, etc.).

***Citric acid cycle***

The citric acid cycle involves the biosynthesis of several organic acids, many of which serve as precursors for the biosynthesis of several groups of amino acids. In the first reaction, oxaloacetate combines with acetyl CoA to form citrate and is mediated by citrate synthase (Fig. 3.4). In the next step, citrate is converted to isocitrate by the action of aconitase. The next two steps in the cycle involve oxidative decarboxylation. The conversion of isocitrate to a-ketoglutarate involves the removal of a carbon dioxide molecule and reduction of NAD to NADH. This step is catalyzed by isocitrate dehydrogenase. a-Ketoglutarate is converted to succinyl CoA by a-ketoglutarate dehydrogenase, along with the removal of another molecule of carbon dioxide and the conversion of NAD to NADH. Succinate, the next product, is formed from succinyl CoA by the action of succinyl CoA synthetase that involves the removal of the CoA moiety and the conversion of ADP to ATP. Through these steps, the complete oxidation of the acetyl CoA moiety has been achieved with the removal of two molecules of carbon dioxide. Thus, succinate is a four-carbon organic acid. Succinate is further converted to fumarate and malate in the presence of succinate dehydrogenase and fumarase, respectively. Malate is oxidized to oxaloacetate by the enzyme malate dehydrogenase along with the conversion of NAD to NADH. Oxaloacetate then can combine with another molecule of acetyl CoA to repeat the cycle. The reducing power generated in the form of NADH and FADH (succinate dehydrogenation step) is used for the biosynthesis of ATP through the transport of electrons through the electron transport chain in the mitochondria.

***Gluconeogenesis***

Several fruits store large amounts of organic acids in their vacuole, and these acids are converted back to sugars during ripening, a process termed as gluconeogenesis. Several irreversible steps in the glycolysis and citric acid cycle are bypassed during gluconeogenesis. Malate and citrate are the major organic acids present in fruits. In fruits such as grapes, where there is a transition from a sour to a sweet stage during ripening, organic acids content declines.

Grape contains predominantly tartaric acid along with malate, citrate, succinate, fumarate, and several organic acid intermediates of metabolism. The content of organic acids in berries can affect their suitability for processing. High acid content coupled with low sugar content can result in poor quality wines. External warm growth conditions enhance the metabolism of malic acid in grapes during ripening and could result in a high tartarate/malate ratio, which is considered ideal for vinification. The metabolism of malate during ripening is mediated by the malic enzyme, NADP dependent malate dehydrogenase. Along with a decline in malate content, there is a concomitant increase in the sugars suggesting a possible metabolic precursor product relationship between these two events. Indeed, when grape berries were fed with radiolabeled malate, the radiolabel could be recovered in glucose. The metabolism of malate involves its conversion to oxaloacetate mediated by malate dehydrogenase, the decarboxylation of oxaloacetate to phosphoenol pyruvate catalyzed by PEP-carboxykinase, and a reversal of glycolytic pathway leading to sugar formation (Ruffner et al., 1983). The gluconeogenic pathway from malate may contribute only a small percentage (5%) of the sugars, and a decrease in malate content could primarily result from reduced synthesis and increased catabolism through the citric acid cycle.

The inhibition of malate synthesis by the inhibition of the glycolytic pathway could result in increased sugar accumulation. Metabolism of malate in apple fruits is catalyzed by NADP-malic enzyme that converts malate to pyruvate. In apples, malate appears to be primarily oxidized through the citric acid cycle. Organic acids are important components of citrus fruits. Citric acid is the major form of the acid followed by malic acid and several less abundant acids such as acetate, pyruvate, oxalate, glutarate, and fumarate. In oranges, the acidity increases during maturation of the fruit and declines during the ripening phase. Lemon fruits, by contrast, increase their acid content through the accumulation of citrate. The citrate levels in various citrus fruits range from 75 to 88%, and malate levels range from 2 to 20%. Ascorbate is another major component of citrus fruits. Ascorbate levels can range from 20 to 60 mg/100 g juice in various citrus fruits. The orange skin may possess 150–340 mg/100 g fresh weight of ascorbate, which may not be extracted into the juice.

***Anaerobic respiration***

Anaerobic respiration is a common event in the respiration of ripe fruits and especially becomes significant when fruits are exposed to low temperature. Often, this may result from oxygen-depriving conditions induced inside the fruit. Under anoxia, ATP production through the citric acid cycle and mitochondrial electron transport chain is inhibited. Anaerobic respiration is a means of regenerating NAD, which can drive the glycolyic pathway and produce minimal amounts of ATP.

Under anoxia, pyruvate formed through glycolysis is converted to lactate by lactate dehydrogenase using NADH as the reducing factor, and generating NAD. Accumulation of lactate in the cytosol could cause acidification, and under these low pH conditions, lactate dehydrogenase is inhibited. The formation of acetaldehyde by the decarboxylation of pyruvate is stimulated by the activation of pyruvate decarboxylase under low pH conditions in the cytosol. It is also likely that the increase in concentration of pyruvate in the cytoplasm may stimulate pyruvate decarboxylase directly. Acetaldehyde is reduced to ethanol by alcohol dehydrogenase using NADH as the reducing power. Thus, acetaldehyde and ethanol are common volatile components observed in the headspace of fruits, indicative of the occurrence of anaerobic respiration. Cytosolic acidification is a condition that stimulates deteriorative reactions. By removing lactate through efflux and converting pyruvate to ethanol, cytosolic acidification can be avoided.

Anaerobic respiration plays a significant role in the respiration of citrus fruits. During early stages of growth, respiratory activity predominantly occurs in the skin tissue. Oxygen uptake by the skin tissue was much higher than the juice vesicles. With advancing maturity, a decline in aerobic respiration and an increase in anaerobic respiration was observed in Hamlin orange skin. In parallel with this, the levels of ethanol and acetaldehyde increased. As well, a decrease in the organic acid substrates, pyruvate and oxaloacetate, was detectable in Hamlin orange juice. An increase in the activity levels of pyruvate decarboxylase, alcohol dehydrogenase, and malic enzyme was noticed in parallel with the decline in pyruvate and accumulation of ethanol. In apple fruits, malic acid is converted to pyruvate by the action of NADP-malic enzyme, and pyruvate subsequently converted to ethanol by the action of pyruvate decarboxylase and alcohol dehydrogenase. The alcohol dehydrogenase in apple can use NADPH as a cofactor, and NADP is regenerated during ethanol production, thus driving malate utilization. Ethanol is either released as a volatile or can be used for the biosynthesis of ethyl esters of volatiles.

### 3.7.2. Lipid metabolism

Among fruits, avocado and olive are the only fruits that significantly store reserves in the form of lipid triglycerides. In avocado, triglycerides form the major part of the neutral lipid fraction, which can account for nearly 95% of the total lipids. Palmitic (16:0), palmitoleic (16:1), oleic (18:1), and linoleic (18:2) acids are the major fatty acids of triglycerides. The oil content progressively increases during maturation of the fruit, and the oils are compartmentalized in oil bodies or oleosomes. The biosynthesis of fatty acids occurs in the plastids, and the fatty acids are exported into the endoplasmic reticulum where they are esterified with glycerol-3-phosphate by the action of a number of enzymes to form the triglyceride. The triglyceride-enriched regions then are believed to bud off from the endoplasmic reticulum as the oil body. The oil body membranes are different from other cellular membranes since they are made up of only a single layer of phospholipids.

The triglycerides are catabolized by the action of triacylglycerol lipases, which release the fatty acids. The fatty acids are then broken down into acety CoA units through ß-oxidation. Even though phospholipids constitute a small fraction of the lipids in fruits, the degradation of phospholipids is a key factor that controls the progression of senescence. As in several senescing systems, there is a decline in phospholipids as the fruit undergoes senescence. With the decline in phospholipids content, there is a progressive increase in the levels of neutral lipids, primarily diacylglycerols, free fatty acids, and fatty aldehydes. In addition, the levels of sterols may also increase. Thus, there is an increase in the ratio of sterol/phospholipids. Such changes in the composition of membrane can cause the formation of gel-phase or nonbilayer lipid structures (micelles). These changes can make the membranes leaky, thus resulting in the loss of compartmentalization, and ultimately, senescence (Paliyath and Droillard, 1992).

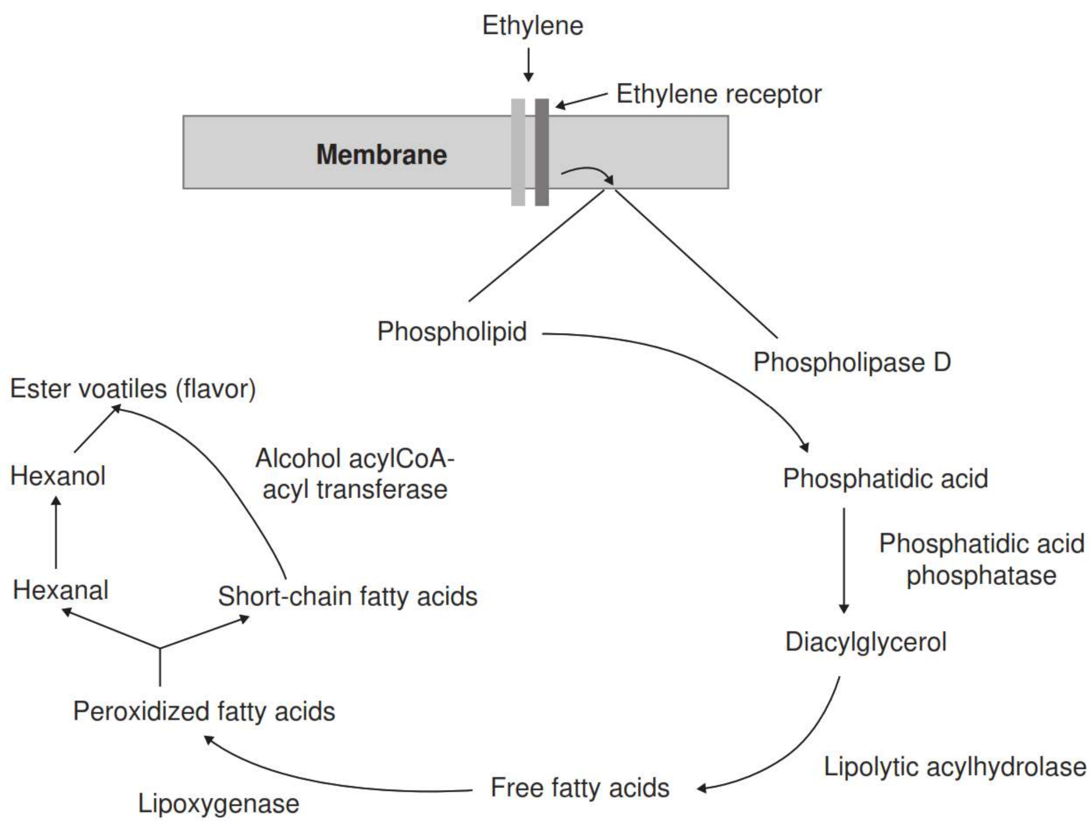



**Fig.** Phospholipid catabolic pathway and its relation to fruit ripening.

Membrane lipid degradation occurs by the tandem action of several enzymes, one enzyme acting on the product released by the previous enzyme in the sequence. Phospholipase D (PLD) is the first enzyme of the pathway, which initiates phospholipids catabolism, and is a key enzyme of the pathway (Fig. 3.6). Phospholipase D acts on phospholipids, liberating phosphatidic acid and the respective headgroup (choline, ethanolamine, glycerol, inositol). Phosphatidic acid in turn is acted upon by phosphatidate phosphatase, which removes the phosphate group from phosphatidic acid, with the liberation of diacylglycerols (diglycerides). The acyl chains of diacylglycerols are then deesterified by the enzyme lipolytic acyl hydrolase, liberating free fatty acids. Unsaturated fatty acids with a *cis*-1,4pentadiene structure (linoleic acid, linolenic acid) are acted upon by lipoxygenase, causing the peroxidation of fatty acids.

This step may also cause the production of activated oxygen species such as singlet oxygen, superoxide, and peroxy radicals. The peroxidation products of linolenic acid can be 9-hydroperoxy linoleic acid or 13-hydroperoxy linoleic acid. The hydroperoxy-linoleic acids undergo cleavage by hydroperoxide lyase resulting in several products including hexanal, hexenal, and ω-keto fatty acids (keto group toward the methyl end of the molecule). For example, hydroperoxide lyase action on 13-hydroperoxylinolenic acid results in the formation of *cis*-3-hexenal and 12-keto-*cis*-9-dodecenoic acid. Hexanal and hexenal are important fruit volatiles. The short-chain fatty acids may feed into catabolic pathway (ß-oxidation) that results in the formation of short-chain acyl CoAs, ranging from acetyl CoA to dodecanoyl CoA. The short-chain acyl CoAs and alcohols (ethanol, propanol, butanol, pentanol, hexanol, etc.) are esterified to form a variety of esters that constitute components of flavor volatiles that are characteristic to fruits.

The free fatty acids and their catabolites (fatty aldehydes, fatty alcohols, alkanes, etc.) can accumulate in the membrane, causing membrane destabilization (formation of gel-phase, nonbilayer structures, etc.). An interesting regulatory feature of this pathway is the very low substrate specifity of enzymes that act downstream from phospholipase D, for the phospholipids. Thus, phosphatidate phosphatase, lipolytic acyl hydrolase, and lipoxygenase do not directly act on phospholipids, though there are exceptions to this rule.

Therefore, the degree of membrane lipid catabolism will be determined by the extent of activation of phospholipase D. The membrane lipid catabolic pathway is considered as an autocatalytic pathway. The destabilization of the membrane can cause the leakage of calcium and hydrogen ions from the cell wall space, as well as the inhibition of calcium and proton ATPases, the enzymes responsible for maintaining a physiological calcium and proton concentration within the cytoplasm (calcium concentration below micromolar range, pH in the 6–6.5 range). Under conditions of normal growth and development, these enzymes pump the extra calcium and hydrogen ions that enter the cytoplasm from storage areas such as apoplast and the ER lumen, in response to hormonal and environmental stimulation using ATP as the energy source.

# Chapter -Four

## 4.1. Postharvest Technology and Applications

All fruits, vegetables and root crops are living biological organisms, having a respiratory system, similar to that of humans. They continue their living processes after harvest. Respiration is the process by which plants take in oxygen and give out carbon dioxide. On the basis of their respiration rate and ethylene production patterns during maturation and ripening, fruits can be classified in two groups: climacteric fruits (they exhibit a large increase in carbon dioxide and ethylene production rates coincident with their ripening) and non-climacteric fruits (which exhibit no changes in their generally low carbon dioxide and ethylene production rates during ripening). In accordance with the respiration rate most horticultural commodities can be classified as follows:

- ✓ Low respiration rate - Nuts, dates, dried fruits and vegetables, apples, citrus, grape, garlic, onion and sweet potato.
- ✓ Moderate respiration rate - Banana, cherry, plum, cabbage, carrot, lettuce, pepper and tomato.
- ✓ High respiration rate - Cauliflower, avocado, berries and green onion.
- ✓ Extremely high respiration rate - Broccoli, peas, spinach and sweet corn.

Ethylene is a natural product of plant metabolism and is produced by all tissues of higher plants. It is considered the natural aging and ripening hormone and is active even at small traces. Horticultural commodities can be classified as follows, based on the amount of ethylene they produce:

- ✓ Low ethylene production - Cauliflower, cherry, citrus, leafy vegetables, root vegetables, potato, cucumber, eggplant, pepper, pineapple, pumpkins and watermelon.
- ✓ Moderate ethylene production - Banana, guava, honey dew melon, mango, plantain and tomato.
- ✓ High and very high ethylene production - Apples, avocado, cantaloupe, papaya, kiwi, pear, plum, passion fruit, sapote and cherimoya.

Fruits, vegetables and root crops contain 65 to 95 percent of water and their post- harvest life depends on the rate at which they use up their stored food reserves and their rate of water losses. When food and water reserves are exhausted the produce dies and decays.

***Objective of postharvest handling***

Both quantitative and qualitative losses occur at all stages in the post-harvest handling system of the distribution chain of perishables (from harvesting, through handling, packing, storage and transportation to final delivery of the fresh produce to the consumer).

Factors affecting post-harvest losses vary widely from place to place and are more and more difficult. A farmer growing fruits for his/her family's consumption does not mind too much if his produce has a few bruises and scars and if it is not packed for a suitable transportation to a market at a certain distance. Meantime if he/she is producing for the market at any distance from his own farm he must have a different attitude if he wants to get the best return from his produce: he/she mast know about the quality requirements wanted by the consumers and the proper containers needed for the transport.

Two examples below help to explain the importance of post-harvest handling.

**Example 1.** By knowing the market and its needs, the grower can and must judge how important are the requirements of appearance, maturity and flavor of his/her produce for the consumer. Those requirements are strictly related with maturity indexes, which are influenced by a proper harvesting time. A farmer must, therefore, know the proper harvesting time for his produce.

**Example 2.** The farmer must decide whether the investment in packaging will increase his/her revenue from the crop. It will be of no value to buy expensive containers for his/her produce if the harvesting is not properly done and bruises and scars damage the content before packaging. It is more important for the grower to change his attitude toward reducing post-harvest losses, through improving harvesting, than to think that the purchase of expensive packages will automatically solve his/her problem and increase his income.

The objective of post-harvest handling is, therefore, the creation of an understanding of all the operations concerned from harvesting to distribution so as to enable people to apply the proper technology in each step and in such a way to minimize losses and maintain quality as high as possible during the distribution chain. The farmer must give, among others, special and careful attention to the following steps of the post-harvest chain:

- ✓ Market demand for the produce they are planning to grow
- ✓ Market requirements and buyers
- ✓ Knowledge of the fresh produce
- ✓ Cultivation practices
- ✓ Factors affecting post-harvest deterioration
- ✓ Harvesting and field handling
- ✓ Packing in the field
- ✓ Handling and packing in the packing house
- ✓ Common storage and refrigeration;
- ✓ Transport
- ✓ Sale to agents, traders or consumers
- ✓ Market handling
- ✓ Shelf-life of the produce

### 4.2. Procedures in Postharvest technology

***A. Temperature management practices***

Temperature management is the most important tool that we have to extend shelf-life of fresh horticultural commodities after harvesting the produce. Temperature management begins with a rapid removal of the field heat by using one of the following cooling methods:

- ✓ Hydro cooling
- ✓ In package ice
- ✓ Top icing
- ✓ Evaporative cooling
- ✓ Room cooling
- ✓ Forced air cooling
- ✓ Serpentine forced air cooling
- ✓ Vacuum cooling; and
- ✓ Hydro-vacuum cooling
- ✓ Forced air cooling

Cold storage facilities should be well constructed and adequately equipped. They should have:

- ✓ Good construction, and insulation and vapor barrier
- ✓ Strong floor
- ✓ Adequate doors for loading and unloading
- ✓ Effective distribution of refrigerated air
- ✓ Properly located controls
- ✓ Enough refrigerated coil surface
- ✓ Capacity adequate to expected needs
- ✓ Appropriate stacking of the produce

***B. Control of relative humidity***

Appropriate relative humidity is important to control the following:

- ✓ Water losses
- ✓ Decay development
- ✓ Incidence of some physiological disorders
- ✓ Uniformity of ripening

Proper relative humidity should be 85-95% for the majority of the fruits, 95-98% for vegetables (except dry onions and pumpkins at 70-75%) and 95-100% for some root vegetables. Relative humidity can be controlled by the following methods:

- ✓ Addition of moisture to air by humidifiers
- ✓ Regulation of air movement in relation to produce
- ✓ Maintaining coil temperature to 1˚C difference to air temperature
- ✓ Wetting the floor in the storage room
- ✓ Addition of crushed ice

***C. Controlled atmosphere***

Controlled atmosphere means the addition or removal of gases resulting in an atmospheric composition surrounding the commodity that is different from that of the air 79% of nitrogen, 21% of oxygen and traces of carbon dioxide. Usually this involves reduction of oxygen and elevation of carbon dioxide, in a perfectly sealed room. The use of controlled atmosphere can be considered only as a supplement to the proper temperature and humidity procedures. Controlled atmosphere is used for a certain number of crops to extend shelf-life, reduce disorders such as chilling injuries, reduction of pathogens and some insect control.

***D. Supplemental procedures***

The following treatments may be applied to horticultural commodities:

- ✓ Curing of certain roots, tubers and bulbs vegetables
- ✓ Sorting for defect elimination
- ✓ Waxing and other surface coatings
- ✓ Hot water treatment
- ✓ Treatment with post-harvest fungicides or bactericides
- ✓ Use of sprout inhibitors
- ✓ Special post-harvest chemical treatment
- ✓ Fumigation for insect control

- ✓ Films wrapping
- ✓ Ethylene treatment for de-greening and ripening certain fruits, such as citrus, bananas and mangos

**4.3. Ripening fruits with ethylene gas**

In the post-harvest physiology of most horticultural crops, ethylene plays an important role, sometime beneficial (improving quality of the produce by faster and more uniform ripening prior to retail distribution) and often deleterious (increasing the rate of senescence and reducing shelf-life).

Systems for ethylene treatments. Handlers can equip existing rooms for use as ripening chambers or they can install specially built ones. Both need automatic control of temperature (for heating and cooling), humidity and ventilation. The room should be as tight as possible, to prevent leakage of gas, but not essentially hermetically sealed.

Amount of gas needed. It is recommended100 ppm of gas. Higher concentration will not speed up the ripening process. Too much gas may result an explosive air- gas mixture. Safety precautions have to be followed.

Temperature and humidity. Optimum temperature varies from 18 to 25˚C. At lower temperature ripening is slowed, from 25 to 30˚C ripening may be inhibited and decay accelerated. Relative humidity should be as high as possible.

***Other technologies for using ethylene:*** - fruits ripening could also be induced with the following methods:

- ✓ Explosion-proof ethylene mixed with an inert gas
- ✓ Ethylene generators, widely used in developed countries
- ✓ Ethephon
- ✓ Calcium carbide which, in a furnace, releases acetylene (which has an ethylene like response) when combined with water
- ✓ Fruits already ripe (included in the high ethylene producing category) can be used in very small commercial operations, or at home, to ripen other fruits

Deleterious effect of ethylene. The potent effect of ethylene on senescence of perishables commodities can greatly reduce the shelf-life of product sensitive to it. Techniques to remove it (such as the utilization of potassium permanganate, ozone, hypobaric storage and oxidizers) or reduce its effect (such as loss of green color in certain vegetables, accelerate ripening, sprouting and decreased shelf-life) are of considerable importance. Storage of perishables sensitive to the gas should not be done in the same room where products which have a high or very high production of ethylene are kept. See more details in the first part of this chapter.

**4.4. Postharvest deteriorations**

The interaction of metabolic and environmental factors is responsible for many post-harvest deteriorations. Among the main causes of wastage are the following:

- ✓ General senescence
- ✓ Water loss
- ✓ Diseases and pests
- ✓ Physical damages (mechanical injury)
- ✓ Injuries from temperature effects (chilling injuries) and other causes.

1.4. Standardization, quality factors, quality standards and quality control

Almost all agricultural commodities in developed countries are now marketed on the basis of official standards established under national or international laws. The role of the official standards is particularly important in the case of perishable commodities such as fresh fruits vegetables and root crops.

Standardization, as applied to fresh commodities can be described as "common acceptance of the practice of classifying produce and offering it for sale, in term of quality characteristics that have been precisely defined and are constant over the time and distance". Time and distance are important parameters since produce quality deteriorates with increased time and/or handling. Products that leaves the farm or the packinghouse as Grade 1 may be Grade 2 on arrival at the wholesale or retail market as a result of improper harvesting and handling, bad packaging, rough transport, excessive delays and other malpractices.

Definition of quality. The word quality is used in various ways in reference to fresh fruits, vegetables and root crops, such as market quality, edible quality, dessert quality, shipping quality, table quality, nutritional quality, internal quality, and appearance quality. Quality of fresh horticultural commodities is a combination of characteristics, attributes, and properties that give to the commodity value to humans for food (fruits, vegetables and root crops). Producers should be concerned that their commodities have good appearance and few visual defects, but for them a useful cultivar must have high yield, disease resistance, easy to harvest and shipping quality. To receivers and market distributors, appearance quality is most important, followed by firmness and shelf-life. Consumers consider good quality, fruits and vegetables which look good, are firm, and offer good flavor, good edible quality and nutritive value.

### 4.5. Postharvest quality components

The various components of quality are used to evaluate commodities in relation with specifications for grades and standards, and evaluation of responses to various environmental factors and post-harvest treatments. The relative importance of each factor depends upon the commodity and its intended use, fresh or processed. The main components are:

***Appearance*** − Many defects can influence the quality appearance of horticultural crops. Morphological defects are sprouting of potatoes, onions and garlic, rooting of onions, germination inside tomatoes and peppers, floret opening in broccoli, etc. Physical defects include shriveling and wilting of all commodities, internal drying of some fruits, mechanical damage such punctures, cuts and scratches, spitting and crushing, skin abrasions, deformation and bruising. Temperature related disorders (such as sunburn, chilling, sunscald), blossom end rot. Pathological defects include decay provoked by fungi and bacteria.

- ***Texture*** −It is important for eating and cooking quality.

- ***Flavor*** − Evaluating flavor quality involves perception of taste and aroma.

- ***Nutritive value*** − Fresh fruits and vegetables play an important role in human nutrition, especially as a source of vitamins, minerals and dietary fibers. Physical damage may reduce the nutritive value of a commodity.

- ***Safety*** − Safety factors include the presence of toxicants such as the greening of potatos, chemical residues and mycotoxine produced by fungi.

***Factors influencing quality*** − Many pre and post-harvest factors influence the composition and quality of fresh horticultural crops. They may include:

- ✓ Genetic factors: cultivar selection and rootstocks
- ✓ Pre-harvest environmental factors: climatic conditions, cultural conditions and time and method of harvesting
- ✓ Harvesting: maturity, ripeness, physiological age
- ✓ Post-harvest treatments: handling methods, storage time between harvesting and consumption
- ✓ Interaction among the above detailed factors

Some form of grading and quality control is always carried out whenever fruits, vegetables and root crops are traded. The most basic quality standard is that the produce must be edible, so severely diseased or badly damaged produce is not accepted even in the simplest market. Other quality requirements vary depending on the stage of development of the market and personal preferences of the consumers and become more and more complex as the economic prosperity of the community where the produce is traded increases.

Important quality components can be described as:

Attributes of produce, which are important to consumers and therefore could be incorporated into grading or quality standards, can be grouped under:

***Appearance characteristics*** - The most important quality attributes of fresh fruits and vegetables appearance are:

***Size*** – For most commodities consumers have a definite preference as to the desirable size, which is the most widely used quality parameter. This preference must be expressed as weight, diameter, circumference, length or width. Where produce is graded according to size, it is a normal practice to package those of similar size together. The uniformity of size allows produce to be placed into a container in a regular packing array, with the result firstly to have a more efficient use of packing space so that either more produce can be placed in the container or the size of the container reduced which means a reduction of the cost of packaging per unit of produce.

***Shape*** – While shape differs greatly between commodities, it one of the major recognition factors used by consumers who will place a lower value on a commodity, which lacks the expected characteristic shape.

***Color*** – Many produce show distinctive color changes during maturation which have been correlated by the consumers with the development of other desirable quality attribute so that the correct color of the skin is often the basis for a decision to purchase the commodity displayed on the shelves of the supermarkets.

***Conditions*** – It is a quality attribute usually referring to freshness and stage of senescence or ripeness of a commodity.

Factors which detract from the desirability of a commodity include, among others:

- ✓ Wilting of leafy vegetables
- ✓ Shriveling of fruits
- ✓ Skin blemishes such as bruises, scratch marks and cuts
- ✓ Surface contamination by soil, birds or insects secretions, plant secretions such as latex straining
- ✓ Residues from chemicals applied during the growing season
- ✓ Texture and flavor

***Texture*** is the feeling a food gives in the mouth. It is a combination of sensation derived from the lips, tongue, walls of the mouth, teeth and even the ears.

***Flavor* comprises** two factors: taste provoked by sugar and acidity of the produce and aroma provoked by volatile organic compound detected by the nose.

**4.6. Objectives of quality standards**

The ideal quality standard is one which can be related to a numerical value derived from a simple test conducted quickly in the field, packing house or market with minimum equipment to establish with a certain accuracy when to harvest, store or consume a produce. The test would mainly be used by farmers to determine when to harvest produce. It could also be used during storage or in the market to ensure that the produce being sold has retained an acceptable eating quality or has a predetermined self-life.

**Main objective quality standards are:**

- ✓ **Color** Research has developed charts for apple, pears and stone fruits. Similar ones are for bananas and tomatoes.
- ✓ **Flesh firmness** The measurement of the texture of the flesh is applied mostly in apples and pears with a penetrometer to establish the proper harvesting time suitable for a long cold storage of the produce.
- ✓ **Soluble solids** The sugar content measured with a refractometer is a suitable maturity index for a number of fruits, such as grapes, melons, pineapples and citrus.
- ✓ **Titratable acidity** With the approach of maturity we assist in the reduction of the acidity in the majority of fruits. It is useful for a number of fruits but correct measurement can be done only in a laboratory.
- ✓ **Sugar/acid ratio** The ratio between sugar and acidity is used to assess the acceptability of citrus, pineapple and grapes.

**4.7. Development of grading standards**

Developed countries have comprehensive sets of regulations for fruits, vegetables and root crops marketed in the countries themselves or for export. An increasing number of developing countries have developed the same regulations to export their produce to developed ones. The regulations stipulate the market grade classifications which must be used and define in detail the physical characteristics and quality parameters of produce in each grade. They also often specify the type and size of the containers (packages) that can be used, labeling requirements, recommended storage and transport conditions and permitted post-harvest treatments.

The regulations usually categorize produce into three or four classes, with the lowest class being considered only just acceptable for marketing. The appearance of the produce in each class is decided on the basis of shape and color, the type and extent of blemishes that can be present and physical characteristic specific to that commodity.

***Starting grade standards at the farm:*** The first simple grading which could be introduced at farm level for marketing produce within the country should merely be to codify the informal market practices that are currently in use. Future refinements should be gradual and with the aim at eliminating undesirables and inefficient practices. When a set of regulations have been gradually introduced, it is necessary to conduct an intensive education campaign to ensure that everyone is fully aware of what the changes are and how farmers will benefit from the changes.

***Starting grade standards for export:*** Grade standards for export can be introduced only after the introduction of simple but clear grades standards for marketing the produce within the country. The grades standards to be introduced will have to be those established and implemented in the country where the export is planned. Standards should be introduced at trade level or at farm level in case this is well organized. Few exporting countries have established standards, which are even stricter than those prevailing in the importing country. This ensures that only top quality produce is exported.

### 4.8. Quality control

Fresh produce is highly perishable and it is natural that some deterioration of quality will occur during the marketing process. The rate of deterioration will depend on the care or abuse exerted on the produce during harvesting, handling, transport and storage. The development of marketing practices and strategies become more important and refined with the development of marketing practices, standardization, market information service and increased competition. Quality control is one of the most important features in achieving consistency and reliability of products, like all aspects of marketing quality control demands good planning, research, and management together with regular training and reviewing of procedures. When standardization practices have been implemented and there is a degree of policy in the market place, there will also be an elementary form of quality control.

In the developed countries and also in those developing countries, which operate a regular export service to sophisticated markets, the practice of quality control has become a fundamental part of the production and marketing program. Monitoring and testing of production practices, for maximum production of produce, which conforms to market demand, is one area where institutional research particularly in Grenada can be of great assistance to the producer, but the producer has the obligation of adhering to guidelines, such as:

**At harvest time** - the producer must keep a careful check on harvest maturity to ensure that the produce conforms to market and/or storage requirements.

**In field packing and transport** - the producer must carefully check that the operation is properly conducted to ensure that the produce arrives at the packinghouse or to the market in good condition.

**In the packinghouse** - the packer needs to keep a close eye on the performance of his staff to ensure that selection and grading practices are adhered to.

One of the biggest problems concerning implementation of standardization and quality control in developing countries is the lack of personnel with suitable qualification and experience There is a big scope for countries to send promising staff abroad for training. In addition, there is a need for dissemination and training to middle level staff who are already active by organizing practical workshops at the national, district, institutional and school levels.

# Chapter Five

## 5.1. Harvesting and Handling of Horticultural Produces

Farm management is generally aimed at maximizing the yield of a crop from the area of land under cultivation while at the same time maximizing the return. The time, labor and capital expended in bringing the crop to maturity is rewarded by the financial return obtained by the grower during marketing.

For fruits and vegetables, the magnitude of this return mainly depend on:

- ✓ **Quantity of fresh produce harvested and marketed -** which mostly depends on production planning, crop selection, varietal selection, production practices (which include among other irrigation, cultural practices, fertilization and chemical treatments).
- ✓ **Quality attributes to satisfy market and consumer requirements -** The overall quality of fresh produce cannot be improved after harvest, there are a few exceptions like controlled ripening to improve color and flavor and refrigerated and controlled cold storage to extend shelf-life. These exceptions are however limited by pre-harvest conditions.

**Size.** It is the major quality factor and farmers through varietal selection followed by production practices, should try to control it. The aim is to produce a crop of an average desirable size which is not necessarily the largest possible size.

**Mechanical defects.** The need to reduce surface defects is an inevitable consequence of market development. These defects can be physical damages which can be controlled pre-harvest by better plant management to protect the produce from wind, sun, hail, chemical residues, etc.

**Pest and diseases.** A better control with appropriate and controlled application of chemicals and field sanitations practices to control fungal, bacteria and insect attacks and avoid the presence of unsightly marks.

**Varietal selection.** The desired market characteristics of a commodity can often only be obtained by changing the variety being grown. This will often mean that growers have the difficult task of adapting to new varieties which may have very different growing characteristics compared to traditional ones. However, a resistance to change may mean a major loss of income as the traditional varieties become less popular on the market.

**Harvest:** is a specific and singe deliberate action to separates the food stuff with or without non edible portion from its growth medium.

Eg - Plucking of F, V & Flowers - Reaping of cereals

- Lifting of fish from water - Lifting of tuber or roots from soil etc.

Important factors conceded while harvesting crops are:

- ✓ Delicacy of the crop (soft –grapes/strawberry: hard - melons)
- ✓ Importance of speed during/after harvest
- ✓ Economy of the harvest operation.

Remember that damage done to produce during harvest is irreparable; thus improper harvesting leads to shortening of shelf life due to:

- ✓ increased respiration and ethylene bio synthesis
- ✓ increased levels of microorganism infection through damaged areas
- ✓ possible increase in physiological disorder

Employing improper harvesting methods will result in damage to crop by

**I. Cuts -** where produce comes in contact with sharp object during harvesting/ handling

**II. Bruising -** is caused by:

a. **Compression–** due to over filling of boxes, over load in transportations and bulky storing.

b. **Impact –** due to dropping or something hitting the produce

**c. Vibration –** occur due to lose packing in transportation

An important precaution at harvest is to:

- ✓ Avoid contaminating produce with pathogens. Practice such as allowing the mango stem end down on the ground to allow the sap to drain should be discouraged.
- ✓ Harvested produce should be kept under shaded tree or using tarpaulins/shade nets.

Harvesting can be performed by hand or mechanically. However, for some crops - eg. onions, potatoes, carrots and others - it is possible to use a combination of both systems. In such cases, the mechanical loosening of soil facilitates hand harvesting. The choice of one or other harvest system depends on the type of crop, destination and acreage to be harvested.

Fruits and vegetables for the fresh market are hand harvested while vegetables for processing or other crops grown on a large scale are mainly harvested mechanically (peas, beans, potato etc.).

## 5.2. Harvesting factors

The quality and conditions of produce sent to market and their consequent selling price are directly affected by the care taken during harvesting and field handling. Whatever the scale of operations or the resources of labor and equipment available, the planning and carrying out of harvesting operations must observe basic principles.

The objective of the grower should be:

- ✓ to harvest a good quality crop in good condition
- ✓ to keep the harvested produce in good condition (protected from rain, sun or animals) until it is consumed or sold
- ✓ to dispose of the crop to a buyer or through a market as soon as possible after harvest

To meet these objectives, success for the harvesting, field handling and marketing must depend on planning from the earliest stages of production, with particular regard to:

- ✓ crop selection and timing to meet expected market requirements
- ✓ contact with buyers so that the crop can be sold at a good price when ready for harvest
- ✓ planning harvest operations in good time, arranging for labor, equipment, material, cover space to protect the inputs and the harvested crop and transport
- ✓ it is economically sound in terms of returns on investment to improve grading, packing and handling of the produce before it leaves the farm
- ✓ considering the above the grower must ensure that all those working on the farm are properly trained
- ✓ provide full supervision at all stages of harvesting and field handling

## 5.3. Maturity Indices and Maturity at harvest in Horticultural Produce

Fruits and vegetables are considered to be commercially mature when at the stage of physiological development that consumers consider to be the most desirable. However, the stage, at which a commodity reaches commercial maturity, varies greatly. Many leafy vegetables are commercially mature at an early stage of plant development while fruits are often ready for harvest at a fully developed stage.

Maturity standards have been determined for many fruits and vegetables. Harvesting crops at the proper maturity allows handlers to begin their work with the best possible quality produce. Produce harvested too early may lack flavor and may not ripen properly, while produce harvested too late may be fibrous or overripe and have a shorter shelf-life. Pickers can be trained in methods of identifying produce that are ready for harvest.

***Maturity Indices*** - During growth and development of plants there are various stages through which series of events occur which are distinct in each stages. Maturity is viewed as natural phenomenon in plant biology, it is generally considered as stage of development, where plant is super imposed and capable of shifting from vegetative to reproductive stage.

Maturation is process by which fruit / vegetable develops from immature to mature state and this normally applied as:

- ✓ Entire course of fruit development
- ✓ Only a period of development just preceding to senescence
- ✓ Time between final stage of fruit growth and to beginning of ripening

Harvesting of horticultural produce at right stage of maturity is very essential for optimum quality and to maintain further its intact intrinsic quality for maximum returns. Maturity is a stage of full development of the tissues of the fruit only after which it will ripen. Ripening stage comes only after maturity.

**Maturation -** is the stage of development leading the attainment of physiological or horticultural maturity.

**Principles of harvest maturity**

1. Harvested commodity should have its peak acceptable quality when it reaches the consumer.
2. Produce should develop an acceptable flavor or appearance.
3. Produce should have optimum size and shape required by the market.
4. It should not be toxic or un acceptable.
5. Harvest maturity should have adequate shelf life.

**5.4. Type of Maturity**

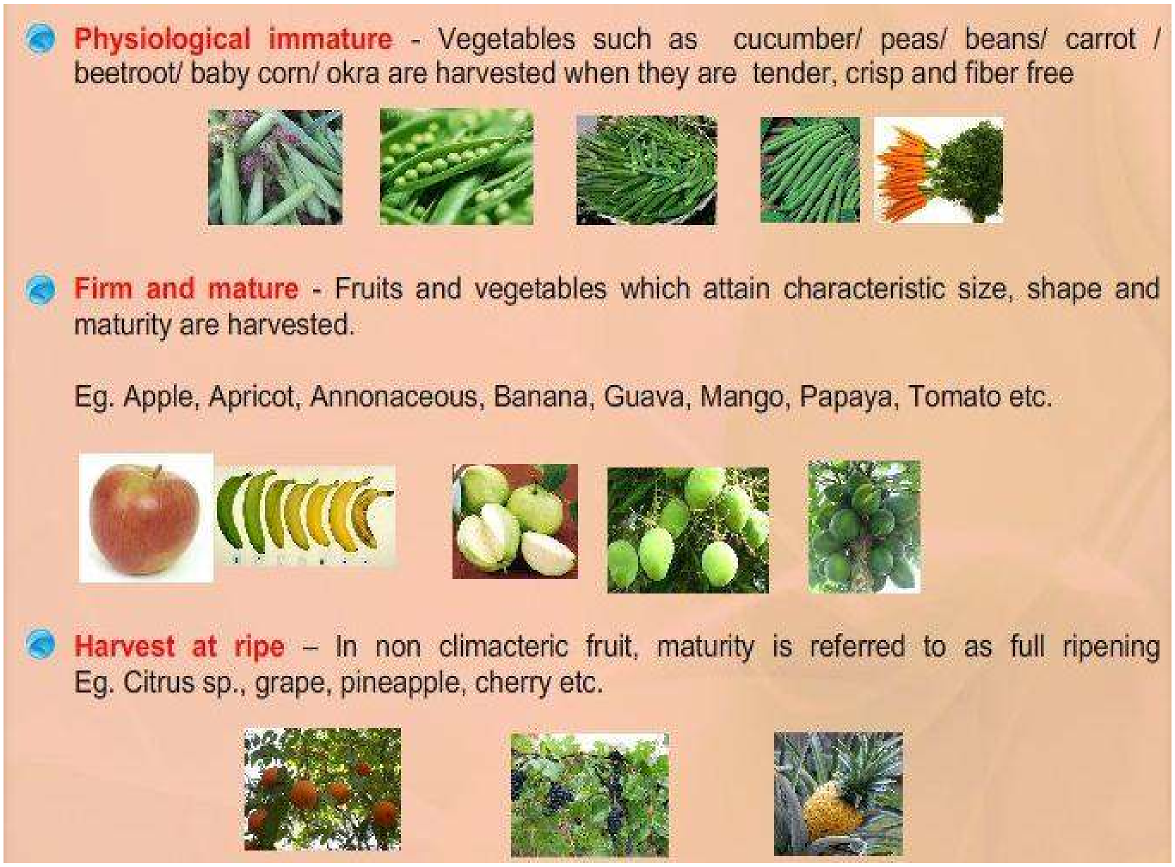
I. **Physiological maturity:** Attainment of full development of stage just prior to ripening or ripening in non-climacteric fruits. Eg.: Fruits and vegetables produced for seed production

**II. Horticultural /Commercial maturity –** stage at which growth and development is optimum for specific use (stage acceptable for consumers/market oriented). Eg. Fresh vegetables for canning/ dehydration/ IQF – Individual Quick Frozen/ harvesting for local or distant market.

Horticulture maturity is classified into 3 different groups

- ✓ Physiological immature
- ✓ Firm and mature

✓ Harvest ripe




**Judging the maturity in fruits crops:**

1. **Culinary maturity:** For cooking, fruits like papaya, jack fruits, tomato, figs bread fruits, when used as vegetable, harvesting is done at immature/suitable stage

2. **Dessert maturity:** For local market and fresh consumption. Eg.: Jack fruit, watermelon, mango and orange

3. **Shipping maturity:** For long distance transportation fruits will be harvested much earlier than for local consumption (before ripening) which prolongs shelf life. Eg. Mango, banana

4. **Processing maturity or processing**: Harvest time depends on the distance of orchard from the processing units and the type of fruit/vegetable and product to be prepared

**Advantage of Estimation of Maturity**

- ✓ To up keep the quality of product
- ✓ To enhance freshness/appearance /elegance of the produce
- ✓ Improvement in the storage life of the produce
- ✓ Management of ripening and senescence (hasten /delay)
- ✓ Easy of handling
- ✓ To maximize returns
- ✓ To manage the environmental factors
- ✓ To manage pest and diseases

- ✓ Extended utilization of the produce
- ✓ For long distance transportation of the produce

**Determination of maturity indices**

A great considerable variation occurs among the different types of verities, hybrids, cultivars, ecotypes/biotypes of some crop. These variations may be minimized by appropriate judging of maturity.

**How to identify/check the harvest maturity?**

**Sensory /Visual observation -** one of the simplest and easiest methods where, objective and subjective techniques have been employed such as

**Subjective methods**:

**Sight -** colour, size and shape, persistent part of calyx, presence of dried outer leaves, fullness of the fruit, drying of plant part, green tops collapse (onion) and green tops die off (potato).

**Touch -** texture, hardness or softness, rough, smooth. eg- peas, beans, okra

**Smell -** odour or aroma. eg- jack fruit, mango

**Taste -** sweetness, saltiness, sourness, bitterness

**Resonance -** sound when tapped. eg- water melon, jack fruit

**Disadvantage of sensory maturity**

- ✓ When cultivated area is larger, these techniques are tedious.
- ✓ Colour of the each fruit/ bunch cannot be same due to variation in perception.
- ✓ Variation in weather will misleads the judging
- ✓ Variation in biotic and abiotic factors with in orchard (micro climate) influence the crop judgment (plants near pond/compost pit grows luxuriantly)

I. Computational methods

1. Calendar date
2. DFFB
3. Heat units
4. T- stage

II. **Physical methods**

- ✓ Fruit retention strength
- ✓ Fruit size and surface morphology
- ✓ Weight
- ✓ Specific gravity
- ✓ Colour - skin, flesh and seed
- ✓ Firmness
- ✓ Ease of separation
- ✓ Brittleness of the floral part
- ✓ Juice content
- ✓ Bulk density - Cole crops/lettuce structural properties – soft/rough
- ✓ Development of abscission layer - melons

III. **Chemical methods**

- ✓ Titratable acidity
- ✓ TSS/acid ratio
- ✓ Sugars
- ✓ Sugar/ acid ratio
- ✓ Bioelectrical conductance
- ✓ Starch content - Iodine test
- ✓ Tannin content - dates, persimmon and litchi
- ✓ Oil content
- ✓ Juice content

**IV. Physiological methods**

1. Rate of respiration
2. Rate of ethylene production
3. Transpiration
4. Production of volatiles

**V. Geometrical methods**

1. Particles size and shape of the produce
2. Particle composition and orientation in a given tissue or food
3. Moisture content of produce

**Methods of Maturity Indices**

| No. | Maturity Indices | Fruits / Vegetables |
|---|---|---|
| | EXTERNAL | |
| 1 | Visual (OECD colour charts) | All fruits and most vegetables |
| 2 | Calendar date | All fruits |
| 3 | DFFB | All fruits and radish |
| 4 | Heat unit | Apple, pear, grape, mango, ber, litchi, sweetcorn etc. |
| 5 | T-Stage | Apple |
| 6 | Size | All fruits, beans, carrot, cucumber, cherry, asparagus and cauliflower, zucchini |
| 7 | Surface morphology | Grape(cuticle formation), banana, mango, sapota, litchi, tomatoes, netting on some melons, glossy ness of some fruits (development of wax) |
| 8 | Specific gravity (Sinker/floater) | Cherries, mango and ber |
| 9 | Fruit retention strength | Apple |
| 10 | Colour -Surface | All fruits ,tomato, water melon |
| | Seed | Apple, Pears |
| | Flesh<br>Instrument used colourimeter | Mango, papaya, watermelon and muskmelon, tomato(jelly like material) |
| 11 | Leaf changes | Potato, onion, melons(leaf axis on fruit dries ) |
| 12 | Textural Properties | |
| | ➢ Firmness (Penetrometer /Fruit presser tester) | Pome and stone fruits, beans, lettuce and melons |
| | ➢ Tenderness (Tenderometer) | Pea |
| | ➢ Touch/Finger Squeezing | Beans, okra, peas |
| 13 | Shape | Compactness in cabbage, cauliflower & broccoli Angularity of banana Full shoulder development in mango |
| 14 | Abscission layer | Melons |
| 15 | Solidity-Bulk density/X/Gamma rays | Lettuce, cabbage, brussels sprouts |
| 16 | Tight bud/ bud crack<br>Flower opening | Rose and many cut flowers<br>Loose flower- crossandra, marigold etc. |
| 17 | INTERNAL | |
| | ➢ Total solids : Dry weight | Potato, Avocado, Kiwi fruit etc |
| | ➢ TSS | All fruits ,tomato, water melon |
| | ➢ Starch content -Iodine test | Apple, banana, pear etc |
| | ➢ Sugar content (Hand Refractometer) | All fruits |
| | ➢ Acidity or Sugar/acid ratio | Pomegranate, citrus, papaya, kiwi fruit and grape |
| | ➢ Juice Content | Citrus Sp. |

| | | |
|---|---|---|
| | ➢ Astringency (Tannin) | Persimmon and dates |
| | ➢ Oil content | Avocado |
| 18 | **Physiological:** | |
| | ➢ Respiration and $C_2H_4$ rate | Apple and pears and many fruits |
| | ➢ Optical methods (380-730nm) | Apricot, banana, orange, papaya |
| | ➢ Aroma | Many fruits |
| | ➢ Fruit opening | Nutmeg, chow chow (over mature), Ackee |
| | ➢ Acoustic / Vibration | Melons/ Apple, tomato(unripe 110- ripe 80 Hz) |
| | ➢ Electrical Characteristics | Peach (unripe 550,ripe150 Hertz) |
| | ➢ Electormagnetic - Nuclear magnetic resonance (NMR) | Apple, banana, avocado peach, pear, onion |
| | ➢ Near-Infrared reflectance (400-2500 | Mango, pineapple |
| | ➢ Radiation (X-rays & gamma - rays) | Lettuce, potato |

The final decision on harvesting will take account of the current market value of the expected yield, and also the time during which the crop will remain in marketable condition. With seasonal crops, growers are often tempted to harvest too early or too late in order to benefit from higher prices at the beginning and end of the season.

### 5.5. Judging Maturity in Horticultural Produce

The principles dictating at which stage of maturity a fruit or vegetable should be harvested are crucial to its subsequent storage and marketable life and quality. Post-harvest physiologists distinguish three stages in the life span of fruits and vegetables: maturation, ripening, and senescence. 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. Some typical maturity indexes are described in following sections

## *Computational methods*

**1. Calendar date:** is one of the commonly used indices of maturity and is reasonably accurate provided flowering and weather during growing season is normal. But standardization requires study for many seasons for given variety, location, rootstock etc.

Eg. Mango harvesting period – April to July

**2. DFFB (Days From Full Bloom):** is reliable but varies greatly from year – to - year and location –to- location. In such case the optimum date of harvest can be predicted by doing night temperature correction for 15 days fallowing full bloom. For every 10F variation from an average night temperature, a correction of one day is made in the standard figure from full bloom.

Eg. Mango 110 -125 day (Var. Alphonso and Pairi ), Banana 99 - 107 days in dwarf Cavendish

**3. Heat units /Day degree:** Optimum maturity is computed by the sum of mean daily temperature, above base temperature (10ºC/50ºF for apple) for a period concerned. The number of degree-days to maturity is determined over a period of several years. 10oC /50oF is the temperature at which growth occurs for apple and base temperature varies with crop.

The degree day is based on a growth-temperature relation. However, this heat unit work only within limited temperature. Heat units are not useful for photoperiod sensitive species.

**A Heat unit is calculated by -** (daily mean temp – base temp) X No. of Days (flowering to harvest)

Base temperature for tomato, spinach and pumpkin is 150, 20 and 130$^{O}$C respectively.

**Table: Heat requirement for various crops**

| Crop | Cultivars | Base temp | Degree Days |
|---|---|---|---|
| Apple | Red delicious | 18oC | 1659-1705 |
| Grape | Thompson seedless | 10 oC /50oF | 1600-2000 |
| | Bangalore Blue | | 3562 |
| | Gulabi | | 3508 |
| Mango | Banganapalli | 18oC | 1426 |
| Banana | - | 9.8oC | 1930 |
| Asparagus | - | 10 oC /50oF | 120-410 |
| Peas | Early Wisconsin | 4.4 oC /40oF | 1319 |
| | Alaska | | 1200 |

## *Physical methods*

**1. Fruit retention strength:** is the force required to pull the fruit from the tree which indicates

the maturity status of the fruit.

Eg. Immature fruit required more force to detach from mother plant compared to ripe fruits.

**2. Acoustic/sound tests:** the sound of a fruit as it is tapped sharply with a finger knuckle can change during maturation and ripening. This method of testing fruit is sometimes used by consumers when purchasing fruit.

Eg. - Water melon fruit may be tapped in the field to judge whether they are ready to be harvested, ripe fruit gives dull sound and also in jackfruit

**3. Skin color:** This is the common method used in fruits to judge maturity, where, the skin color changes as the fruit matures or ripens. Color changes may vary from cultivars, seasons, site, light etc. In most of the fruits GREEN color changes to LIGHT GREEN/YELLOW/ RED/ PURPLE /VIOLET during ripening after the optimum maturity. When it is still green it may be possible to develop the color after harvest but not all the flavor characteristics. If the fruit is harvested just as the yellow color begins to show in the shoulders / panicles of the fruits, fruit can eventually ripen to an acceptable flavor.

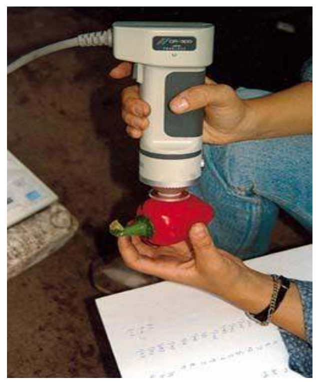


Fig. Objective colour measurement with a colourimeter

The assessment of harvest maturity by skin colour changes usually on the judgement of the harvester, but colour charts are used for some cultivars of apple, chilli, peach and tomato. The chlorophyll fluorescence spectrometer or colorimeter used to detect the loss of chlorophyll.

**4. Shape:** The shape referred to the design of the fruit. Shape of fruit can change during maturation.

- ✓ Eg. Banana - individual fingers become more rounded on maturity from angular shape(refer fig.).
- ✓ Mango - immature fruit shoulder shows slope away from the fruit stalk; on more mature fruit shoulders become more level with point of attachment (fullness of the checks adjacent to the pedicle) (refer fig.).

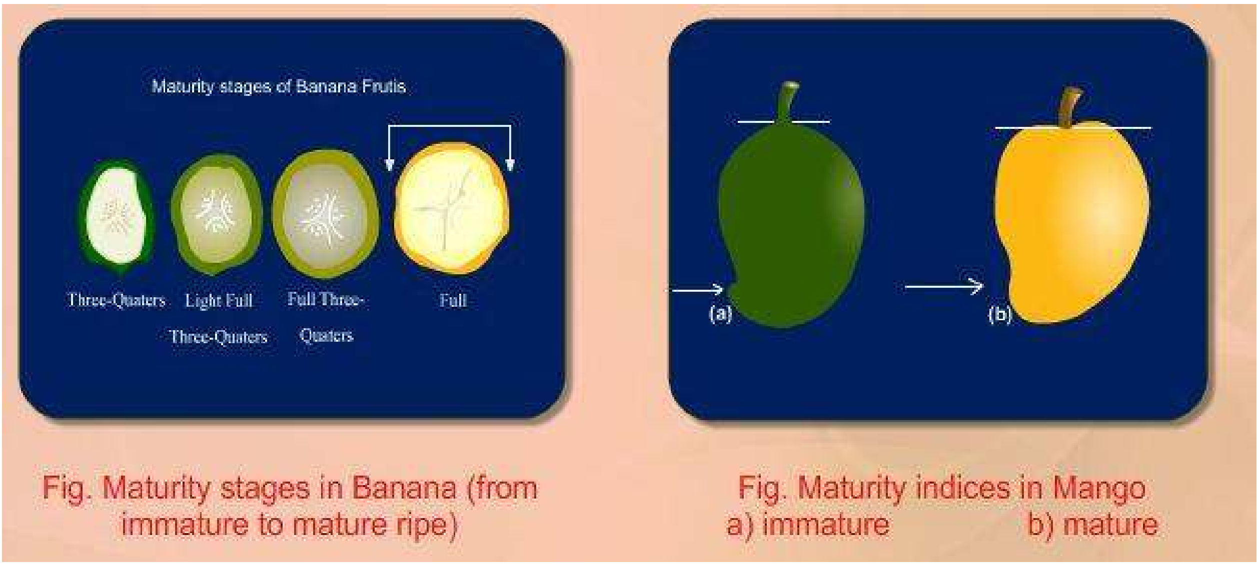


Fig. Maturity stages in Banana (from immature to mature ripe)

Fig. Maturity indices in Mango a) immature b) mature

**5. Size:** The change in size of crop as it is growing are frequently used to determine when it should be harvested. Eg.

- ✓ Litchi, green beans, okra and asparagus and potato related to size at maturity.
- ✓ In banana width of individual fingers can be used for determining their harvest maturity.
- ✓ In baby corn more immature and smaller cob are marked for maturity.

**6. Aroma/ Orgnoleptic quality:** Fruits synthesize volatile chemicals as they may give its characteristic odor and can be used to determine whether it is ripe or not with indication of fruit flies. This method has limited scope in commercial application.

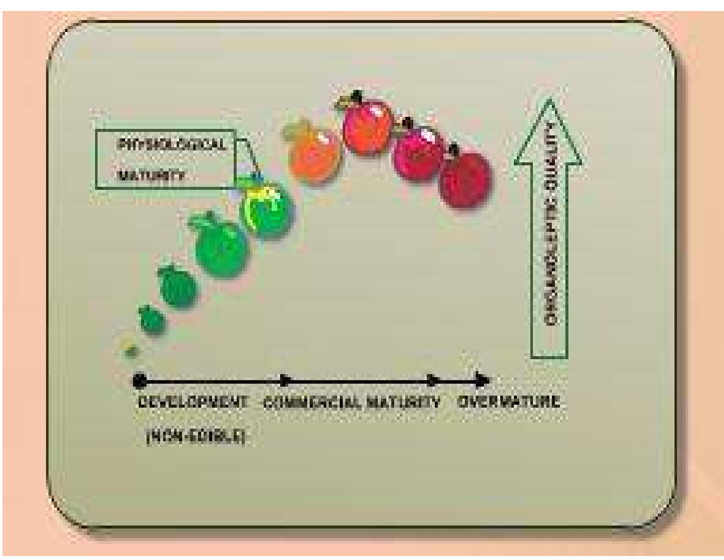



Figure: Organoleptic quality of a fruit in relationship to its ripening stage

7**. Fruit opening**: When the fruit is fully mature on the tree it splits.

Eg. - It is common in fruit of spice tree nutmeg,  ackee tree.

8**. Abscission**: Abscission layer is formed in the pedicel as the natural development in the fruit advanced.  However, fruit harvested at this maturity will have only short marketable life.

Eg.: In cantaloupe, watermelons, harvesting before abscission layer is fully developed results inferior flavored fruit compared with those left on the vine for the full period.

9**. Specific gravity**: is the relative gravity/weight of solids or liquids compared to pure distilled water at 16.7$^{O}$C (62$^{O}$F).

**Eg.** Cherries, watermelon, potato, ber and mango (at 1.015 immature and at 1.02 ready for harvest)

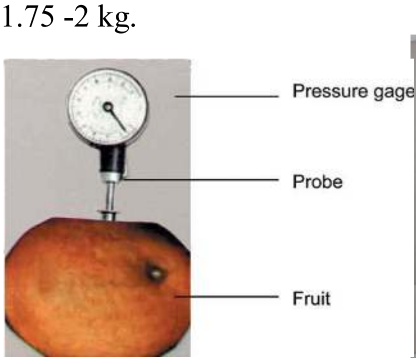
10. **Firmness/solidity**: Here harvester slightly presses vegetables such as cabbage and lettuce with his thumb and finger.  Harvest maturity is assessed on the basis of how much the vegetable yield to this pressure.  Normally the back of the hand is used for testing the firmness of lettuce in order to avoid damage.  Fruit may change in texture during maturation and especially during ripening; excessive moisture loss may also affect the texture of crops.

The textural changes can be detected by following ways;

**Destructive firmness test methods:**

**a**. **Penetrometer / Pressure testers**: Here a representative sample of fruits may be taken from the orchard and tested in a device ( Magness Taylor or Effegi fruit presser tester) which will give a numerical value of texture; when that value reaches a pre-determined critical level then the fruits in that orchard are harvested.

Eg. Firmness test in mango 1.75 -2 kg.



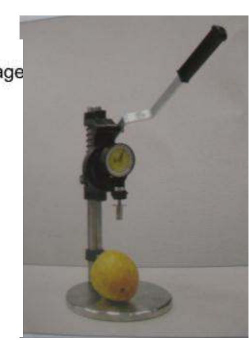



Fig. Objective firmness measurement using Penetrometer

**b. Tenderometer:** It is used in peas only. As pea matures in the pod it is sweet and tender. As maturation progress sugars are converted to starch which coincides with the peas becoming firmer. Therefore for processing sample peas are taken from the field and their texture is tested in a shear cell. The whole field of peas is harvested when a particular tenderometer value is reached.

Fig.Tenderometer to test the pea maturity by presser tester

**c. Fingure squeeze/touch:** Here peas/beans/okra etc. are squeezed between the fingers to determine their firmness. Only experience plays a role here whether to harvest or not.

## *Chemical methods*

**1. Juice content:** The juice content of fruit increases as they mature on the tree. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit it is possible to specify its maturity.

| | Type of citrus fruit | Min. juice content(%) |
|---|---|---|
| 1 | Navel oranges | 30% |
| 2 | Other oranges | 35% |
| 3 | Grape fruit | 35% |
| 4 | Lemons | 25% |
| 5 | Mandarins | 33% |

**2. Oil content:** Oil content of the fruit may be used to determine the harvest maturity of avocados. At the time of picking and at all times there after shall contain not less than 8% of oil by weight of the avocado excluding the skin and seed. There is good correlation between taste and oil content and dry matter.

**3. Dry matter:** Rate of dry matter accumulation is used to predict optimum harvest time by using instrument hydrometer. Dry matter is also being used to as the maturity standard in processing varieties of potato. Potato dry matter content at the time harvesting should be in the range of 18 – 24g.

**4. Sugar:** In climacteric fruit carbohydrates are accumulated during maturation in the form of starch. As the fruit ripens starch is broken down to sugars. In non-climacteric fruits sugars tend to be accumulated during maturation. In both cases it follows that measurement of sugars in the fruit can provide an indication of the stage of ripeness or maturity of that fruits.

Sugar is measured in terms of soluble solids using Brix hydrometer or Refractometer.

| Fruit | TSS (~%) | Fruit | TSS (~%) |
|---|---|---|---|
| Apple | 11.50 -14.50 | Papaya | 11 - 12 |
| Citrus | 12 -14 | Pineapple | 13.00 |
| Grapes | 12-20 | Mango | 12 -18 |
| Kiwi | 8.00 | | |
| Pear | 12.92-12.99 | | |

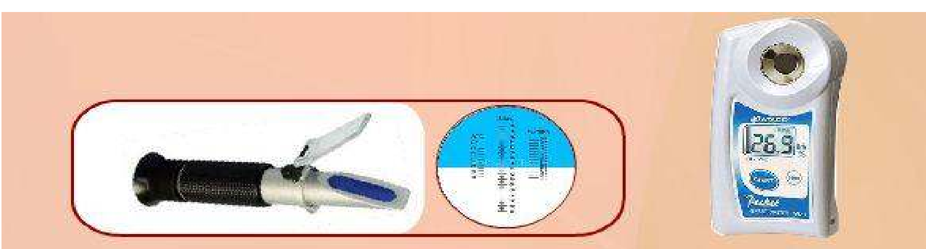



Fig. Hand and Digital Refractometrs

**5. Acidity:** in many citrus fruits and others acidity progressively reduces on maturation and ripening. Extract the juice from the sample and titrating it against a standard alkaline solution gives a measure which can be related to optimum time of harvest. It is important to measure acidity by titration and not the pH of the fruit because of the considerable buffery capacity in fruit juices. This measure gives the brix: acid ratio

**Physiological maturity**

This is the stage where plant attain full development of stage just prior to ripening.

Eg. Fruits and vegetables produced for seed production

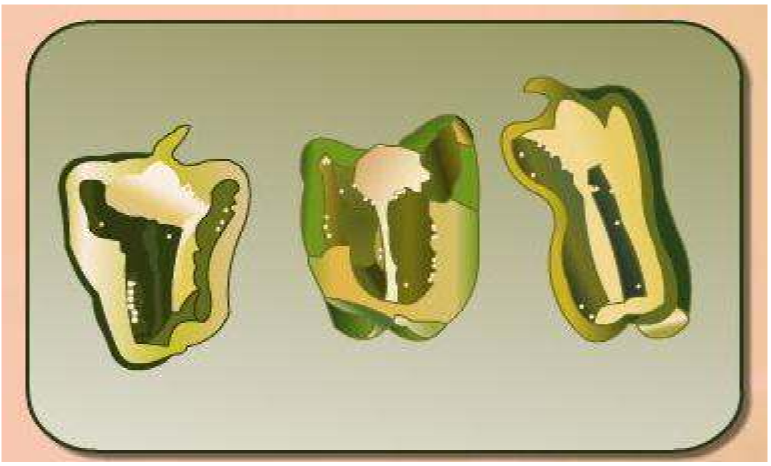


Fig. Physiological maturity in bell pepper is reached when seeds become hardened the internal cavity of fruit starts coloring.

## Table Maturity indexes for fruits

| Index | Examples |
|---|---|
| Elapsed days from full bloom to harvest | Apples, pears |
| Mean heat units during development | Peas, apples, sweet corn |
| Development of abscission layer | Some melons, apples, feijoas |
| Surface morphology and structure | Cuticle formation on grapes, tomatoes<br>Netting of some melons |
| Size | All fruits and many vegetables |
| Specific gravity | Cherries, watermelons, potatoes |
| Shape | Angularity of banana fingers<br>Full cheeks of mangos |
| | Compactness of broccoli and cauliflower |
| Solidity | Lettuce, cabbage, Brussels sprouts |
| Textural properties | |
| Firmness | Apples, pears, stone fruits |
| Tenderness | Peas |
| Color, external | All fruits and most vegetables |
| Internal color and structure | Formation of jelly-like material in tomato fruits<br>Flesh color of some fruits |
| Compositional factors | |

| | |
|---|---|
| Starch content | Apples, pears |
| Sugar content | Apples, pears, stone fruits, grapes |
| Acid content, sugar/acid ratio | Pomegranates, citrus, papaya, melons, kiwifruit |
| Juice content | Citrus fruits |
| Oil content | Avocados |
| Astringency (tannin content) | Persimmons, dates |
| Internal ethylene concentration | Apples, pears |

**Source:** Kader, A. A. 1983. Post-harvest quality maintenance of fruits and vegetables in developing countries

**Vegetables** - are harvested over a wide range of maturities, depending upon the part of the plant used as food. Table 2 provides some examples of maturity indices of vegetable crops.

**Table 2. Maturity indexes for some popular vegetables and root crops.**

| Crop | Index |
|---|---|
| **Root, bulb and tuber crops** | |
| Radish and carrot | Large enough and crispy (over-mature if pithy) |
| Potato, onion, and garlic | Tops beginning to dry out and topple down |
| Yam, bean and ginger | Large enough (over-mature if tough and fibrous) |
| Green onion | Leaves at their broadest and longest |
| **Fruit vegetables** | |
| Cowpea, yard-long bean, snap bean, sweet pea, and winged bean | Well-filled pods that snap readily |
| Lima bean and pigeon pea | Well-filled pods that are beginning to lose their greenness |
| Okra | Desirable size reached and the tips of which can be snapped readily |
| Snake gourd, and dishrag gourd | Desirable size reached and thumbnail can still penetrate |
| | flesh readily (over-mature if thumbnail cannot penetrate flesh readily) |
| Eggplant, bitter gourd, chistophine or slicing cucumber | Desirable size reached but still tender (over mature if color dulls or changes and seeds are tough) |
| Sweet corn | Exudes milky sap when thumbnail penetrates kernel |
| Tomato | Seeds slipping when fruit is cut, or green color turning pink |
| Sweet pepper | Deep green color turning dull or red |
| Muskmelon | Easily separated from vine with a slight twist leaving clean cavity |
| Honeydew melon | Change in fruit color from a slight greenish white to cream; aroma noticeable |

| | |
|---|---|
| Watermelon | Color of lower part turning creamy yellow, dull hollow sound when thumped |
| **Flower vegetables** | |
| Cauliflower | Curd compact (over mature if flower cluster elongates and become loose) |
| Broccoli | Bud cluster compact (over mature if loose) |
| Leafy vegetables | |
| Lettuce | Big enough before flowering |
| Cabbage | Head compact (over mature if head cracks) |
| Celery | Big enough before it becomes pithy |

Source: Bautista, O.K. and Mabesa, R.C. (Eds). 1977. Vegetable production. University of the Philippines at Los Banos.

This variation in physiological development means that there is no single factor that can be used to determine the optimum harvest date for all commodities and much research is still needed to find simple objective tests to reliably indicate when produce is at commercial maturity.

In addition to eating quality, the effect of maturity on the ability of a commodity to be stored or transported can influence the preferred harvest stage. Climacteric fruits are generally harvested prior to the onset of natural ripening so they can be transported in a hard green stage and then ripened in the market. Some other fruits and vegetables are harvested slightly immature as they are then less susceptible to attack by microorganisms. In contrast, apples required for a long cold or controlled atmosphere storage are harvested slightly overripe if we do not want the development of “superficial scald”, unless we want to control the disorder with a post-harvest chemical treatment.

### 5.6. Regulation of ripening processes

During ripening an inedible mature fruit will turn into edible soft fruit with optimum taste and characteristic flavor. Fruits start ripening after reaching maturity by release of a ripening hormone known as ethylene from the fruit. All fruits especially climacteric fruits produce small amounts of ethylene during ripening that triggers ripening changes. During this ripening process fruits attain their desirable color, flavor, quality and other textural properties. A series of metabolic activities like increase in respiration rate of fruits, conversion of starch to sugars, reduction in acidity, removal of astringency or tart taste, softening of the fruit, development of characteristic aroma, surface color and pulp color occur during ripening. However, in some fruits like grapes, litchi, pineapple, strawberry, plum, which are harvested at ready to eat stage, these changes are not significant.

***Control/Delay of ripening***

Manipulating the ripening is important in extending the shelf life and ensuring appropriate quality of fruit to the consumer. Unpredictable ripening during storage, transport and distribution can result in spoilage before consumption. The ripening hormone, ethylene is known to trigger ripening in climacteric fruit and senescence in non-climacteric. The risks of accidental exposure to ethylene can be minimized by reducing ethylene concentrations in the storage environment with practices such as oxidation by potassium permanganate, or ultraviolet light. However, these systems, while being effective for certain commodities, have limited commercial application. Recent development of new chemicals like 1- methylcyclopropene (1-MCP) provides a new approach for manipulation of ripening and senescence.

***1-MCP (1-methylcyclopropene)***

The 1-methylcyclopropene (1-MCP or C4H6) is an ethylene action inhibitor. It binds with ethylene receptors and thereby prevents ethylene dependent responses in many horticultural commodities. 1-MCP has been formulated into a powder that releases its active ingredient when mixed with water. This nontoxic compound can be used at very low concentrations (nL L-1). The beneficial effects of 1-MCP in fresh produce include the inhibition of respiration and ethylene production, delayed fruit softening, restricted skin color changes, prolonged cold storage life and alleviation of certain ethylene- induced post-harvest physiological disorders. 1-MCP treatment is also useful in reducing chilling injury symptoms and decay in tropical fruit during cold storage

***Enhancing ripening***

The ripening process of fruits can start when the fruits are still on the tree if left un-harvested. However, once ripe, handling and marketing of fruit will become difficult. Hence, majority of fruits like mango, banana, papaya, sapota, guava and custard apple are harvested in a mature but unripe condition. They are subsequently allowed to ripen by natural release of ethylene from the fruit. But natural ripening is a slow process leading to high weight loss and desiccation of fruits and sometimes results in uneven ripening in some fruits. Hence, ethylene is externally applied to enhance the ripening process of fruits. Fruits ripened with ethylene will develop better colour, taste and have all the qualities almost near to naturally ripened fruits.

***Artificial ripening of fruits***

In the past, acetylene gas was used as a replacement to naturally released ethylene to enhance the ripening of fruits. Though the acetylene triggers ripening process in fruits, it is an inflammable gas involving risk of fire hazards. Calcium carbide is used as a source of acetylene gas which when comes in contact with water vapour present in the atmosphere releases acetylene gas. However, calcium carbide contains chemical impurities such as arsenic hydride and phosphorus hydride that are highly carcinogenic compounds. Improper use of calcium carbide can therefore cause chemical contamination of fresh produce. Further fruits ripened with calcium carbide though develop attractive surface colour, are inferior in taste, flavour and spoil faster. Government of India has banned the use of calcium carbide for ripening of fruits under PFA Act 8-44 AA, 1954.

Ethylene is recommended in place of acetylene for enhancing the ripening fruits. 2- chloroethane phosphonic acid (available with trade names of Ethrel or ethaphon) is a commercially available plant growth regulator that can be used is a source of ethylene. This ethylene is similar to that naturally released by fruits during ripening process.

Advantage of controlled ripening

- ✓ Improved uniformity of ripening among fruits
- ✓ Minimizes the development of rots
- ✓ product reaches consumers at the right stage of maturity

Majority of world banana is ripened under controlled condition. It can also be carried out on tomatoes, melons, avocados, mangoes and other fruits. Ethylene is known as ripening gas, which is a low molecular weight hydrocarbon.

Non climacteric fruits will not respond to artificial ripening with little or no desirable changes

in the composition after harvest and are not harvested until they fit are for consumption.

Optimum ripening condition for fruits

| | |
|---|---|
| Temperature | 18-25$^{0}$C (<18delay ripening, > 25 microbes ) |
| RH | 85-90% |
| Ethylene conc. | 10-100 ppm |
| Duration | 12 -72 hr |
| Air circulation | sufficient to maintain the air temperature |
| Ventilation | sufficient to prevent accumulation of $CO_2$ |

**Eg. Typical banana ripening process**

**A.** ***Batch/shot process -*** in which the chamber is charged with ethylene gas at once to a concentration of 20-200 µL-1. The chamber has to be ventilated after 24hours to prevent the accumulation of $CO_2$. $CO_2$ Concentration should not exceeds 5000 µL-1 (0.5%) to allow personal to enter the to inspect the fruits. If the chamber is poorly sealed, it may be necessary to recharge the chamber with C2H4 after 12 hours.

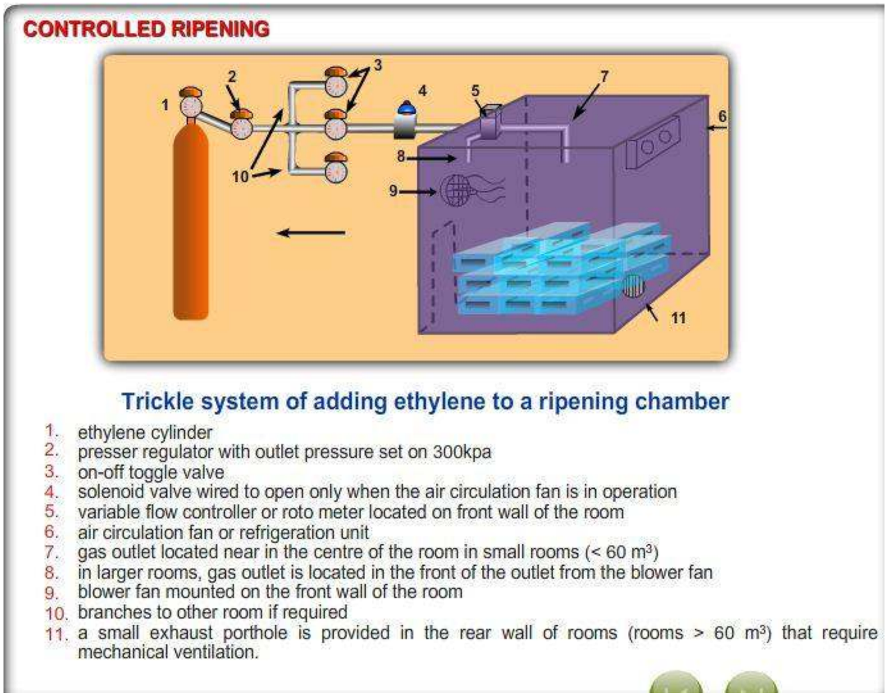
**B. *Trickle/flow process*** – ethylene is introduced into the room slowly in thin stream continuously. into the chamber at a rate just sufficient to maintain the required concentration. The ripening chambers should be ventilated at the rate of about one room volume each 6 hours, to prevent he accumulation of CO2. In practice it not necessary to install a ventilation system in rooms < 60 m3 because they have natural air leakage rates higher than the required minimum rates.

When banana is placed in chamber so as to expose at least two faces to the circulating air, ensuring that fruits temperature is even. Or fruit is packed in vented cartoon, unitized on pallets, and fruit temperature is controlled by forced air temperature. A minimum air flow of about 0.34 L/sec.kg of banana is required. Regulating RH during the course of ripening is important for banana. A relative humidity (RH) range of 85-90% has been recommended at stage 2 (green, trace of yellow), but this should be reduced to 70-75% during the later coloring stages to avoid the skin splitting. If RH is high, fruits will become too soft and may split and if it is low it may cause weight loss, poorer color and more blemishes on fruit. Regular cleaning with chlorine is require to avoid mould growth due to high RH during storage.

It is important to harvest at the correct stage of maturity otherwise quality will be inferior after ripening. At full maturity it is only necessary to hold fruit at desired temperature and RH and ethylene is not always necessary to ripen fruits, some fully developed fruits produce sufficient C2H4 to ripen itself and adjacent fruit (triggering effect).

**Table 3: Conditions for controlled ripening of fruits at RH of 85-90%**

| **Commodities** | **$C_2H_4$ (ppm)** | **Temperature (°C)** | **Treatment time (hr.)** |
|---|---|---|---|
| Avocado | 10-100 | 15-18 | 12-48 |
| Banana | 100-150 | 15-18 | 24 |
| Honeydew melon | 100-150 | 20-25 | 18-24 |
| Kiwifruit | 10-100 | 0-20 | 12-24 |
| Mango | 100-150 | 20-22 | 12-24 |
| Stone fruits | 10-100 | 13-25 | 12-72 |
| Tomato | 100-150 | 20-25 | 24-48 |





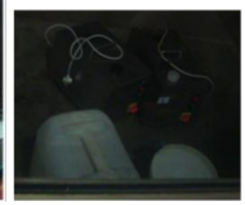


Fig. Controlled ripening of banana with automation. Fig. Ethylene gas in portable can Fig. Ethylene generator

**Sources of ethylene**

1. **Ethylene gas –** pure C2H4 gas enclosed in the can/cylinder is sprayed /injected into chamber. Ethylene portable can which contain 3 g sufficient to ripe 2-6 ton of produce is available commercially

2. **Ethephon –** Used as spray/ dip, acidic in water releases C2H4

3. **Ethylene mixture -** C2H4 + inert gas like $CO_2$. Inert gas because not enough O2 remains in the chambers to provide an explosive mixture. Eg, Ripegas contain 6% C2H4

4. **Ethylene generators -** Widely used method where in liquid spirit produces C2H4 when heated in the presence of catalyst platinised asbestos.

5. **Use of ripe fruits –** cheap and simple, where in ripe fruit with high C2H4 producers such as apple, banana, mango, sapota and tomato is used at home to ripe / degreen

# Chapter Six: Harvesting

## 6.1. Methods of Harvesting

### I. Hand harvesting

It predominates for the fresh market and extended harvest period (due to climate, there is accelerated ripening and a need to harvest the crop quickly) particularly the produce which is more susceptible to physical injury and soft fruit like grapes/litchis/jamum and strawberry and others berries which are borne on low growing plants.

Benefits of hand harvesting

- ✓ hand harvesting is less expensive
- ✓ less damage and harvest rate (times) can be increased

The main benefit of hand harvesting over mechanized harvesting is that humans are able to select the produce at its correct stage of ripening and handle it carefully. The result is a higher quality product with minimum damage.

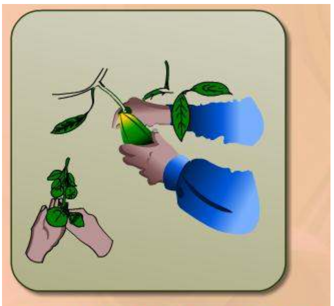
Examples,

- ✓ Breaking off – twisting off pineapple, papaya, tomato
- ✓ Cutting – snipping off mandarins and table grapes with secateurs and apple, roses *etc*

Harvesting methods is also use full reducing incidence of fungal infection in papaya/grapefruit.-When fruit are cut from the tree using clipper shows less infection then the harvesting by twisting and pulling (Fig.).

But harvesting small fruits and from thorny plants are major obstacle(disadvantage).

**Different harvesting practices at filed**



Harvesting from the sharp tools

Harvest containers

## Tools and containers for harvesting

**Tools -** Depending on the type of fruit or vegetable, several devices are employed to harvest produce. Commonly used tools for fruit and vegetable harvesting are secateurs or knives, and hand held or pole mounted picking shears. When fruits or vegetables are difficult to catch, such as mangoes or avocados, a cushioning material is placed around the tree to prevent damage to the fruit when dropping from high trees.

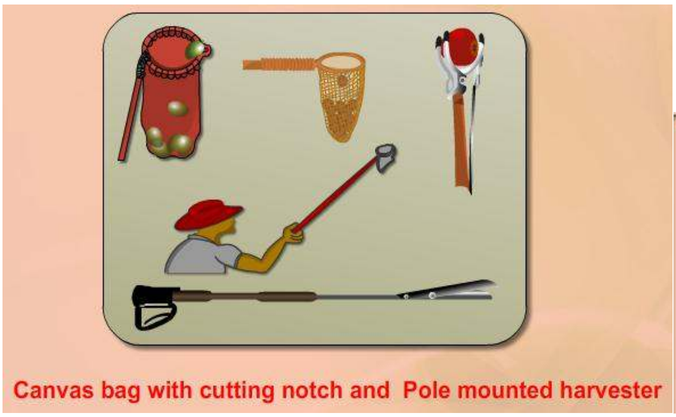
**Containers -** Harvesting containers must be easy to handle for workers for picking/cutting produce in the field. Many crops are harvested into bags. Harvesting bags with shoulder or waist slings (as they are easy to carry and leave both hands free) can be used for fruits with firm skins, like mango, citrus, avocados *etc*. The contents of the bag are emptied through the bottom into a field container without tipping the bag.

These containers are made from a variety of materials such as paper, polyethylene film, sisal, hessian or woven polyethylene and are relatively cheap but give little protection to the crop against handling and transport damage. Sacks are commonly used for crops such as potatoes, onions, cassava, and pumpkins.

Plastic buckets - are suitable containers for harvesting fruits that are easily crushed, such as tomato. These containers should be smooth without any sharp edges that could damage the produce. Use of bulk bins (commercial growers) - with a capacity of 250-500 kg, in which crops such as apples and cabbages are placed, and sent to large-scale packinghouses for selection, grading and packing. Other types of field harvest containers include baskets, carts, and plastic crate. For high risk products, woven baskets and sacks are not recommended because of the risk of contamination. Eg. Strawberry

Fig. Harvesting strawberry


Fig. Harvesting aid to remove soft fruit



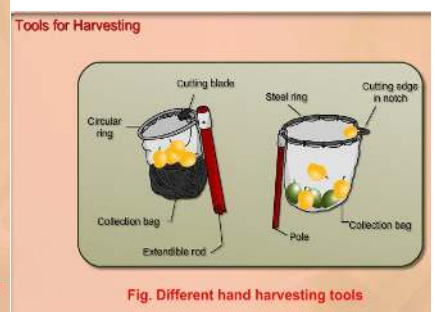




**Fig. Different hand harvesting tools**

## II. Mechanical harvesting

In region where labor cost is high machine harvest is popular for processing crops because it could damage the produce and subsequent faster deterioration. Eg. Peas for freezing, peaches for canning and grapes for wine making. Likewise, machine harvest is used for robust, low-unit-value ground crop such as potatoes and onions. The main advantages of mechanized harvesting are speed and the reduced costs per ton harvested. However, because of the risk of mechanical damage, it can only be used on crops that require a single harvest.

***i. Mechanical assistance –*** These are the simple machine used to provide assistance to hand pickers with ladder and positioners (tree towers and platforms). Combination of these process is possible by process by providing bins mounted on trailers moving along the plant rows. ‘Flying foxes’ (overhead ropeways) are similar systems provided to convey heavy banana bunches into packing house.

***ii. Harvesting machine –*** it employs direct harvest by contact methods such as:

- ✓ Shaking machine
- ✓ Picking pole fitted with cutter device – For fruits high on trees like mango, avocados
- ✓ The ‘shake and catch’ machine used in apple and citrus to harvest and collect the fruit

by shaking the trunk and collection the fallen fruit on the canvas which spread under the tree.

- ✓ Use of vibrating digger is used harvest underground roots/tuber/rhizomes.
- ✓ Use of robotics to harvest mushroom by method of sucker end-effecter.


Positioners and ladder to harvest fruits from tall trees


Fig. Tree shaker and catcher


Fig. Harvesting lettuce at filed


Fig. Raspberry harvester


Fig. Potato harvester

The following care is required while harvesting the produce

- ✓ Harvesting should be done in the cool hours of the day - produce exposed to sunlight soon become 4 – 6$^{o}$C warmer than air temperature.
- ✓ Harvested produce should not be kept on the soil.
- ✓ Hand gloves should be used for harvesting on spiny plants.
- ✓ Falling of produce on earth should be avoided while harvesting.
- ✓ Ladders should be used to harvest produce in case of tall trees.
- ✓ Produce selected for harvesting should be of right maturity.
- ✓ Harvesting should be done gently, without jerks to protect the produce from possible damage.
- ✓ While harvesting underground crops like potato, onion, radish, carrot and beet root etc.
- ✓ care should be taken that produce should not get damaged by digging implements.
- ✓ Trained labor should be deployed for harvesting.

### 6.2. Training field workers for harvesting

This training should cover general aspects of produce harvesting and handling for all workers and specific training for those engaged in tasks requiring greater skill, like grading, sizing and packing. Harvesting operations are simple and will permit the maintenance of produce quality if people know what to do and how to do it. Never forget that field workers should always be trained before starting the harvesting operations in using the correct techniques. They should be fully supervised during the harvesting operations. Aspects which need to be covered in a training program includes:

- ✓ quality criteria for selecting the items to be harvested
- ✓ desirable methods of detaching and the correct use of any harvesting aids
- ✓ degree of care required during harvesting and any additional operation like introducing produce in the container and handling the same
- ✓ proper field hygiene to prevent unnecessary contamination of the produce with soil, infected tools and human bacteria

General training for everyone concerned with harvesting and field handling should include:

1. Demonstrations of the causes and effects of damages to produce, emphasizing the need for careful handling at all time to avoid mechanical injuries from such causes as:

- ✓ Wooden containers with rough edges, splinters, protruding nails or staples
- ✓ Over packing containers which are to be stacked one over the other
- ✓ Damaging produce with long fingernails, rings and jewelry
- ✓ Dropping or throwing produce into containers at a distance
- ✓ Throwing, dropping, rough handling or sitting on field containers

2. An explanation of the need to avoid the contamination of harvested produce from causes such as:

- ✓ Placing the produce directly on the soil, especially when wet;
- ✓ Using dirty harvesting or field containers contaminated with soil, crops residues or decaying produce: containers must always be kept clean; and
- ✓ Contact with oil gasoline or any chemical than those used specifically for authorized post-harvest treatments.

**Specific training**

Specific training should be given to workers allocated to specialized tasks, such as crop harvesting and selection, and the post-harvest selection, grading, sizing and packing. This kind of training will include demonstration and explanation of:

- ✓ The methods of evaluating the readiness of the crop for harvesting
- ✓ The rejection of unsuitable produce at harvest, according to market requirements
- ✓ The actual technique to be employed in harvesting produce e.g. breaking the stem with the fingers in the suitable place or plucking with the end, clipping and cutting with scissors
- ✓ The use of harvesting sacks, containers, the transfer of the produce to field or marketing containers and eventual grading when emptying the sacks, by introducing different grades in different containers; this operation is important when a field assembly point does not exist for filling with the produce ready for the market.
- ✓ The selection of marketable produce at the field assembly point and grading for color, size and quality, if applicable
- ✓ The correct application of post-harvest treatments when necessary
- ✓ The method of packing market packages or other containers.

**Harvesting time**

When the decision to harvest has been taken the preferred time for harvest varies from crop to crop. However, the preferred time is the coolest part of the day, usually in the early morning or late afternoon. This is particularly so for leafy vegetables. Other factors considered are the availability of labor and transport and the distance to a packing house or temporary storage area are necessary.

The selected time should be that which minimize the time between harvest and transport to a packing shade. For example, if night transportation is used it is not advisable to harvest early morning unless produce can be placed under cover and a well ventilated place during the daytime.

Local weather conditions could affect the harvesting time:

- ✓ It is not desirable to harvest produce when it is wet from dew or rain as this greatly increases the risk of post-harvest spoilage and the tissue is more prone to physical damage.
- ✓ It is also not advisable to harvest during a hot and sunny day if the produce is left in the field and cannot be protected by the sunrays and the heat.
- ✓ Protect harvested produce in the field by putting it under open-sided shade when transport is not immediately available.
- ✓ Leafy green vegetables such as spinach and salad lose water quickly because they have a thin waxy skin with many pores.

## 6.3. Harvesting technique and operations

In developing countries most of the produce for internal rural and urban markets is harvested by hand. Larger commercial producers may find a degree of mechanization an advantage, but the use of sophisticated harvesting machinery will be limited for the most part to agro-industrial production of cash crop for processing or export. In most circumstances, if harvesting properly is done by hand by trained and experienced workers, will result in less damage than if produce is machine harvested. Hand-harvesting is usually preferred when fruits, such as peaches, and other produce, such as green vegetables, are at different stages of maturity and there is need on repeated visits to harvest the crop over a period of time. When the crop is ready for harvesting, labor and transport available and harvesting operations organized, the decision as to when to start harvesting will depend largely on the **weather conditions** and the **state of the market.**

Possible flexibility of the harvesting date will depend on the crop. Some, such as root crops, can be harvested and sold over a long period, or stored on the farm awaiting for favorable prices. Others such as berries and peaches must be harvested when ready and marketed as soon as possible or they will be spoiled.

### Fruits

Many ripe fruits such as apples and some immature seed-bearing structures such as legumes pods have a natural breakpoint of the fruit stalk, which can be easily broken by twisting and lifting the stalk taken between the thumb and index. Fruits and other seed-bearing structure harvested in the immature or unripe green stage are more difficult to pick without causing damage either to the produce or the plant. These are best harvested by cutting them from the plant, using clippers, secateurs or sharp knife. The clippers can be mounted on long poles for tree fruits such as soursop, with a bag attached to the pole to catch the fruit.

**Plucking methods vary according to the kind of produce being harvested:**

- ✓ **Ripe fruits with a natural break –** point, which leave the stalk attached to the fruit are best removed by a "lift, twist and pull" series of movements, e.g. tomato and passion fruit.
- ✓ **Mature green or ripe fruits with woody stalks -** which break at the junction of the fruit and the stalk are best clipped from the tree, leaving up to a centimeter of fruit stalk attached. If the stem is broken off at the fruit itself, diseases may enter the stem scar and give rise to stem end rot, e .g. mango, citrus, avocado;
- ✓ **Immature fruits with fleshy stem -** can be cut with a sharp and clean knife, e. g. zucchini, okra, papaya, capsicum; these can also be harvested by breaking the stem by hand, with

the risk of damaging the plant or the fruit and the rough cut will make the produce and the plant more susceptible of decay.

Harvesting is basically a simple operation involving the removal of the produce from the parent plant and placing it in containers for removal from the field to the market, or to the packing shade in the farm itself or to the packing – house.

Vegetables. Either the whole or a part of vegetative growth can be harvested by hand only or sharp knife. Knives may be kept sharp and clean at all times to avoid spreading of virus diseases from plant to plant.

Harvesting methods varies in accordance with the plant part harvested:

- ✓ Leaves only (spinach, rape, etc.) and lateral buds (Brussels sprouts, etc): the stem is snapped off by hand
- ✓ Above–ground part of the plant (cabbage, lettuce, etc.): the main stem is cut through with a heavy knife, and trimming (roots and external unsuitable leafs are discarded) is done in the field. Do not forget that the cut stem must not be placed in the soil
- ✓ Immature green onions can usually be pulled from the soil by hand; leek, garlic and mature bulb onions are loosened by using a digging fork as for root crops such as carrots and lifted by hand. Simple tractor implements are available for undermining bulbs and bringing them to the surface
- ✓ Flower structure vegetables. Immature flower heads (cauliflowers, broccoli) can be cut with a sharp knife and trimmed in the field.
- ✓ Mature flowers (squash, chayote, pumpkins) are plucked individually by hand or shoot bearing flowers are harvested as a vegetable.

**Root and tuber crops.**

Most roots and tubers that live beneath the soil are likely to suffer mechanical damage ay harvest because of digging tools, which may be wooden sticks, machetes, hoes or forks. Harvesting of those crops is easier if they are grown on raised beds or mounds, or “earthed up” as is common with potato growing. This enables the digging tool to be pushed into the soil under the roots or tubers, which then can be levered upward, loosening the soil and decreasing the possibility of damage to the crop.

Other root crops, such as taro, carrots, turnips, radishes, etc. can be loosened from the soil at an angle and leaving the root upward. This method can be used also for celery if it has been earthed up or buried to blanch the stem.

Following the harvesting, other field operations, which may vary or have a different sequence (given below) according to the produce, may include: inspection; trimming; cleaning; washing;

sorting; grading; sizing; packing in field crates; transport to a cover shade which may protect from rain or sun and may permit packing in the final container for the market; and transport to the packinghouse and packing in the final container for the market.

All operations should be carried out to minimize any damage or loss of quality. Key elements in the maintenance of quality are to;

- ✓ Keep the handling operations to a minimum, but ensure that each operation is carried out with maximum care
- ✓ Minimize the time between harvest and transport from the harvesting place to the packing place
- ✓ The detrimental effects of poor harvesting practices are often not evident at harvest but will be greatly magnified during storage and marketing

**Harvesting tools**

Because the supply of fresh produce to domestic markets in Grenada comes mainly from relatively small-scale producers, mechanical systems for crop harvesting are likely to be rare. There is scope, however, for the use of mechanical aids in modest commercial operations where a tractor can be used in harvesting potatoes, sweet potatoes, onions, and other root crops by lifting up the crops and leaving them on the soil surface.

Many fruits (for example mangoes and avocadoes) and vegetables (for example tomatoes) are adequately harvested by hand, without mechanical aids. However, the provision of simple harvesting tools such as knife-edge or scissors will invariably increase the speed of harvesting for crops such as grapes, lemons and oranges. A neat cut of the stem will also eliminate rough edges created when the stem is hard with produce, which does not break easily. This will also have the advantage of reducing the incidence of mechanical post-harvest damages. Sharp knives are indispensable for harvesting of commodities like lettuce, cabbage and broccoli.

Most tools are specifically designed for each commodity and have to be as practical as possible to facilitate its utilizations by the workers. At the end of the harvesting day they have to be cleaned and sharpened to prevent them being a source of microorganism contamination and have them ready for the following harvest.

The desirability and need of harvesting tools increases as the size of the plant increases Many fruit trees, like new grafted varieties of mango and avocado, and old varieties of golden apples, are too large to allow manual harvesting from the ground and it is more efficient to use a suitable harvesting tool from the ground rather than have to harvest by climbing the tree.

It is almost compulsory that the harvesting of roots and tubers be carried out with some digging implement if damage has to be reduced or avoided. The device should gently locate the roots and lever them to the surface causing as few injuries as possible, freeing the tubers from most of the soil.

**Harvesting and field containers**

The packing of produce directly into marketing packages in the field at harvest reduces the damage caused by multiple handling and is used increasingly by commercial growers in developed countries. It is not a common practice in rural areas, where produce is sent to nearby markets and elaborate packaging cannot be justified, but commercial growers can view it as cost-effective if the packaging takes produce in better conditions to market, where it can command a higher price.

The field containers for harvesting must be of a size that can be conveniently carried by the harvest workers while moving through the field. The following are suitable according to the produce harvested:

- ✓ Harvesting bags with shoulder or waist slings can be used for fruits with firm skins like citrus and avocados. They are easy to carry and leave both hands free. They should be designed for opening at the base to allow produce to be emptied through the bottom into a field container without tipping the bag.
- ✓ Plastic buckets or other containers are suitable for fruits that are more easily crushed, such as tomatoes. The containers should be smooth with no sharp edges or projections to damage the produce;
- ✓ Baskets are often used for harvesting once they do not have sharp edges or splinters that can provoke an injury to the produce. If they are not sturdy, they may bend out of shape when lifted or tipped – especially if they are large-and crush or otherwise may damage the content. The inner part of the basket is often filled with a sack cloth woven on the top to reduce the damage to the content not properly deposited by the worker and reduce bruises.
- ✓ Bulk bins, usually of 250-300 kg capacity, are used for commercial operations by big growers.
- ✓ Jute and/or woven sacks.

**Transport from the farm -** The destination of the produce leaving the farm will usually be one of the following:

- ✓ A local market. Produce is usually in small containers carried sometimes by animals or in animal drawn carts; public transport is sometime used .Usually produce is graded and packed in the field.
- ✓ A commercial packing house. Produce may be in palletized field containers or in hand loaded sacks or wooden or plastic boxes. In the packing-house the produce is graded and packed in suitable containers for the market.
- ✓ A city market. This applies only where produce is graded and packed in marketing containers on the farm or the packinghouse.

**Packaging -** The principal benefit of packaging is to provide protection against physical damages through inadequacies in handling and transport of a fresh produce.

There are additional benefits, which can be derived from packaging:

- ✓ Barrier protection, to prevent contamination of produce by undesirable environmental agents such as dust and micro-organisms;
- ✓ No utilization of produce, to create relatively small units of produce, which are easier and quicker to handle than unpacked goods. It also gives better utilization of space during storage and transport.
- ✓ Trading aid, to provide a standard size unit for market trading and thereby eliminating the need to weigh or count all items of produce being traded.
- ✓ Marketing aid, through the display of basic market information and attractive designs on the package.

### 6.4. Damages suffered by packed produce

Fruits, vegetables and roots vary widely in their susceptibility to physical damage and in the type of damage that is likely to be sustained. Some commodities are more susceptible to impact bruising, whereas others are more prone to compression or vibration bruising. Susceptibility to the different types of damage will require a different type of protection to be incorporated into the package. The choice of packaging material will also be influenced by factors such as susceptibility to water losses and microbial infections or heat accumulation and may be the primary consideration in the type of package required.

The physical damage suffered by the packaged fresh produce are caused mainly from the following:

- ✓ Injuries caused by sharp objects piercing the packages. This results in deep puncture, leading to water loss and rapid decay.

- ✓ Impact caused by throwing or dropping the packages. This results in bruising the content and / or bursting the package.
- ✓ Compression caused by overfilling the container or stacking them too high. This result in bruising or crushing the content.
- ✓ Vibration of the vehicle from rough roads: bursting the packages and bruising and crushing the contents.
- ✓ Heat damage caused by exposure of packages to direct sunlight or poor ventilation within the package: this results in fruits becoming overripe or soft and decay develops rapidly.
- ✓ Freezing damages caused by subzero ambient temperature: the result is the damage to chilling-sensitive produce. Most produce is affected by break - down after thawing.
- ✓ Moisture damages caused by exposition to rains, dew or high humidity: this results in softening and collapse of the containers, crushing the produce and decay.
- ✓ Insects, or/and animal damages: these results in rejection of the produce by the buyer.
- ✓ Damage from light: this results in disintegration of plastic sacks.

### 6.5. Prevention of injuries to the produce

Suitable packages and handling techniques can reduce the amount of damage to which fresh produce is exposed during marketing:

- ✓ To keep the packaging itself from damaging the produce during handling and transport, wooden boxes and /or cardboard cartons must be properly assembled; nails, staples and splinters are always a danger in wooden boxes and should be used carefully and properly;
- ✓ Individual items of produce should be packed to avoid rubbing against each other during handling and transport; loose fill packs are particularly susceptible to vibration damages;
- ✓ Much bruising results from overfilling containers or from the collapse of boxes; collapse may be caused by weak walls of boxes, by the softening of cardboards walls because of moisture or by failing to stack boxes so that the side or the walls support those above; stack of boxes should never exceed the height recommended by the manufacturer or the experience.
- ✓ Produce in woven jute sacks or nets is especially susceptible to shock damage; sacks of 25 or 50 kg capacity are normally used for relatively low valued produce, such as roots, tuber

crops, cabbages, etc. and are often roughly handled on account of their weight. Whenever possible, handling of bagged produce should be minimized by stacking sacks in unit loads on pallets and avoiding over stacking.

**Package selection**

The most appropriate package for a commodity can only be determined following a thorough examination of the current marketing system. Never forget that packaging can be the major item of expense in produce marketing, so the selection of suitable containers especially for commercial-scale marketing requires a careful consideration.

The steps involved in package selection are:

- ✓ Understand the need of the commodity, particularly in terms of physical protection;
- ✓ Select the packaging material that will economically satisfy the above needs; and
- ✓ Select a package that offers the greatest protection to produce and is acceptable to the intended market.

Besides providing a uniform-size package to protect the produce, there are other requirements for a container:

- ✓ It should be easily transported when empty and occupy less space than when full, e.g. plastic or wooden boxes which nest in each other when empty collapsible cardboard boxes, fiber or paper or plastic sacks
- ✓ It must be easy to assemble, fill and closes either by hand or by use of a simple machine
- ✓ It must be easy and cheap to repair
- ✓ It must provide adequate ventilation for the content during transport and storage
- ✓ Its capacity should be suitable for market demands
- ✓ Its dimensions and design must be suited to the available transport in order to load neatly and firmly
- ✓ It must be cost-effective in relation to the market value of the commodity for which will be used and the sophistication of the market
- ✓ It must be readily available, preferably from more than one supplier

### 6.6. Packaging material and types of packages

**Packaging for fresh produce is of several types:**

1. **Natural material**

   Baskets and other traditional containers are made from raw material locally available such as bamboo, rattan, straw and palm leaves. Both raw material and labor costs for the manufacture of the containers are normally low, and if the containers are well made, they can be reused for several times. They are mostly used for handling the produce in the field, at farm level and seldom for the local market.

Disadvantages are:

- ✓ They are difficult to clean and easily contaminated
- ✓ They lack rigidity and easily bend out of shape when stacked
- ✓ They load badly for their shape
- ✓ They cause pressure damage if tightly filled
- ✓ They often have sharp edges or splinters and cause damage unless they internally lined with sacks, cotton or other materials.

**2. Wood**

Sawn wood is used to manufacture reusable boxes or crates, but less so recently because of cost. Veneers of various thicknesses are used to make various boxes or trays. Wooden boxes are rigid and reusable and if made to a standard size, it will stack well on trucks and in storage. They are used for produce handling at farm and packing – house levels.

Disadvantages are:

- ✓ Difficult to clean adequately for multiple uses;
- ✓ Heavy and costly to transport for the reutilization; and
- ✓ They have sharp edges, requiring some form of liner to protect the content.

## 2. Cardboard and fiberboard.

Containers are made from solid or corrugated cardboard. The types closing with either fold-over or telescopic tops are called boxes or cases. Shallower and open-topped ones are called trays. Boxes are supplied in a collapsible form and are set up by the users. The setting up and closing often requires taping, gluing or stapling. Cardboard boxes are lightweight and clean and in some cases are reusable because they may be easily collapsible when empty.

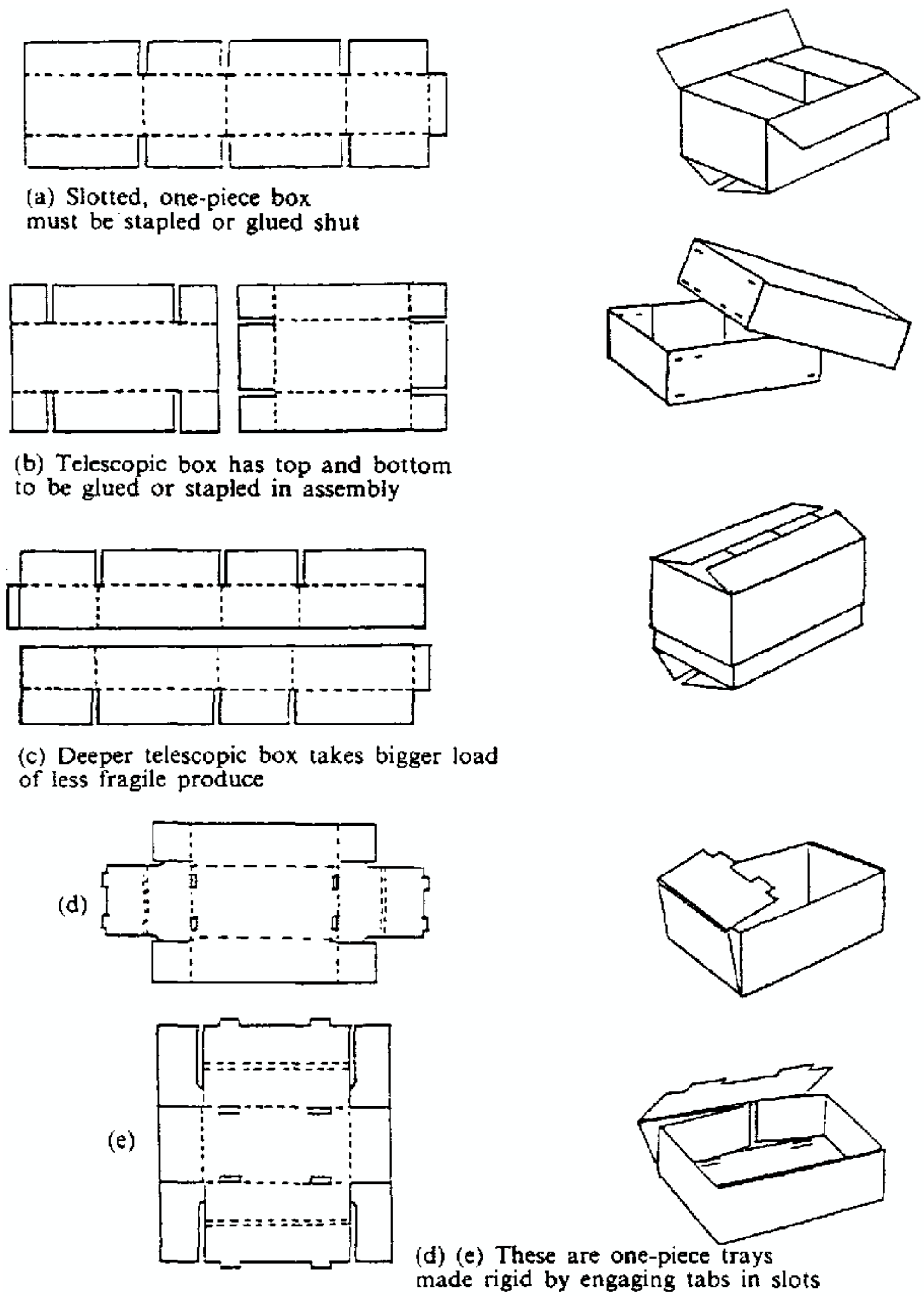



Figure 9. Samples of cardboard cartoons. Source: FAO, 1989

Disadvantages are:

- ✓ They may, if used only once, prove an expensive recurring cost
- ✓ They are easily damaged by careless handling and stacking
- ✓ They are seriously weakened if exposed to moisture, unless they are wax –coated
- ✓ They can be ordered economically only in large quantities
- ✓ Many small countries do not manufacture their own boxes and imports are expensive

**3. Molded plastics**

Reusable boxes molded from high-density polythene are widely used for transporting produce in many countries they can be made to almost any specifications. They are strong, rigid, smooth, easily cleaned and made to stack and nest when empty in order to conserve space. In spite of the cost, however, their capacity for reuse can make them an economical investment.

Disadvantages are:

- ✓ They can be produced economically only in large quantities, but are still expensive
- ✓ They have to be imported in most of the developing countries, adding to the cost of foreign currency
- ✓ They are attractive and have many alternative uses and are subject to high pilferage
- ✓ They require a very tight organization and control for use in a regular go-and-return service
- ✓ They deteriorate rapidly when exposed to the sunlight, unless treated with ultraviolet inhibitor

**4. Natural and synthetic fibers**

Sacks or bags for fresh produce can be made from natural fibers like jute or sisal or from synthetic polypropylene. Bags usually refers to small containers of up to about 5 to 10 kg capacity, woven to a close texture or made in a net form of about 15 kg bags or sacks are mostly used for less easily damaged product such as potatoes, onions and roots avoiding in any case to damage the produce with a careful handling.

Disadvantages are:

- ✓ Lack of rigidity
- ✓ Rough handling may damage the content
- ✓ They are often too large for careful handling and for the weight they are easily dropped with result of damage
- ✓ The reduced ventilation when stacked if they are finely woven

- ✓ They are difficult to stack and may be unstable and collapse

**5. Paper or plastic films.**

They are often used to line packing boxes in order to reduce water losses or to prevent friction damage. Paper sacks may have a capacity of about 25 kg and are mostly used for produce of low value. Closure is done by machine – stitching or in the field by twisting wires ties around the top.

Disadvantages are:

- ✓ Walls of papers are permeable by water, vapor or gases;
- ✓ Heat can be slow to disperse from stacks of sacked produce; and
- ✓ Mishandling provokes damage to the content.

**6.7. Some major Post-harvest handling operations**

Post-harvest handling operations encompass those steps required for harvested produce to be selected or modified to meet market quality standards and to be packaged in a form suitable for storage or marketing.

**A. Field operations**

The simplest operation is where produce is placed into a container in the field directly after harvest, which is then placed into storage or transported to a market without additional sorting or packing. A common variation is to trim off excess leaves or stems before placing into the field container. These simple packing operations are adequate where there is only a small distance between farm and market and produce is sold directly to consumers. This is commonly the case for vegetables grown close to the towns and/or consuming areas.

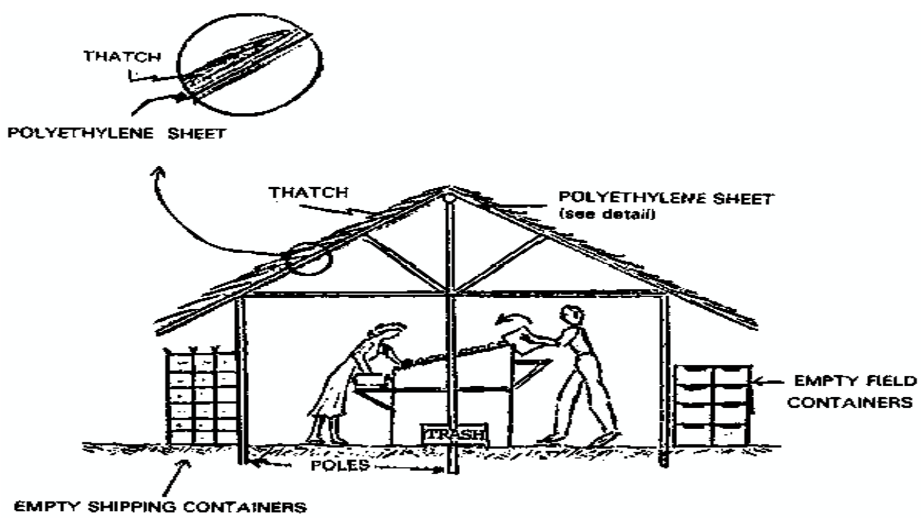



Figure. Handling produce in a field packing station.

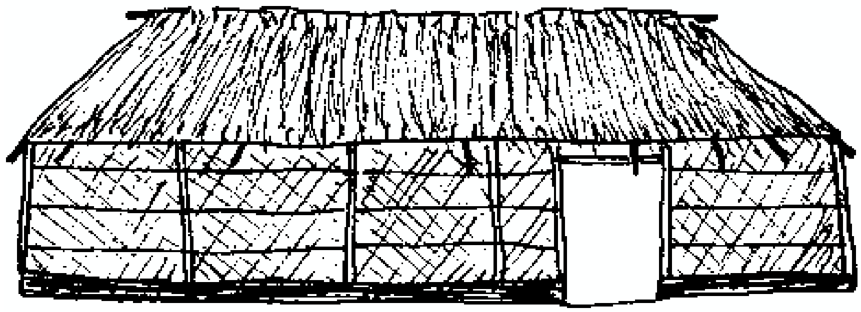


Figure 11. Simple field packinghouse made from straw and wire mesh. Source: FAO, 1989

Field sorting is also recommended for produce, which is highly sensitive to repeated handling. All sorting and grading should be conducted in the field in one operation and the produce packed directly into containers suitable for retailing. For most produce, sorting and trimming of excess plant material in the field is desirable only to minimize the volume of produce transported from the farm.

**B. Field curing root, tuber and bulb crops**

Curing roots and tuber crops such as potatoes, sweet potatoes, cassava and yams is an important practice if these crops are to be stored for some time. Curing is accomplished by holding the produce at high temperature and high relative humidity for several days after harvesting with the objective to heal the wounds and form a new protective layer of cells. While curing can be initially costly, the extended length of storage life makes the practice economically worthwhile. Best conditions for curing vary among crops as follows: potato at 15-20o C, 90-95 % R. H., for 5-10 days; sweet potato at 30-32o C, 85-90 % R.H., for 4-7 days; yam at 32-40o C., 90-100 % R.H., for 1-4 days; cassava at 30-40o C, 90-95 % R.H., for 2-5 days.

It is common practice to cure onion and garlic bulbs, directly following harvest, by allowing the external layers of skin and neck tissue to dry out prior to handling and storage. Onions and garlic can be cured in the field in regions where harvesting coincides with the dry season. These crops can be undercut in the field, windrowed and left in the soil to dry for five to eight days, depending on the air temperature and moisture. The separated dry tops of the plants can be arranged to cover and shade the bulbs during the curing process to protect the produce from excessive heat and sunburn. The dried layer of skin will protect the produce from further water loss during storage and reduce mould and bacteria attacks.

The crops can be cured also after packing into 15 to 25 kg fiber or net sacks.

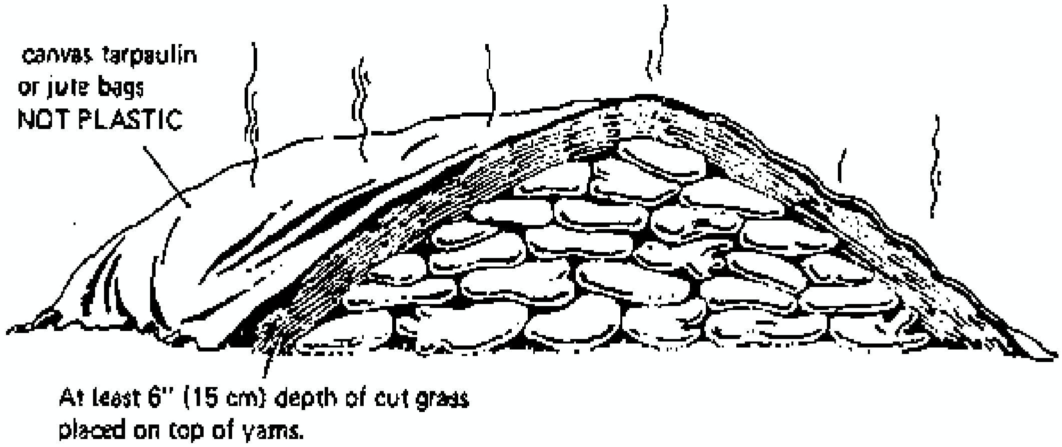



Figure 12. Curing yam in the field. Source: Wilson, J., (IITA, Ibadan, Nigeria.)

In regions where solar radiation is limited, relative humidity high and natural air movement low curing can be done with the produce packed in sacks, covered under sheds and ventilated with ceiling fans. Curing can be done also with heated air, positioning the heaters on the floor near to the packed produce.

### 6.8. Packinghouse

In many situations it is necessary to establish a specific site for packing operations.

### A. Need for a packinghouse

The site for the packing operations may simply be the provision of a portable or temporary shelter in the field adjacent to the harvesting area to protect the produce and workers from the weather during field handling. This is of considerable importance for produce harvested in hot, sunny conditions where exposure to the weather for only a few hours can markedly accelerate senescence or in rainy periods where the chance of microbial infection is greatly enhanced if the produce becomes wet.

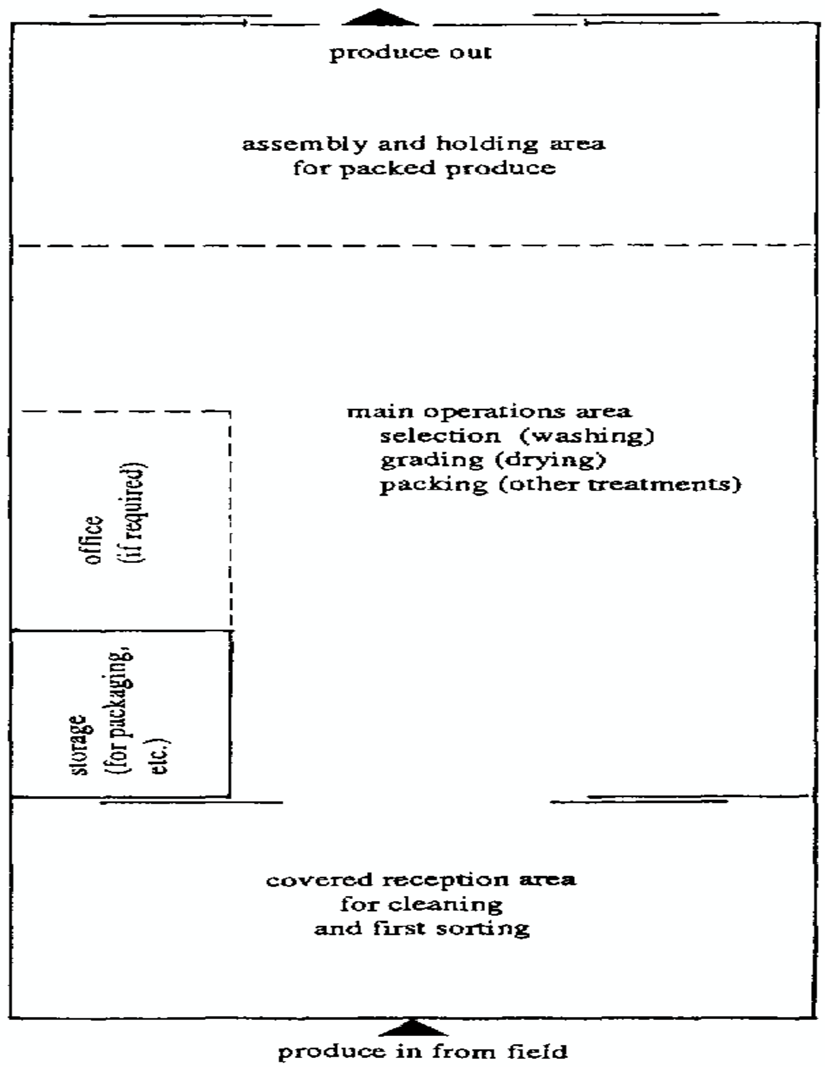



Figure: Layout of a small packinghouse. Source: FAO, 1989

The need for a more permanent structure increases as the complexity of grading, sizing and sorting operations increases and where the volume of production or the lengths of the period of harvesting is substantial.

The structure of a packinghouse should only be as elaborate as necessary. A packing place constructed with a bamboo frame and grass thatched roof without water or electricity services is satisfactory for a low manual sorting and packing operations. The complexity of packin house operations increase, as market requirements for quality and uniform grading become more demanding. The standards of the required building will also increase along with more sophisticated equipment and a larger and more skilled work force.

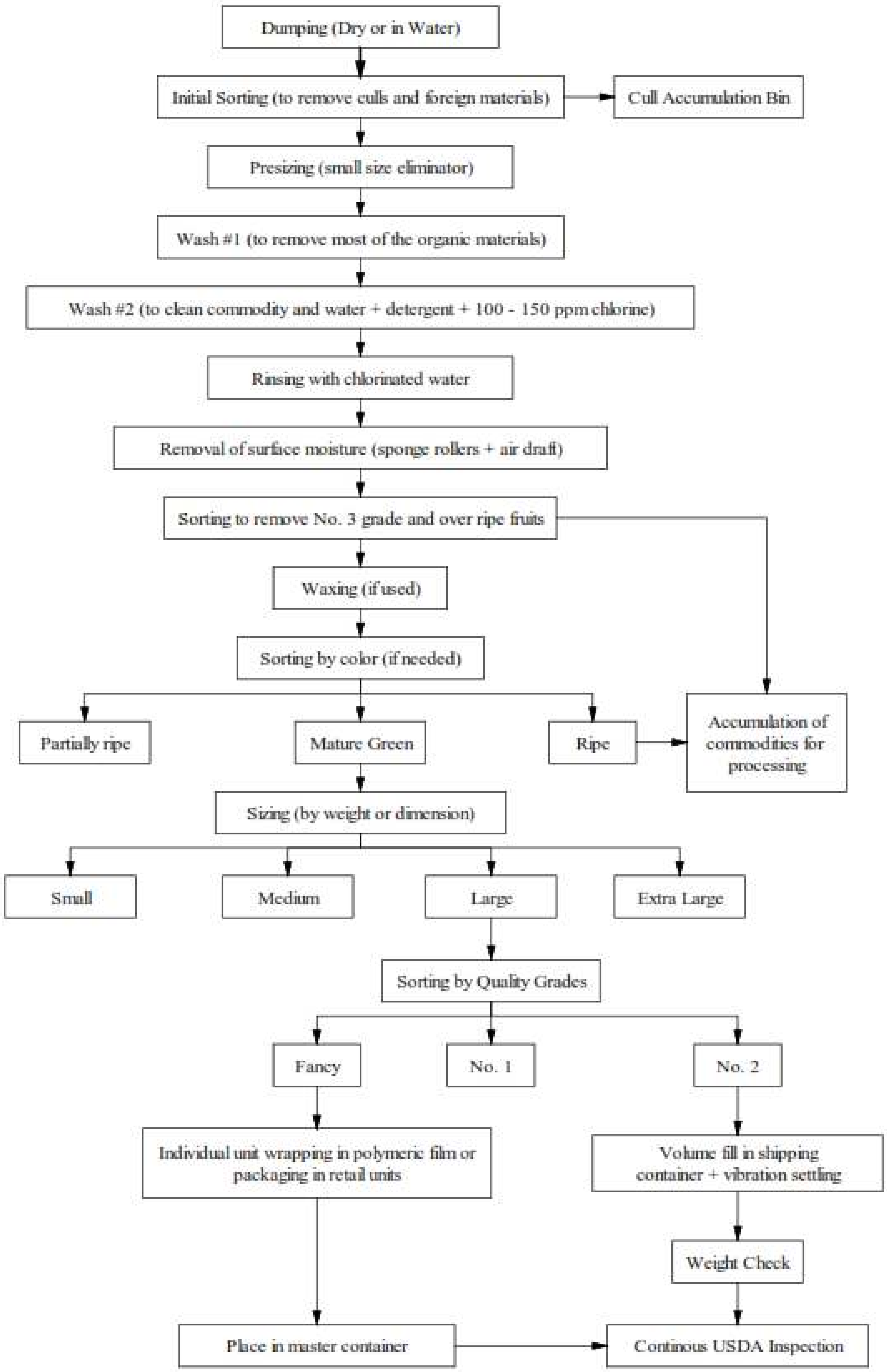



Figure: Flow diagram on handling fruits in a modern packinghouse. Source: Kader,A.1993

**B. Packing house operations**

The actual operations to be carried out will be determined by the market system and volume of produce passing through the packing place.

A packinghouse can fulfill a variety of functions. It may, for example, accept produce from the field and prepare it for the market or act as a preliminary quality control operation to ensure that only quality produce is placed into storage. A packing house may also be used to repack produce after storage for retail marketing.

Packing houses for small-scale operations can be utilized for:

- ✓ Receiving produce where, the quantity and quality are checked on arrival before being transferred to a temporary storage area
- ✓ Treatment, where excess part plants are trimmed off, surface contaminants removed by washing or brushing, and chemicals applied to extend storage or market life;
- ✓ Grading, where substandard items are removed, produce is graded for factors such as maturity, color and the separated grades are sized and packed
- ✓ Temporary shelter for produce waiting for being loaded for dispatch.

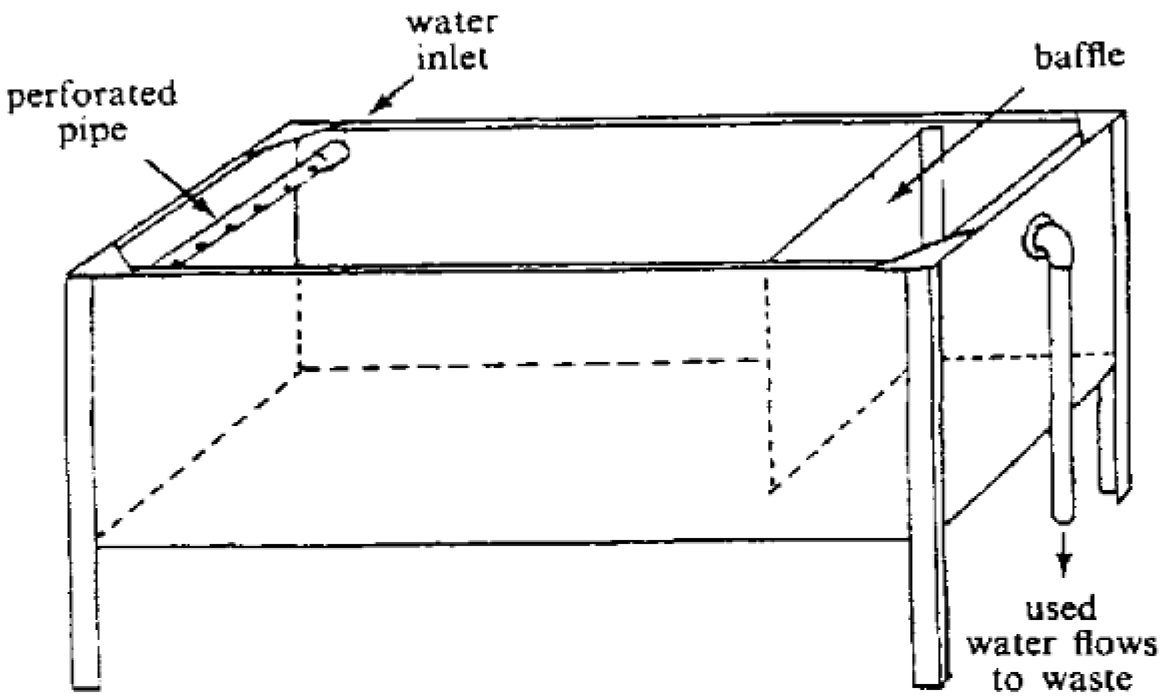
All packinghouse operations can be executed manually, mostly small scale, or with a range of mechanical devices of varying sophistication, mostly for larger operations. For packinghouses with small throughput, economics will favor manual operations with workers performing more or all the tasks. The advantage of human labor is that it provides flexibility of operation since it can perform a variety of tasks with equal efficiency.

***Receipt -*** On arrival to the packinghouse produce is usually unloaded, weighed, sampled shlegt down for quality and recorded.

***Sorting -*** A preliminary sorting of produce should remove unmarketable pieces and foreign matters, such as plant debris, soil and stones, before the produce passes on to further operations. All discarded material should be quickly hauled away from the packing place

***Cleaning and washing -*** The removal of soil and stones mentioned above can be done by hand-picking or by sieving. Some type of produce can be washed, brushed or cleaned with a soft cloth. Washing is required to clean produce which has acquired latex stains from injuries from bad harvesting or handling, such as mango, papaya, breadfruit and most of the root crops.

It is important to note that washing should be carried out only when absolutely essential. If it is necessary to wash produce, a fungicide should be normally applied immediately afterward. Use only clean water. The washing of produce in recirculated water should be avoided because it can quickly become heavily contaminated with decay organisms, leading to rotting of the washed produce. Hypochlorites or chlorine may be added to washing water but its use is not recommended for small-scale operations, because they are quickly inactivated by the organic material present in the dirty water.




Washed produced to be treated with fungicide should first be drained after washing to reduce the danger of reducing the concentration of the fungicide When washing is not followed by chemical treatment, the washed produce should be spread out in a single layer on racks of mesh, in the shade but exposed to good ventilation to aid rapid drying.

**6.9. Fungicide treatment**

Decay caused by molds or bacteria is one of the major causes of loss of fresh produce during storage and marketing. Infection may occur before or after harvest, either through injuries or direct penetration of the intact skin of the produce. Post-harvest application of fungicide is usual in crops such as apples, bananas and citrus fruits which have to be stored for a long period or those which undergo long periods of transport. Fungicide is normally applied only after the produce has been washed and drained. In small-scale packinghouse operations, fungicide can be applied by:

***Dipping*** **-** Treatment is normally carried out by hand operation using a suspension of fungicide agitated using stick. Wire-mesh baskets are used to dip the fruits. After dipping produce should be drained and dried.

***Spraying*** **-** This can be done using a hand-operated sprayer while the produce is still in trays or racks after washing and drying. It is often done on bananas following the de-handing of bunches.

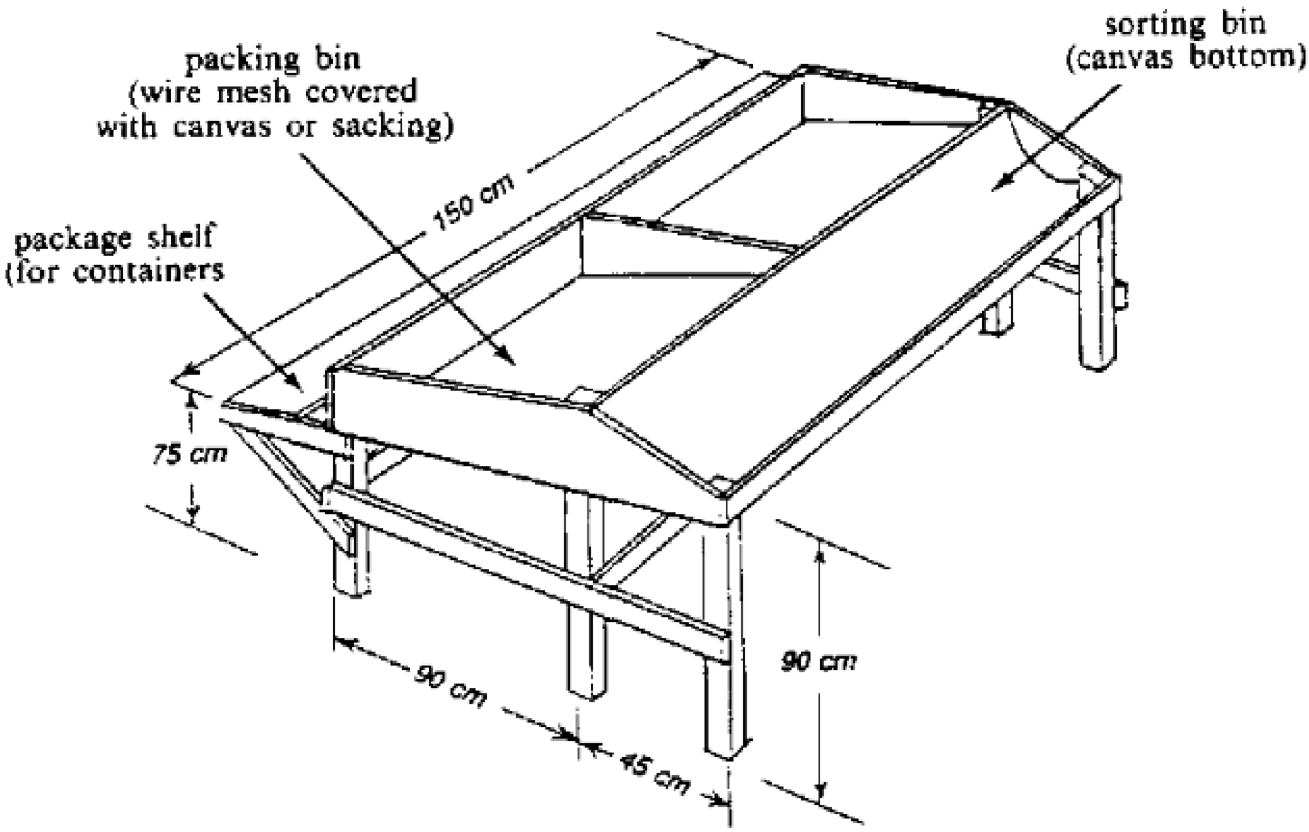



Figure. Packing table for small operations. Source: FAO, 1986

**6.10. Quality selection and size-grading -** Although produce will have to be sorted on the farm or on its arrival at the packinghouse there may be a further selection for quality and size immediately before it is packed. The scope of these operations depends on the market. Will the buyer be ready to pay premium prices for quality- graded produce? Many urban costumers are more demanding of quality than are rural markets. Selection and grading in a small packinghouse are best done by the human eye and by hand, with the produce on a table, assisted by sizing rings.

***Waxing -*** The application of wax or similar coating to enhance appearance and limit water losses from produce such as citrus requires specialized equipment and has little relevance to small-scale packing. Waxing is normally preceded by fungicide treatment.

***Packaging -*** Packaging in small-scale operations means the filling of marketing containers by hand, often using a packing stand or a table.

There are various methods of packing:

- ✓ **Loose-fill jumble pack** is used where there is no advantage to size- grading: weighing is necessary
- ✓ **Multilayer pattern pack** has size-graded produce normally sold by count of the produce such as citrus and apples
- ✓ **Multilayer size-graded pack** mostly used in mechanical packing has separator trays between layers; it is normally sold on per-box basis
- ✓ **Single-layer packs** for high value produce may have each piece wrapped in tissue (often chemically treated) or placed in a divider holding it alone

**6.11. Special treatments after packing**

Special post-packing treatments applied to certain produce are more common in large operations for urban and export markets. They are:

- ✓ Fumigation. The treatment is to control insect pests
- ✓ Initiation of fruits ripening
- ✓ Degreening of citrus fruits

## 6.12. 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 crops, such as carrots and potatoes, to meet a regular continuous demand and provide a degree of price stabilization it also meets the demands of populations of developed countries and of the richer consumers of developing countries, providing year round availability of various local and exotic fruits and vegetables of acceptable quality.

In many developing countries, however, where seasonally produced plant foods are held back from sale and released gradually, storage in a controlled environment is not possible because of the cost and the lack of infrastructure development and maintenance and managerial skill. Even in developed countries, however, there are still many peoples who, for their own consumption, preserve and store fresh produce by traditional methods.

***Storage potential***

Much fresh produce (i.e. that which is most perishable) cannot be stored without refrigeration, but the possibilities of extending the storage life of even the most durable fresh produce under ambient conditions are limited.

***Organs of survival -*** The organs of survival which forms the edible parts of many crops such as potatoes, yams, beets, carrots and onions have a definite period of dormancy after harvest and before they resume growth, at which time their food value declines. This period of dormancy can usually be extended to give the longest possible storage if appropriate conditions are provided. This factor is called the storage potential. It is important to recognize the variation in the storage potential of different cultivars of the same crop. Experienced local growers and seed suppliers can usually provide information on this subject.

***Edible reproductive parts -*** These are largely confined to the fruits or seeds of leguminous plants (peas and beans). In their fresh condition these products have brief storage life which can be only slightly extended by refrigeration. They can also be dried and then are called pulses. Pulses have a long storage life, provided they are kept dry, and do not present a storage problem as is the case of fresh produce.

***Fresh fruits and vegetables -*** These include the leafy green vegetables, fleshy fruits and modified flower plants. (e.g. cauliflower and pineapple). The storage potential of these, particularly tropical fruits in tropical countries, is very limited under ambient conditions. They quickly deteriorate because of their fast respiration rates, which cause rapid heat build-up and depletion of their high moisture content. Most fresh fruits and vegetables have a storage life of only a few days under even the best environmental conditions.

### 6.13. Factors affecting storage life

The natural limits to the post -harvest life of all types of fresh produce are severely affected by other biological and environmental conditions.

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

***Transpiration and water losses*** - High temperature, low humidity in the store and injuries to produce can greatly increase the loss of water from stored produce beyond that unavoidable lost from natural causes. Maximum storage life can be achieved by storing only undamaged produce at the lowest temperature tolerable by the crop and at the Relative Humidity appropriate for the produce.

***Mechanical damage*** - Damage caused during harvesting and subsequent handling (i.e. injuries, impact bruising) increase the rate of deterioration of produce and renders it liable to attacks by decay organisms even under refrigerated storage. 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 wound –healing process.

***Decay in storage*** - Decay of fresh produce during storage is mostly caused by the infection of mechanical injuries provoked by microorganisms, mostly bacteria and fungi. Furthermore, many fruits and vegetables are attacked by decay organisms which penetrate through natural openings or even through the intact skin. These infections may be established during the growth of the plant in the field but lie dormant until after harvest, often becoming visible only during storage or ripening.

### Storage structures

**Ventilated stores -** Naturally ventilated structures can be used for the storage of produce with a long storage potential, such as roots and tubers, pumpkins, onions and hard white cabbage. Such stores must be designed and built specifically for each intended location. Any type of building can be used, provided that it allows the free circulation of air through the structure and its contents.

**Clamps** - These are simple, inexpensive structures used to store root crops, particularly potatoes.

**Other simple storage methods.**

**Windbreaks -** are narrow, wire mesh, basket-like structures about 1 m wide and 2 m high, 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 any convenient length, on a raised wooden base. The onions are covered on top with a 30cm 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.

**Refrigeration and controlled atmosphere storage -** For large –scale commercial operations, refrigeration storage may be used in a cold –chain operation to carry regular consignments from production areas to urban markets and retailers. This can be highly complex operation requiring expert organization and management.

Cold storage can also be used for long, medium and short-term storage of seasonal crops. The objective of refrigeration is to extend the shelf-life of the produce

The storage life of some fruits, such as apples and pears and flowers, can be extended by combining refrigeration with a controlled environment consisting of a mixture of oxygen and carbon dioxide in an airtight room. This last storage mechanism is an expensive operation with high maintenance and running costs, and demand skilled and experienced management. They have relatively little application to small-scale production in developing countries.

**Transportation to the market**

Transportation is often the most important and costliest factor in the marketing channel of fresh produce. The method of transport of the fresh fruits and vegetables is determined by distance, perishability and value of the produce, all these factors being regulated by time.

Whatever the method used the principle of transport are the same:

- ✓ Loading and unloading should be as careful as possible
- ✓ Transit time should be as short as possible
- ✓ The product should be well protected in relation to its suitability to physical injuries
- ✓ Overheating should not be permitted
- ✓ Water losses by the produce should be restricted to the minimum
- ✓ Whenever possible the transport vehicle should not stop under the sun and the produce protected with a cover
- ✓ Providing shelter from sun and rain at loading and unloading areas

The method of stowage of the produce in the transport vehicle will depend on the package, commodity and type and size of the vehicle.

Useful guidelines are the following:

- ✓ Load the package tightly to reduce movement and make best use of space
- ✓ Distribute weight evenly only stack to a load height which the lower container can withstand the weight without crushing or damaging the content
- ✓ Use rope whenever needed to avoid shaking of the containers on the higher side. If the container shakes most probably the content will get bruised
- ✓ Cover the top boxes with tarpaulin to avoid sun damages and overheating to the produce.
- ✓ The cover will, also, reduce shaking of the containers.

**Causes of losses during transportation**

The damage and losses incurred during non-refrigerated transport are caused primarily by mechanical damage and overheating.

***Mechanical damage -*** Damage of this type occurs for many reasons, including:

- ✓ Careless handling of packed produce during loading and unloading;
- ✓ Vibration (shaking) of the vehicle, especially on bad roads;
- ✓ Fast driving and poor condition of the vehicle; and
- ✓ Poor stowage, which allows packages in transit to sway; the stow may collapse.
- ✓ Packages stacked too high. Vibration of produce within a package increases in relation to its height in the stack, provoking bruising.

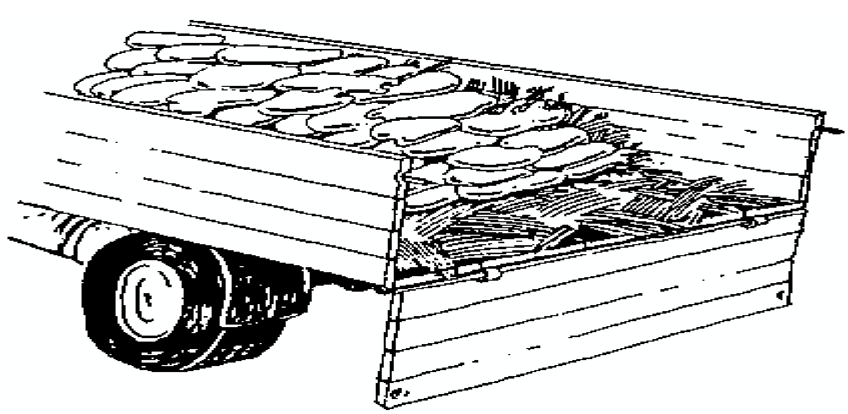


Figure: Bulk loads of yams carefully loaded in vehicle lined with straw. Source: Wilson. IITA, London.

***Overheating -*** This can occur not only from external sources but also from heat generated by the produce within the package itself. Overheating promotes natural breakdown and decay and increases the rate of water loss from the produce: remember water loss means shriveling and shrinkage.

The causes of overheating include:

- ✓ The utilization of closed vehicles without ventilation
- ✓ Close-stow stacking patterns blocking the movement of air between and trough the packages, hindering the disposal of air
- ✓ Lack of adequate ventilation of the packages themselves
- ✓ Exposure of the packages to the sun waiting for transport, when trucks stop underway or awaiting unloading.

# Chapter Seven

**Factors affecting the postharvest quality of horticultural produce**

I. Pre-Harvest Factors

II. Harvest Factors

III. Post-Harvest Factors

**I. Pre Harvest Factors**

- ✓ Genetic / variety
- ✓ Light
- ✓ Temperature
- ✓ Humidity
- ✓ Mineral nutrition
- ✓ Water relation/ Irrigation
- ✓ Canopy manipulation
- ✓ Rainfall
- ✓ Seasons / Day and day length
- ✓ Carbon dioxide
- ✓ Use of agrochemicals
- ✓ Planting density
- ✓ Root stock, pruning and crop rotation
- ✓ Pest and diseases

**II. Harvest Factors**

- ✓ Stage of harvest
- ✓ Time of harvest
- ✓ Methods of harvest

**III. Post – Harvest Factors**

- ✓ Temperature
- ✓ Light
- ✓ Humidity
- ✓ Water quality
- ✓ Ethylene
- ✓ Ventilation, spacing & packaging
- ✓ Preservatives
- ✓ Growth regulators

**7.1. Pre – harvest factors**

**1. Genetic / variety –** Varieties with shorter shelf-lives are generally prone to higher post-harvest losses. Varieties with thick peel, high firmness, low respiration rate and low ethylene production rates would usually have longer storage life. The cultivars that have ability to withstand the rigors of marketing and distribution will have lesser losses after harvest. Varieties with resistance to low temperature disorders and/or decay-causing pathogens can be stored well for longer duration with minimum storage losses. Hence, while growing horticultural crops, one must choose such varieties that inherently have got good quality and storage potential in addition to the high yield and pest resistance potential.

**2. Light –** light regulates several physiological processes like chlorophyll synthesis, phototropisum, respiration and stomatal opening. The duration, intensity and quality of light affect the quality of fruits and vegetables at harvest. Most of the produce needs high light intensity (3000-8000 f.c.). Absorption of red light (625-700 nm) through pigments, phytochrome, is essential for carbohydrates synthesis which determines the shelf life of the produce. The vase life of the carnation and chrysanthemums is longer under high light intensity than low.

Citrus and mango fruits produced in full sun generally had a thinner skin, a lower weight, low juice content and lower acidity but a higher TSS. And citrus fruits grown in the shade may be less susceptible to chilling injury when subsequently stored in cold storage.

In tomatoes, leaf shading of fruits produced a deeper red color during the ripening than in the case of those exposed to light. The side of the fruit that have been exposed to sun will generally firmer than the non-exposed side. In general, the lower the light intensity the lower the ascorbic acid content of plant tissues. In leafy vegetables, leaves are larger and thinner under condition of low light intensity.

**3. Temperature –** all type of physiological and biochemical process related to plant growth and yield are influenced by the temperature. The higher temperature during field conditions decreases life and quality of the produce. At high temperature, stored carbohydrates of fruits, vegetables and flowers are quickly depleted during respiration and plant respires at the faster rate. The produce which is having higher amount of stored carbohydrates show longer storage/vase life. For example- high temperature during fruiting season of tomato leads to quick ripening of fruits on and off the plant.

Orange grown in the tropics tend to have higher sugars and TSS than those grown sub tropics. However, tropical grown oranges tend to be green in color and peel less easily and it is due to the lower diurnal temperature that occurs in the tropics.

**4. Humidity –** High humidity during growing season results in thin rind and increased size in some horticultural produce and this produce is more prone to high incidence of disease during post harvest period. Humid atmosphere may cause the development of fungal and bacterial diseases, which damages produce during storage and transport. Damaged produce remove water very quickly and emit a larger concentration of ethylene than healthy ones. Low humidity may cause browning of leaf edge on plants with thin leaves or leaflets. High humidity can maintain the water – borne pollutants in a condition so that they can be more easily absorbed through the cuticles or stomata's. Reduced transpiration leads to calcium and other elemental deficiency.

**5. Rainfall -** Rainfall affects water supply to the plant and influences the composition of the harvested plant part. This affects its susceptibility to mechanical damage and decay during subsequent harvesting and handling operations. On the other hand, excess water supply to plants results in cracking of fruits such as cherries, plums, and tomatoes. If root and bulb crops are harvested during heavy rainfall, the storage losses will be higher.

**6. Wind -** Wind damages the produce by causing abrasions due to rubbing against twigs or thorns. These mechanically damaged produce are more prone to spoilage during post harvest period and have shorter post-harvest life.

**7. Mineral nutrition –** balanced application of all nutrient elements is necessary for the maintaining growth and development of the plants. The application of fertilizers to crops influences their post-harvest respiration rate. Excess or deficiency of certain elements can affect crop quality and its post-harvest life. Numerous physiological disorders are also associated with mineral deficiencies which ultimately lead to post harvest losses.

***Nitrogen -*** High N fertilization reduces while moderate to high K improves PH life and quality of anthurium, cut flowers and many horticultural produce. Application of K in water melon tend to decrease the PH respiration. High levels on N tend to decrease flavor, TSS, firmness and color of the fruit and in stone fruits it increases physiological disorders and decrease fruit colour.

Generally, crops that have high levels of nitrogen typically have poorer keeping qualities than those with lower levels as. High nitrogen increases fruit respiration, faster tissue deterioration thereby reducing their storage life.

***Phosphorous -*** Application of phosphorous minimizes weight loss, sprouting and rotting in bulb crops compared with lesser application. Phosphorous nutrition can alter the post harvest physiology of some produce by affecting membrane lipid chemistry, membrane integrity and respiratory metabolism. The respiration rate of low-phosphorous fruits will be higher than that of high phosphorous fruits during storage.

***Potassium -*** potassium fertilizers improves keeping quality, its deficiency can bring about abnormal ripening of fruits and vegetables. Potassium helps in reducing some physiological storage disorders, e.g. superficial rind pitting in oranges.

***Calcium-*** the storage potential of the fruits is largely dependent on the level of Ca and it is associated with produce texture. The higher level of N, P and Mg and low levels of K and Bo lead to the Ca deficiency in fruits and reduce its storage life. Reduction in calcium uptake causes lateral stem breakage of poinsettia. Calcium treatment delays ripening, senescence, reduces susceptibility to chilling injury, increase firmness and reduces decay subsequent to storage in avocados and improves the quality.

Physiological disorders of storage organs related to low Ca content of the tissue are:

- ✓ Bitter pit in apples
- ✓ Cork spot in pears
- ✓ Blossom end rot in tomato
- ✓ Tip burn in lettuce and hallow heart in potato etc.
- ✓ Red blotch of lemons

Zn is known to act as vehicle for carrying ions across tissue and increase Ca content of the fruit. Adequate supply of Bo improves the mobility of Ca in the leaves and the fruits and subsequently increases fruit firmness, TSS, organic acids and reduce the incidence of the drought spot, bitter pit and cracking disorders. And impart diseases resistance.

The incorporation of 4% Ca into proto pectin of middle lamella form bond with the cellulose of the cell wall and thus delayed softening in fruits. Infused Ca inhibits the internal browning, retarded respiration, and reduced the metabolism of endogenous substrates.

Post climacteric respiration of apple decreased as peel Ca level increased from 400 to 1300 ppm. Ca may reduce the endogenous substrate catabolism by limiting the diffusion of substrate from vacuole to the respiratory enzymes in the cytoplasm (limited membrane permeability).

**Table:** Storage disorder and storage characteristic of Cox's Orange Pippin apple in relation to their mineral content

| | Composition (mg 100 g-1) | | | | |
|---|---|---|---|---|---|
| | N | P | Ca | Mg | K/Ca |
| Bitter pit | | | < 4.5 | >5 | >30 |

| | | | | | |
|---|---|---|---|---|---|
| Break down | | <11 | < 5 | | >30 |
| Lenticel blotch pit | | | <3.1 | | |
| Loss of firm ness | >80 | <11 | < 5 | | |
| Loss of texture | | <12 | | | |

Application of $CaCl_2$ delayed the accumulation of free sugars, decreased inorganic contents, mold development, softening and development of red color in strawberry. In pears reduced cork spot, increased flesh firmness, total acidity and juiciness and in apple even after 90 day of storage at ambient condition shown acceptable quality.

**8. Water relation and Irrigation –** stress due to excessive or inadequate water in the medium reduce the longevity of the produce. Crop like carnation require 850 to 1200 g of water to produce one gram of dry matter. In general, <5 % of water absorbed in the plant system is utilized for the development of different plant components. Moisture stress increases the rate of transpiration over the rate of absorption and irregular irrigation/ moisture regime leads fruits/vegetable cracking (potato and pomegranate cracking). Higher level of moisture stress affects both yield and quality by decreasing cell enlargement.

Crops which have higher moisture content generally have poorer storage characteristics. An example of this is the hybrid onions, which tend to give high yield of bulbs with low dry matter content but which have only a very short storage life. If fully matured banana harvested soon after rainfall or irrigation the fruit can easily split during handling operations, allowing microorganism infection and Postharvest rotting. If orange is too turgid at harvest (early morning) the flavdeo/oil gland in the skin can be ruptured during harvesting, releasing phenolic compounds and causes Oleocellosis or oil spotting (green spot on the yellow / orange colored citrus fruit after degreening).

***Quailing* –** 'harvested produce is kept in the basket for few hours in the field before being transported to pack house, this will allow the produce to loose little moisture'. Some growers have practice of harvesting lettuce in the late in the morning/ early afternoon because when they are too turgid the leaves are soft and more susceptible to bruising.

***In green leafy vegetables***, too much rain or irrigation can result in the leaves becoming harder and brittle, which can make them more susceptible to damage and decay during handling and transport. Mango hot water treatment is better if there is delay of 48 hr. between harvest and treatment and resulted better efficiency of hot water in disease control.

Generally, crops that have higher moisture content or low dry matter content have poorer storage characteristics. Keeping quality of bulb crops like onion and garlic will be poor if irrigation is not stopped before three weeks of harvesting.

**9. Canopy Manipulation –** (A). ***Fruit thinning –*** increases fruit size but reduces total yield. It helps in obtaining better quality produce

**(B).** ***Fruit position in the tree –*** Fruits which are exposed to high light environment possesses higher TSS, acidity, fruit size, aroma, and shelf life compared to which lies inside the canopy. Hence better training system should be practiced to circulate optimum light and air. Eg.: Grapes, Mango, peaches, kiwifruits

**(C).** ***Girdling -*** increases the fruit size and advance and synchronized fruit maturity in peach and nectarines. Increases fruitfulness in many fruit tree species.

**10. Season / Day –** seasonal fluctuation and time of the day at harvest will greatly affects the postharvest quality of the produce. Synthesis of higher amount of carbohydrates during the day time and its utilization through translocation and respiration in the night is responsible for the variation in the longevity of the cut flowers. Roses and tuberose have been found to show longer keeping quality in the winter season under ambient condition than in the summer seasons. Generally, produce harvested early in the morning or in the evening hours exhibits longer postharvest life than produce harvested during hot time of the day.

***Day length -*** If long days Onion (temperate) grown during short day (tropics) condition it leads

to very poor storage quality.

**11. Carbon dioxide –** quality planting material, early flowering, more flowering, increased yield and rapid crop growth and development at higher level of $CO_2$. Production of chrysanthemum under green house at 1000 – 2000 ppm of $CO_2$ showed an increase in stem length, fresh weight, leaf no. and longevity of cut flowers.

**12. Use of Agro chemicals –** Pre-harvest application of chemicals such as BA, IAA, $GA_3$, growth retardants like B-9, CCC, A-Rest and Phosphon-D have been reported to improve quality and longevity of flowers crops. Application of $GA_3$ @ 50-100 ppm improves PH quality of roses by anthocyanin development. And it stimulates the accumulation of N, K, Mg and S. Pre-harvest spray with Alar(1500ppm), MH(500ppm), and Cycocel (500ppm) increased vase life of Aster. Beneficial effect of leaf manure, K and $GA_3$ is found to enhance the longevity of tuberose flowers.

Use of chemicals on the plants to prevent the pathogen will have direct impact on extending the postharvest life. Generally, if produce has suffered an infection during development its storage or marketable life may be adversely affected. Banana which suffers a severe infection with diseases such as leaf spot may ripen pre maturely or abnormally after harvest and in mango it is rapid postharvest loss. Pre harvest application chemicals like MH on onion filed prevent them sprouting during storage.

**13. Pest and Diseases –** infection by fungi, bacteria, mites and insects reduces the longevity as well as consumer acceptability. Tissue damage caused by them show wilting and produce ethylene leads to early senescence. Vascular diseases/stem rot /root rot of floral corps hinder the transport, affects the post-harvest life and quality. The potato tuber moth may infest tubers during growth if they are exposed above the soil and subsequently in the storage. Note : Refer lecture schedule - 7 for study questions and references.

### 7.2. Harvest factors

Maturity at harvest stage is one of the main factors determining compositional quality and storage life of fruit, vegetables and flowers. All fruits, with a few exceptions, reach peak eating quality when fully ripened on the tree. However, since they cannot survive the post-harvest handling system, they are usually picked/plucked mature but not ripe.

**1. Stage of Harvest –** Harvesting can also affect final quality. For instance, when fruits and vegetables are harvested too late or too early in the season, overall taste, texture, and color may be compromised. Maturity at harvest is therefore an important factor that determines the final quality of the produce. Harvesting of fruits and vegetables at immature stage leads to both qualitative and quantitative losses. Immature fruits fail to ripen normally with low nutritive values and have inferior flavor quality when ripe. On the other hand, over mature fruits are likely to become soft and mealy with insipid flavor soon after harvest.

Many vegetables, in particular leafy vegetables, and immature fruit-vegetables (such as cucumbers, green beans, peas, and okras), attain optimum eating-quality prior to reaching full maturity. This often results in delayed harvest, and consequently in produce of low quality. Most of the cut flowers are harvested at the immature stage. Roses are harvested at tight bud stage/cracked bud stage than the half open or full open stage

**2. Time of Harvest -** It is advisable to harvest produce when temperature is mild as high temperature causes rapid respiration rate and excessive water loss. The recommended time for harvest of fresh horticultural produce is early morning hours or late evening hours.

The amount of time between harvesting and delivery to a market also can damage the quality of the fruit, vegetable or flower. If fresh produce isn't processed quickly, it may also lose nutritional value.

**3. Methods of Harvest –** The method of harvesting (hand vs mechanical) can also have significant impact on the composition and post-harvest quality of fruits and vegetables. Sharp tools/ secateur /harvester/hand gloves/digger/vibrater/ trimmer/ any such items should always be used to detach the fruits/vegetable/flowers from the mother plant. Mechanical injuries (such as bruising, surface abrasions and cuts) can accelerate loss of water and vitamin C resulting in increased susceptibility to decay-causing pathogens.

Cut flowers with long stem have higher post-harvest life than short stem because shorter stem have less carbohydrate reserves. While cutting cut flowers care should be taken to give slant cut and not to crush. Slant cut helps in facilitating the maximum surface area to absorb water at rapid rate during vase life.

Management of harvesting operations, whether manual or mechanical, can have a major impact on the quality of harvested fruits and vegetables. Proper management procedures include selection of optimum time to harvest in relation to produce maturity and climatic conditions, training and supervision of workers, and proper implementation of effective quality control.

Expedited and careful handling, immediate cooling after harvest, maintenance of optimum temperatures during transit and storage, and effective decay-control procedures are important factors in the successful post-harvest handling of fruits and vegetables. Attention must be paid to all of these factors, regardless of the method of harvesting used. These factors are nevertheless more critical in the case of mechanically harvested commodities.

### 7.3. Postharvest factors

**1. Temperature -** Optimal temperature is a major important factor in determining the postharvest life of the produce. Senescence accelerate at higher temperature, whereas at low temperature, respiration comes down and in F, V and flowers lesser amount of ethylene and the multiplication of microorganism does not take place at faster rate.

Harvested produce is ideally transported and stored under reduced temperature likely to maximize longevity. However, the effect of reducing temperature on maintaining produce quality is not uniform over the normal temperature range i.e. 0 - 300C for non-chilling sensitive produce; 7.5 - 300C for moderately chilling sensitive produce; 13 - 300C for chilling sensitive plants. Normal ripening occurs at temperature range of 10-300C, but best quality fruit develops ripening at 20-230C (Fig 1 & 2).

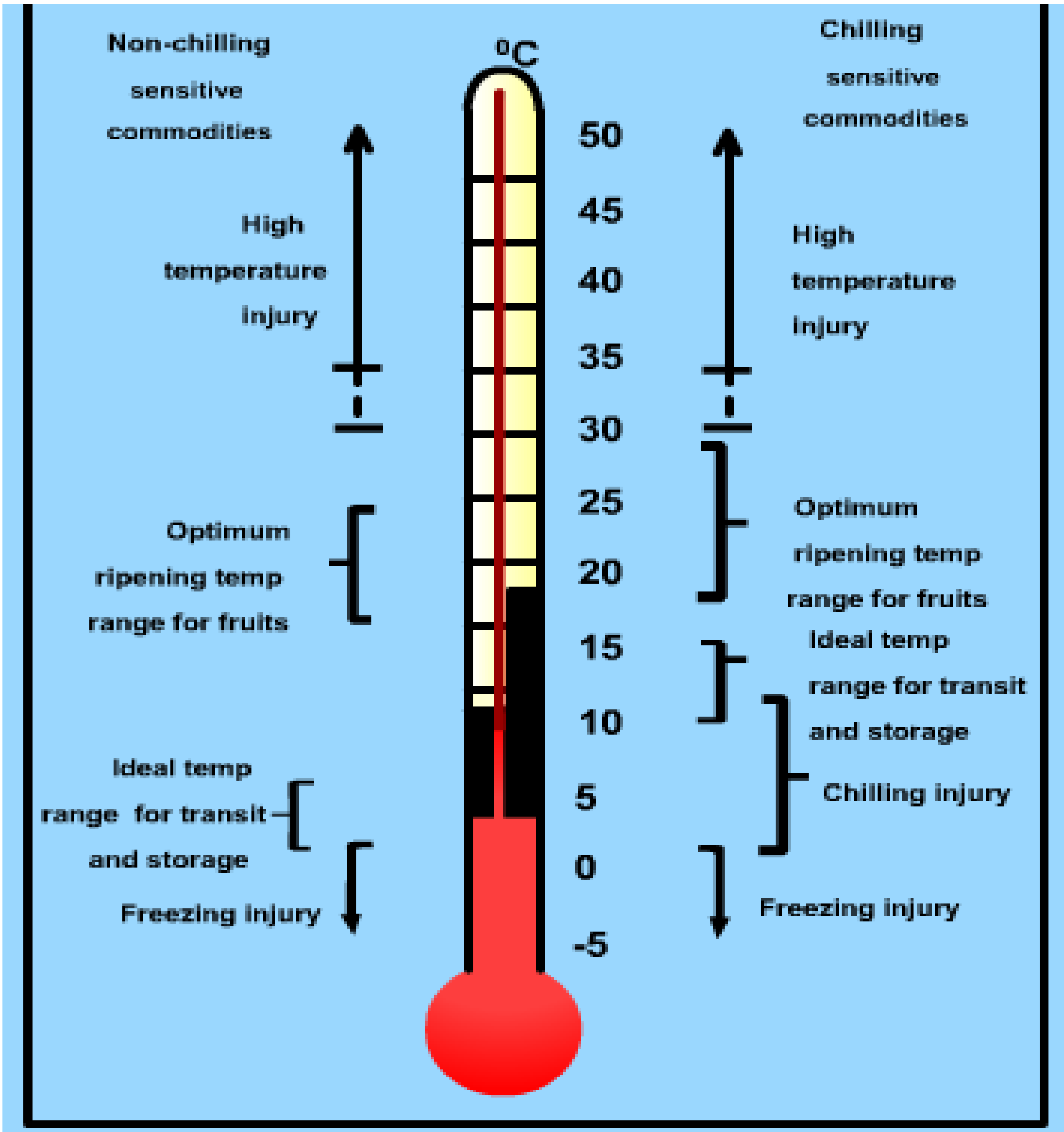



Fig. Response of non-chilling sensitive and chilling sensitive Produce to temperature

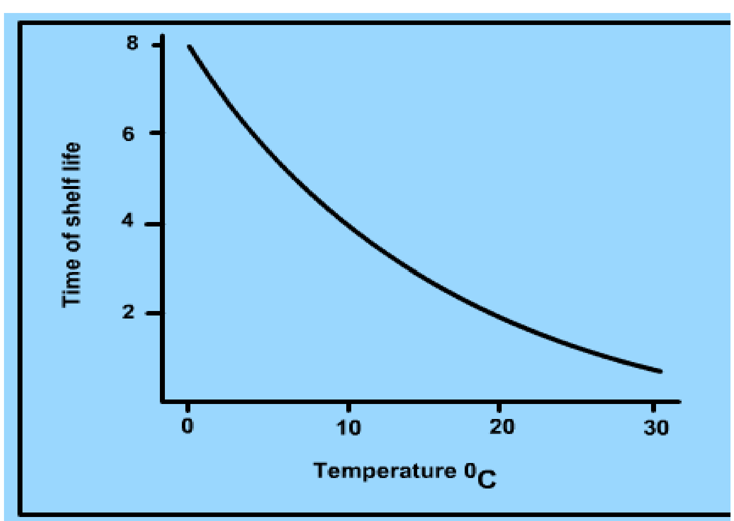



Fig. Effect on temperature on length of shelf life

**2. Light –** Potted flowering plants/cut flower, it is advisable to illuminate the plants with 2 - 3 k lux (200-300 f.c.) with fluorescent and incandescent to create illumination of red and blue light.

**3. Humidity -** Many horticultural produce should be kept at 80-95% RH for maintenance of freshness/turgidity. Produce start showing wilting symptoms when they have lost 10-15% of their fresh weight. The rate of transpiration from the produce is reduced with the increases of high RH. Care should to be taken not to maintain high RH coupled with high temperature results in faster infection by pathogen. Produce should not be stores in dry atmosphere because they become less turgid through quick transpiration.

**4. Water Quality –** water quality relates to pH, EC values, hardness contents of phytotoxic elements and microorganism causing vascular obstruction affecting longevity of the produce particularly cut flowers. Saline water decreases vase life flowers. Longevity of flowers reduced when salts concentrations reaches 200 ppm (roses, chrysanthemum and carnation) and 700 ppm (gladiolus). Basic ions like Ca++ and Mg++ present in hard water are less harmful than soft water containing sodium ions. Use of de-ionised water is better than ordinary tap water in enhancing vase life and even use of boiled water containing less air then tap water is readily absorbed by stem.

Use of Millipore filter water enhances flow rate of water through cut stem and reduction of air blockage from vessel. Acidification of alkaline water with $H_2SO_4$ and HCL has been found to increase the vase life of cut flowers. At low pH, microbial population in stem of the flowers decreases. Acidification of water through citric acid is also helpful. The optimum pH for extending the vase life of flowers varies from 4.0 - 5.0.

Wetting agents/surfactants like Tween -20®/APSA® at 0.1 -0.01%(1.0 ml - 0.1 ml L-1) decrease the surface tension of water, increase the lateral water flux which removes air bubbles and helps to maintain a continuous xylem water column in cut flowers.

**5. Plant hormones –** Use of Cytokinin(Kinetin, BA and B-9), auxin(IAA) and gibberellins (GA3) are will delay senescence of the produce and are known to be ethylene inhibitors.

Abscisic acid – ABA accelerate the developmental process associated with aging and increase sensitivity of the tissue to the ethylene production. ABA is also involving in senescence to increase the permeability of the tonoplast leading to cell disorganization, resulting in decreased water uptake and development of water/ion stress effects.

**6. Preservatives –** in the form of tablet containing a mixture of chemicals such as sugars, germicides, salts, growth regulators, etc. is being used to extend the vase life of the flowers. Sugars, biocides, anti-ethylene compounds (1-MCP, Potassium permanganate) and hydrated compound are used for conditioning. All sugars used in holding solution make excellent media for the growth of micro-organism causing stem plugging. Therefore, sugars must be used in the combination with germicides in the vase solution. Metallic salts like silver nitrate, cobalt chloride, Al So4, Zn So4, calcium nitrate and nickel chloride are used to extend the vase life of flowers. Growth regulators such as BA, IAA, NAA, 2.4.5.T, GA3, B-Nine and CCC are also used.

**7. Ventilation, Spacing & Packaging –** provision for air circulation must be maintained to remove respiration heat. Sufficient commodity spacing should be provided so that at least one side remains exposed for air circulation to prevent heat generation. And only pre cooled products are allowed to be packed, but there should not be any direct contact between product and the containers (Refer chapter storage and packing).

**8. Packing and packaging of fruits, vegetables and flowers:** Preparation of produce for market may be done either in the field or at the packing house. This involves cleaning, sanitizing, and sorting according to quality and size, waxing and, where appropriate, treatment with an approved fungicide prior to packing into shipping containers. Packaging protects the produce from mechanical injury, and contamination during marketing. Corrugated fiberboard containers are commonly used for the packaging of produce, although reusable plastic containers can be used for that purpose.

Packaging accessories such as trays, cups, wraps, liners, and pads may be used to help immobilize the produce within the packaging container while serving the purpose of facilitating moisture retention, chemical treatment and ethylene absorption. Either hand-packing or mechanical packing systems may be used. Packing and packaging methods can greatly influence air flow rates around the commodity, thereby affecting temperature and relative humidity management of produce while in storage or in transit.

**9. Length of Storage:** One of the most significant factors that affect the quality of fresh produce is storage. Making sure that fresh produce is stored at optimum conditions is a key to retain their quality. If it is stored in poor storage conditions such as high temperatures, it will lose its nutritional value or spoil quickly. Storing fresh produce beyond the recommended periods even at optimum temperature can still cause loss of nutritional value.

# Chapter Eight

## 8.1. Causes of Postharvest losses in horticultural produce

It is well known fact that fruits, vegetables and flowers are living commodities even after harvest and continue to respire, transpire and carryout other biochemical activities. Therefore, they are more perishable when compared to other agricultural commodities. The deterioration in harvested fresh produce occurs both quantitatively and qualitatively. The losses that occur from the time of harvesting of fresh produce till they reach the consumer are referred as post-harvest losses.

Post-harvest losses occur in terms of:

**Quantitative loss -** referring to the reduction in weight due to moisture loss and loss of dry matter by respiration

**Qualitative loss -** referring to freshness deterioration leading to loss of consumer appeal and nutritional loss including loss in vitamins, minerals, sugars, etc.

Cost of preventing losses after harvest in general is less than cost of producing a similar additional amount of produce and reduction in these losses is a complimentary means for increasing production. These losses could be minimized to a large extent by following proper pre- harvest treatments, harvesting at right maturity stage and adopting proper harvesting, handling, packing, transportation and storage techniques.

The factors that are responsible for the deterioration of Horticultural produce are:

I. Biological factors

II. Environmental factors

**I. Biological factors**

Following biological factors are responsible for deterioration of Horticultural Produce:

- ✓ Respiration rate
- ✓ Ethylene production
- ✓ Compositional changes
- ✓ Growth and development
- ✓ Transpiration
- ✓ Physiological breakdown
- ✓ Physical damage
- ✓ Pathological breakdown
- ✓ Surface area to volume
- ✓ Membrane permeability

**1. Respiration rate -** being living entities fruits, vegetables, flowers respire actively after harvest. Detailed quantities a qualitative occurring due life of horticultural to this factors is detailed in lecture - 3 (Physiology and Biochemistry of Horticultural Produce).

**2. Ethylene production -** ethylene plays a vital role in postharvest produce.

3**. Compositional changes -** Many pigment changes also takes place even after harvest in some commodities.

These changes are:

- ✓ Loss of chlorophyll (green color) – In vegetables
- ✓ Loss of carotenoids (yellow and orange color) – In apricot, peaches, citrus fruits and tomato
- ✓ Loss of anthocyanins (red and blue color) – In apples, cherries and strawberries
- ✓ Change in carbohydrates
- ✓ Starch to sugar conversion – potato
- ✓ Sugar to starch conversion – peas, sweet corn
- ✓ Breakdown of pectin and other polysaccharides – causes softening of fruit
- ✓ Change in organic acids, proteins, amino acids and lipids. – can influence flavor g. Loss in vitamins – effects nutritional quality

**4. Growth and development -** In some commodity growth and development continue even after harvest which accelerates deterioration. For example;

- ✓ Sprouting of potato, onion and garlic
- ✓ Fresh rooting of onions
- ✓ Harvested corps continues to grows even after harvest but is very much evident in Asparagus
- ✓ Increase of volume in lettuce

**5. Transpiration -** Most fresh produce contain 80-90 % of water when harvested. Transpiration is a physical process in which high amount of water is lost from the produce, which is the main cause of deterioration. This exchange of water vapor in produce is carried through the cuticle, epidermis cells, stomata and hairs of the produce. Produce stored at high temperature will have high transpiration rate.

When the harvested produce loses 5 % or more of its fresh weight, it begins to wilt and soon becomes unusable. Water loss also causes loss in quality, such as reduced crispness and other undesirable changes in color, palatability and loss of nutritional quality.

**Factors influence the transpiration rate in various commodities:**

- ✓ Surface of the commodity - commodities having greater surface area in relation to their weight will lose water more rapidly. It is clearly visible in leafy vegetables where the water loss is much faster than a fruit as they have more surface area to volume ratio
- ✓ Surface injuries - Mechanical damages accelerate the rate of water loss from the harvested produce. Bruising and abrasion injuries will damage the protective surface layer and directly expose the underlying tissues to the atmosphere allowing greater transpiration
- ✓ Maturity stage - less matured fruits lose more moisture then matured fruits/vegetables
- ✓ Skin texture - Fresh produce having thin skin with many more spores lose water quickly than those having thick skin with fewer spores
- ✓ Temperature - Water loss is high with increase in storage temperature. The loss will be further enhanced when high temperature is combined with low relative humidity
- ✓ Relative humidity - The rate at which water is lost from fresh produce also depends on the water vapor pressure difference between the produce and the surrounding air. So water loss from fresh produce will be low when the relative humidity i.e. moisture content of the air is high. Further, the faster the surrounding air moves over fresh produce the quicker will be the water loss.

Transpiration results in following type of deterioration:

- ✓ Loss in weight
- ✓ Loss in appearance (wilting and shriveling)
- ✓ Textural quality (softening, loss of crispiness and juiciness)

**6. Physiological breakdown -** When produce is exposed to an undesirable temperature physiological breakdown takes place.

Following physiological breakdowns are common in various commodities:

- ✓ Freezing injury - when commodity stored at below their freezing temperature
- ✓ Chilling injury - when commodity stored at below their desired storage temperature
- ✓ Heat injury - when commodity exposed to direct sunlight or at excessively high temperature. It causes defects like sunburn, bleaching, scalding, uneven ripening and excessive softening.
- ✓ Very low $O_2$ (<1%) and high $CO_2$ (>20%) atmosphere during storage can cause physiological problems
- ✓ Loss of texture, structure and microbial damage

**7. Physical damage**

Various types of physical damages responsible for deterioration are

- ✓ Mechanical injury/cut - during harvesting, handling, storage, transportation *etc*.
- ✓ Bruising due to vibration (during transportation), impact (dropping) and compression (overfilling)

**8. Pathological breakdown**

This is the most common symptom of deterioration where it is mainly caused by the activities of bacteria and fungi (yeast and mould). Succulent nature of fruits and vegetables make them easily invaded by these organisms. The common pathogens causing rots in fruits and vegetables are fungi such as *Alternaria, Btrytis, Diplodia, Phomopsis, Rhizopus, Pencillium* and *Fusarium* and among bacteria, *Ervina* and *Pseudomonas* cause extensive damage

Microorganisms usually directly consume small amounts of the food but they damage the produce to the point that it becomes unacceptable because of rotting or other defects. Losses from post-harvest disease in fresh produce can be both quantitative and qualitative. Loss in quantity occurs where deep penetration of decay makes the infected produce unusable. Loss in quality occurs when the disease affects only the surface of produce causing skin blemishes that can lower the value of a commercial crop.

**9. Surface area to volume -** grater surface leads to greater weight and respiratory loss

**10. Membrane permeability -** fluctuation in storage temperature and physiological injuries like chilling injury leads to membrane damage resulting in electrolyte leakage.

**II. Environmental factors**

Following environmental factors are responsible for deterioration:

- ✓ Temperature
- ✓ Relative humidity
- ✓ Atmospheric gas compositions
- ✓ Ethylene
- ✓ Light
- ✓ Other factors

**1. Temperature**

Environmental temperature plays very major role in deterioration of produce:

- ✓ Every increase of 10ºC temperature above optimum increases the deterioration by two times
- ✓ Exposure to undesirable temperature results in many physiological disorders like; freezing injury, chilling injury and heat injury *etc*.

- ✓ Temperature influence growth rate of fungal spores and other pathogens.
- ✓ It affects the respiration and transpiration rate of produce.

**2. Relative humidity**

The rate of loss of water from fruit, vegetables and flowers depends upon the vapor pressure deficit between the surrounding ambient air, which is influenced by temperature and relative humidity. The rate of deterioration is a combined factor of temperature and relative humidity and affects the produce in following manner:

- ✓ Low Temp. & High Relative Humidity -- Low deterioration
- ✓ Low Temp. & Low Relative Humidity -- Moderate deterioration
- ✓ High Temperature & High Relative Humidity -- High deterioration
- ✓ High Temperature & Low Humidity -- Very high deterioration

**3. Atmospheric gas composition**

Buildup of undesirably high carbon dioxide and very low levels of oxygen in the storage facility can lead to many physiological disorders leading to spoilage. Eg. Hollow heart disease in potato is due to faulty oxygen balance in storage or during transportation.

Exposure of fresh fruits and vegetable to $O_2$ levels below the tolerance limits or to $CO_2$ levels above their tolerance limits in storage rooms may increase anaerobic respiration and the consequent accumulation of ethanol and acetaldehyde, causing off-flavours. The other bad effects of unfavourable gas composition include irregular ripening of certain fruits, soft texture, lack of characteristic aroma, poor skin color development, etc.

Example: CA storage of Apples (0-10$^{O}$C with 1-2%$CO_2$ and 2-3%$O_2$, RH 90-95%) for 6-12 month.

**4. Ethylene**

Effect of ethylene on harvested horticulture commodities may be desirable or undesirable. On one hand ethylene can be used to promote faster and more uniform ripening of fruits. On other hand exposure to ethylene can deteriorate the quality of certain vegetables such as destruction of green colour in leafy and other vegetables, early senescence of flowers, bitterness in carrots, increased toughness, accelerated softening, discoloration and off-flavor, etc.

**5. Light**

Exposure of potatoes to light results in greening of the tuber due to formation of chlorophyll and solanine which is toxic to human on consumption.

**6. Other factors**

Various kinds of chemicals (eg. pesticides, growth regulators) applied to the commodities also contribute to deterioration. Many of the chemical constituents present in stored commodities spontaneously react causing loss of color, flavor, texture and nutritional value. Further there can also be accidental or deliberate contamination of food with harmful chemicals such as pesticides or lubricating oils.

**8.2. major pre and post-harvest defects**

During crop growth and subsequently after harvest many imperfection and blemishes occur due various means.

Causes of defects in various Horticultural produce are categories as follows:

- ✓ Insect pests
- ✓ Microorganisms
- ✓ Nutritional deficiencies
- ✓ Birds / animals
- ✓ Mis-handling
- ✓ Environment
- ✓ Mechanical means
- ✓ Delayed harvesting
- ✓ Improper cultural practices
- ✓ Improper trimming and pruning
- ✓ Improper cold storage
- ✓ Physiological disorder

| No. | Defects | Damage |
|---|---|---|
| 1. | Insect pests | Holes and mis-shapen |
| 2. | Microorganisms | Black scurf, canker, Scab, Blight, Blisters, Sooty blotch, Rotten/decay |
| 3. | Nutritional deficiency | Dry circular crevices |
| 4. | Improper cultural practices | Green spot(potato) |
| 5. | Environmental factors | Russeting, water core, discoloration, staining, dried leaves, hail damage, dull/ pale look, shriveling / wrinkling, sunburn, sun scald, superficial sunscald,<br>lanky, torn leaves, black/brown calyx, water core, fresh rooting, splitting, cracks, natural growth cracks, water berry, scales on surface |
| 6. | Birds / animals | Bird damage |
| 7. | Delayed harvesting | Mature/over mature, fibrous, over ripe, seed stem |
| 8. | Handling | Black edges, handling damage, packing<br>damage, pressure damage, shatter or loose berry, damage, soft, bruises and broken |

| | | |
|---|---|---|
| 9. | Mechanical means | Healed dark brown marks, chipped, hole, punctured skin, , cuts, mechanical damage |
| 10. | Improper washing, cleaning, trimming and pruning | Long stalk, dirty outer leaves, secondary roots, wrapper/extra covered leaves, unclean |
| 11. | Physiological disorders | Bitter pit, puffiness, cracking |
| 12. | Improper cold storage | Dried berries, sprouting, hollow heart |
| 13. | Genetic abnormalities | Misshape and double |

Causes of defects (FAO, 1986)

Above mentioned defects can be broadly categorized into three main groups. Like one which occur before harvesting and other which develops after harvesting.

Some defects however are common to both the categories.

| **Pre- harvest** | **Post- harvest** | **Both** |
|---|---|---|
| Misshaped | Black edges | Damage |
| Bird damage | Black/brown calyx | Dull look/Pale look |
| Bitter pit | Broken | Fungal infection |
| Black scurf | Bruising | Hole |
| Blight | Chipped | Rotten/ Decay |
| Blister | Cuts | Black/ brown spots on surface |
| Bottle neck | Dirty outer leaves | Dried berries |
| Canker | Dried leaves | Over ripe |
| Cracks | Dull look | Punctured/ damaged skin |
| Dark/healed brown marks | Fresh rooting | |
| Discoloration | Handling damage | |
| Double | Long stalk | |
| Dry circular crevices | Mechanical damage | |
| Fly speck | Packing damage | |
| Green spot | Pressure damage | |
| Hail damage | Shattered or loose berry | |
| Healed brown marks | Shriveling / wrinkling | |
| Hollow heart (potato) | Slanky | |
| Insect damage and presence of insects like scales, mealy bugs *etc*. on the surface of the produce | Soft | |
| Mature | Sprouting | |
| Natural growth cracks | Unclean | |
| Pale look | Wilted | |
| Puffy | Wrapper/Extra covered leave | |
| Riciness | | |
| Russeting | | |
| Scab | | |
| Scar | | |
| Secondary roots | | |
| Seed stem | | |
| Sooty blotch | | |
| Splitting | | |
| Staining | | |
| Sun burn | | |

| | | |
|---|---|---|
| Sun scald | | |
| Superficial scald | | |
| Torn leaves | | |
| Water core | | |
| Yellow tip | | |

Causes of defects (FAO, 1986)

Quality of the fruits, vegetables, flowers and others depend on the various factors on and off the field of production site such as Factors affecting the quality of horticultural produce

# Chapter Nine

## Handling and supply chain management of horticultural produce

### 9.1. Important considerations

Moment produce is harvested, from that point on quality cannot be improved; only maintained. Remember the suitability of produce for sale begins at harvest. Damage done to produce during harvest is irreparable. No postharvest treatments or miracle chemicals exist which can improve inferior quality produce resulting from improper handling.

Fruit and vegetables are highly perishable and unless great care is taken in there harvesting, handling and transportation, they soon decay and become unfit for human consumption. The process of decay being accelerated if poorly harvested and handled produce is placed in storage for any length of time.

Growers should understand that although there is a place for added value approach to the sale of produce, it is however of no value to purchase expensive equipment and packaging for produce if the basic product is already spoilt by poor harvesting, handling and storage. Hence, production costs, harvesting, handling, packaging, transport and marketing costs are the same irrespective of whether produce makes a premium at point of sale or is acceptable for storage or not.

Where/ How to handle horticultural produce?

It has been observed that improper handling of fresh fruit and vegetables is a major cause of deterioration and postharvest losses. To minimize this produce should be handled carefully during entire supply chain. Handling at each stage plays an important role in protecting the quality and enhancing the shelf life of produce. Produce handling plays an important role in

following stages of supply chain:

- ✓ At the time of harvest
- ✓ At the field
- ✓ At the time of loading and unloading
- ✓ At the time of transportation
- ✓ At whole sale market
- ✓ At retail market
- ✓ At customer end

1. **Handling at the time of harvest:**

The throwing of produce during hand harvesting or handling should not be allowed. When crops are harvested at some distance from the packinghouse, the produce must be transported quickly for packing.

Conveying banana from field to pack house through conveyor

- ✓ Containers - avoid the use of dirty containers, contaminated with soil/crop residues/ the remains of decayed produce. Containers should be cleaned and disinfected at the end of each storage period.
- ✓ Growers should make certain that harvesting labours are fully conversant with the quality control strategy employed on the farm.
- ✓ Mechanical damage during harvesting and subsequent handling operations can result in defects on the produce and expose to disease-causing microorganisms. The inclusion of dirt from the field further aggravates the process.
- ✓ Every effort should be made to harvest produce at its optimum maturity, as storage life is reduced proportionate to the immaturity and/or over maturity of a vegetable crop.

**2. Handling at the field**

As all fruit and vegetables are tender and have soft texture/skin should be handled gently to minimize bruising and breaking/rupturing of the skin. After harvesting, produce is handled at the field for three main activities before dispatch to the market for sale.

- ✓ Washing, cleaning and dressing
- ✓ Sorting-grading
- ✓ Weighment and packaging
- ✓ Washing, cleaning and dressing/trimming

**3. Washing, cleaning and dressing:** After harvest all underground vegetables and most of the leafy vegetables require washing and cleaning before sorting-grading and packing. While washing and cleaning care should be taken that produce does not get damaged while rubbing to clean the outer surface and only clean water should be used for washing to protect the produce from contamination. Removal of extra water is a must before packing to avoid rotting.

Eg. - Washing with 100 ppm chlorine solution is better to control microbial growth.

- Vegetables like Cauliflower, Cabbage, Radish and other leafy items require to be dressed by removing unwanted leaves and stalk before sending them for marketing.

**4. Sorting-grading:** All defective produce such as bruised, cut, decayed and insect infested pieces should be discarded while sorting-grading. This will help to control further deterioration of the produce while in transit. Care should be taken that produce is picked gently and should not be thrown.

**5. Weighment and packing:** Packing material and package itself play a protective role against mechanical damage, dust and infection. They also diminish the rate of loss of water, or hinder gaseous exchange and thus modify the composition of the atmosphere around the produce. Type of packaging material and pack size for primary and secondary packaging is very important to enhance life of the produce after harvesting. Different types of packs are suitable for different type of produce depending upon the distance of location and transport mode used. Pack should not have inside sharp edges. Proper cushion in the pack helps the produce to sustain jerks/vibrations during transportation. As far as possible, uniformly graded produce should be packed in one type of pack.

Packing must withstand the following:

- ✓ Rough handling during loading and unloading
- ✓ Compression from the overhead weight of other containers
- ✓ Impact and vibration during transportation
- ✓ High humidity during pre-cooling, transit and storage

After packing, each pack has to be weighed before sending to the market for sale. Each pack should have some extra quantity to take care about the moisture loss during transit.

**6. Handling during loading-unloading**

During entire supply chain loading and unloading mainly takes place at following stages:

- ✓ At field
- ✓ At pack house
- ✓ At wholesale market

- ✓ At retail market

Following care is required while loading and unloading of produce:

- ✓ Care should be taken that all the packs should be gently placed on the transport vehicle
- ✓ While loading and unloading packs should not be thrown
- ✓ Hooks should be avoided for picking the bags and crates
- ✓ Torn bags and broken crates should not be used
- ✓ Different grade packages should be kept separately

**7. Handling during transportation**

Post-harvest handling is the ultimate stage in the process of producing quality fresh fruits/vegetables/flowers for market or storage. Getting these unique packages of water (fresh produce) to the point of retail or safely into store with the minimum of damage and exposure to disease risk must be a priority for all growers. Much damage is done to fresh produce during transport and growers should take all necessary remedial measures to ensure that produce leaving the field/firm for markets / storage arrives in the same condition as it left the field or the firm.

All transport vehicles should be checked for following before loading the produce:

- ✓ Cleanliness - The vehicle should be well cleaned before loading
- ✓ Damage - Walls, floors, doors, and ceilings should be in good condition

- No sharp object should be there inside the vehicle.

- ✓ Temperature and humidity control – For refrigerated transport temperature, humidity and air circulation should be checked before loading.

Following care should be taken during transportation of fruit and vegetables:

- ✓ Transport vehicle loaded with fresh produce should be driven safely as driving too fast on fields, rough farm tracks or the highway will cause compression damage to produce.
- ✓ Containers, bulk bins or sacks should be loaded onto transport carefully and in such a way as
  to avoid shifting or collapse of the load during transportation.
- ✓ Bulk loads or open top containers traveling long distances should be covered with
- ✓ Hessian/shade net/plastic to prevent excessive dehydration.

- ✓ Transport loaded with vegetables should not remain grounded (halted) for long periods, as this causes excessive heat build-up and will accelerate the onset of breakdown, cause condensation and make produce more vulnerable to diseases. If fresh vegetable deliveries are delayed, vehicles should preferable be placed with covers removed/ in a covered open sided building or at least in the shade.
- ✓ In wet weather however loads of vegetables destined for storage should be covered to protect the produce from getting wet as the first priority.
- ✓ Supervision is needed at all stages of field transport to minimize the accumulation of physical injuries.
- ✓ Nobody should be allowed to sit on top of the loaded packs inside the vehicle.

Following type of damages takes place to the produce during transportation:

- ✓ Impact bruises occur when packs are dropped or bounced.
- ✓ Compression bruises results from stacking of overfilled field containers.
- ✓ Vibration bruises may occur when fruits move or vibrate against rough surfaces of other fruit during transport.

Machinery used during transportation at the filed

Machineries like Field fork lift system, Trailer system and gondola system are used in transportation of horticultural produce at the field level in Peach, citrus, apple, plum and prune orchard

**8. Handling at wholesale market**

At wholesale market produce may get damage at the following stages:

- ✓ Unloading – Handle gently
- ✓ Storage - store in cool, clean and shaded place
- ✓ Loading for retail dispatch

**9. Handling of produce at retail market**

- ✓ It should be ensured that produce is unloaded at the shop with proper care
- ✓ After unloading only required quantity of produce should be displayed in the shop for sale

Display of large quantity produce not only reduce the shelf life of produce, it gives customer a opportunity to pick and choose from a large lot, which results in loss of freshness/luster and damage of the produce by customers touching and mis-handling. Normally the harvested produce stays at retail market for longer duration. Therefore, special care is required to store and protect the produce from mishandling by the customers.

- ✓ Produce which is not kept on display should be stored only in polythene bags or in wet gunny sacs to maintain its freshness.
- ✓ Periodic water spray on leafy items helps in maintain the quality for longer period or centralized air conditioned shop.
- ✓ Customers should not be allowed to break/put pressure, squeeze or damage the produce during sale.

**10. Handling at customer end**

Last person to handle the produce in entire supply chain is consumer. When customer purchases the fruit, vegetables and flowers, lot of damage is already taken place, sometimes this damage is not visible at the time of purchase, but develop within few hours of purchase. Visibility of any damage to the produce itself is an indication that produce should be consumed as early as possible to avoid further deterioration. Users who have refrigeration facility may buy 3-4 days requirement at a time.

At low temperature if produce stored in following manner it can be kept fresh for a longer period:

- ✓ Green leafy vegetables - wrap in wet cloth and store.
- ✓ Beans, Brinjal, Cauliflower, Cabbage, Radish, Carrot, Chilli, Capsicum and rooty vegetables

– keep in polythene bag and store. Before keeping in bag extra moisture should be removed.

- ✓ Apple, Guava, Onion and Garlic should be avoided along with other vegetables due to their typical flavor/aroma.

***Tips for handling fruit and vegetables:***

- ✓ Pick all the fruits very gently with thumb and middle finger only
- ✓ Never press any fruit and vegetable (Any damage to produce due to bad handling is not visible but damage occurs; however, it develops over a period of time.)
- ✓ Do not pick banana from the body; Pick them by stem only
- ✓ Do not pick leafy vegetables by the leaf end; Pick them from stem only

- ✓ Do not press citrus fruits; It damage oil cells present on skin and turn brown after some time
- ✓ Do not press ripe fruits like sapota, banana and mango *etc*. to check the ripening

Examples for checking ripeness

- ✓ Papaya – Punch the body with fine needle, if thick milk secretion comes it is unripe, if watery substance comes out it is ripe
- ✓ Sapota – Place in your full hand and feel the ripening with slight pressure
- ✓ Mango- Press the mango from its beak.; if it hard it is unripe, if it takes pressure/smooth, it is ripe

Growers should follow basic principles when handling fresh produce:

- ✓ All labor engaged in handling and transporting fresh produce should be trained
- ✓ All cut produce, such as cabbage/others should be kept away from being placed in contact with soil
- ✓ Remove or minimize the effect of all likely damage points from within the handling system
- ✓ Use methods of padding or cushioning when first filling containers or transport to minimise the risk of bruising or scuffing of produce
- ✓ Make certain that vegetables being transferred from one point to another during harvesting or grading and sorting, that they suffer the absolute minimum of drop
- ✓ Protect harvested produce from the debilitating effect of sun, wind and rain each of which cause problems specially to crops destined for long term storage.

## 9.2. Methods of Extending Shelf Life of Horticultural Produces

### A. Pre-cooling:

Pre-cooling refers to removal of field heat (quick cooling) after harvest; if not, its deterioration is faster at higher temperature of 1 hour at 320C = 1day at 100C or 1 week 00C. The entire products must be pre-cooled as early as possible to the recommended storage temperature and relative humidity. Pre-cooling is done just above chilling and freezing temperature.

Advantages of pre-cooling:

- ✓ It removes the field heat
- ✓ Reduces the rate of respiration and ripening
- ✓ Reduces the production of ethylene
- ✓ Reduces /inhibits the growth of spoilage organisms

- ✓ Reduces the loss of moisture
- ✓ Eases the load on the cooling system (refrigeration) of transport or storage chamber
- ✓ Reduce bruise damage during transits
- ✓ Above factor helps in extends the product shelf life

Pre cooling depends on the following factors:

- ✓ Air temperature during harvesting (during summer pre-cooling time is more)
- ✓ Time between harvest and precooling
- ✓ Nature of the crop (High perishable crop require immediate pre-cooling)
- ✓ Difference in temperature between the crop and cooling medium
- ✓ Nature/Velocity of the cooling medium
- ✓ Rate of transfer of heat from the crop to the cooling medium.
- ✓ Type of package material used – Use of water proof ventilated boxes for good air circulation in the room is helpful. Plastic boxes/ fiber board cartons which have been treated with wax will render them water proof.

Choice of pre-cooling method depends:

- ✓ on the nature of the produce
- ✓ economics of the process

***Mechanism of pre-cooling -*** Conduction and convection are the two main heat-transfer mechanisms used for cooling of produce. With conduction, the heat is transferred within a produce to its coldest surface. This is direct movement of heat from one object to another by direct methods (from fresh produce to water or warmer to cooler).

With convection, the heat is transferred away from the surface of the produce via a cooling medium such as moving water or air. Potatoes/ apples/cauliflower/orange and other fruits (bigger mass and lesser surface area) and vegetables require more time to pre-cool than produce which is having smaller mass and large surface area like lettuce/green onion/ carrot tops/peas/corn/brussel sprouts. This is because of the heat from the inside of the crop has to move to the surface before it is transferred in bigger produce.

The rate of cooling depends on individual volume and the exposed surface of product. The difference in temperature between product and the refrigerating medium also needs to be taken into account. For example: large exposed surfaces, leafy vegetables cool almost

5 times faster than large fruit such as melons (more volume, less surface).

Heat with in the crop comes in two ways:

**1. Through the convection from the surrounding air** mainly from the sun in the form of radiation

Eg.: Crop harvested in the early morning will be cooler, since the sun has not been able warm the surrounding air or crop and lower metabolic heat.

**2. From the metabolic heat from chemical reactions** within the crop (respiration)

When the heat is removed by way of evaporative cooling then the fresh produce must not be sealed in moisture proof film like polyethylene bags.

***Pre-sorting -*** Pre-sorting of produce is usually done to eliminate injured, decayed and other unwanted produce before cooling and handling. Pre-sorting will save energy in that culls will not be handled.

Types of pre-cooling methods:

A. Cold air – i. Room cooling; ii. Forced air cooling (presser cooling)

B. Cold water / Hydro cooling

C. Top icing – direct contact with ice

D. Evaporation of water from produce – i. Evaporative cooling; ii. Vacuum cooling

E. Hydrovac cooling – combination of hydro and vacuum cooling

**Commodity –wise cooling methods**

| Cooling methods | Commodities |
|---|---|
| Room cooling | All fruits and vegetables |
| Forced air cooling | Fruits and fruits type vegetables, tubers and cauliflowers |
| Hydro cooling | Stems, green leafy vegetables, fruits and fruit type vegetables |
| Package icing | Roots, stems, cauliflowers, green onion, brussel sprouts |
| Vacuum cooling | Stems, Leafy and flowers type vegetables |
| Transits cooling<br>-Mechanical | All fruits and vegetables |

**B. Room cooling**

- ✓ In room cooling, heat is transferred slowly from the mass of the produce (by convection) to the cold air being circulated around the stacked containers.
- ✓ This is most common and widely used method. Here cold air is passed from the fan and cool by convection process.
- ✓ Its commonest use is for products with relatively long storage life and marketed soon after harvest.
- ✓ Advantages of this room air-cooling are that produce can be cooled and stored in the same room without the need of transfer and hence it is economical.
- ✓ Under this system, cold air from evaporator enters the room, moves horizontally and then passed through the produce containers and return to the evaporator.
- ✓ Disadvantage - It takes more time to cool the products- the removal of heat slowly makes this system unsuitable for highly perishable commodities. This is because the product needs at least 24 hours to reach the required storage temperature.
- ✓ Almost all crops are suitable for this type of cooling but it is mainly used in citrus fruits, potato, onions, garlic, citrus etc.

**C. Hydro cooling**

Principle - 'the transmission of heat from a solid to a liquid is faster than the transmission of heat from a solid to a gas'. i.e. water is better heat conductor than air.

In this method cold water is used for quick cooling of a wide range of fruit and vegetables. Hydro cooling avoids water loss and may even add water to the fruit. Under this method, water is usually cooled by mechanical refrigeration, but ice may be used to make process faster. Chlorine (150-200ppm)/Iodine/Nutrients/Growth regulators/ Fungicides can be added in water to sanitize/ improve nutrient status and prevent post harvest diseases of the produc. For quick cooling of the produce, cold water must constantly be passed over the crop. This can be done by submersing the crop in cold water which is constantly being circulated through a heat exchanges.

**Cooling time -**

- ✓ 2 min for asparagus(long & narrow) & Leafy vegetables (more surface to volume ratio)
- ✓ 10 minutes for small produce like capsicum (large and globular)/ cherries/tomato
- ✓ up to 1 hour for large products such as melons.

Hydro-cooling has the advantage over the pre-cooling method where it helps in cleaning the produce, provides fast, uniform cooling for commodities. It is faster than forced air cooling. Hydrocooling can be achieved by immersion or through means of a chilled water shower. Not all crops can be hydrocooled, because they need to be able to tolerate wetting, chlorine, and water infiltration.

**Disadvantage -**Tank water can be contaminated with microorganisms which can result in increased levels of spoilage during subsequent storage or marketing so chlorine should be added to avoid the problems.

***Two types of hydro coolers are generally used:***

1. **Shower/ batch type -** The water showers over the commodity, which may be in bins or boxes, or loosen a conveyer belt. A common design is to transport the crop on a perforated conveyer belt (the speed of the conveyer can be adjusted to the time required to cool the crop) and cold water is pumped from the tank and allowed to fall on the produce in sprinkled type and then falls through to the tank below then filtered, recycled and re cooled (Fig.3).

Efficient cooling depends upon adequate water flow over the product surface. For product in bins or boxes, water flows of 75-100 lt. /min./ft. (400-600 l/min/m2) of surface area are generally used.

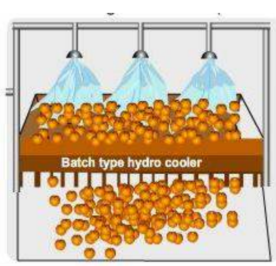



Fig.: Shower/Batch type hydro cooler

**2. Immersion type –** It is simplest type of a hydro-cooler in which produce is dipped in cold water. Here product are normally in bulk, is in direct contact with the cold water as it moves through a long tank of cold. This method is best suited for products that do no float, because, slow cooling would result if the product simply moved out of the water. Immersion hydro coolers convey product against the direction of water and often have a system for agitating the water. Depth of the water tank should be >30 cm and water tends to penetrate inside fruits, particularly those that are hollow such as peppers. Water temperature also contributes to infiltration. It is recommended that fruit temperature is at least 50C lower than liquid.

Eg.: Radish, Asparagus, Artichoke, Green onion, capsicum and leafy vegetables.

Crops normally hydro cooled (see below table)

| | | | |
|---|---|---|---|
| Artichoke | Carrot | Kiwifruit | Potato(early) |
| Asparagus | Cassava | Kohlrabi | Pomegranate |
| Beet | Celery | Leek | Radish |
| Belgian endive | Chinese cabbage | Lima bean | Rhubarb |
| Broccoli | Cucumber | Orange | Snap beans |
| Brussels sprouts | Eggplant | Parsley | Spinach |
| Cantaloupe | Green onions | Parsnip | Summer squash |
| Cauliflower | J. artichoke | Peas | Sweet corn |

**D. Forced air cooling or pressure cooling**

- ✓ In this system ‘cold air is passed by force from one side to other side using big fan’.
- ✓ Cold air movement is through the containers rather than around the containers.
- ✓ Cooling is 4 to 10 times more rapid than room cooling and its rate depends on airflow and the individual volume of produce
- ✓ Air is blown at a high velocity leading to desiccation of the crop. To minimize this effect, air is blown through cold water sprays.
- ✓ It is slow compared to hydro cooling but is a good alternative for crops requiring rapid heat removal which cannot tolerate wetting or chlorine of cooling water.
- ✓ Adequate airflow is necessary. This is because fruits in the center of packages tend to lose heat at a slower rate, compared to those on the exterior.
- ✓ This system is also called as high humidifier. High RH of 90 - 95% is to be maintained in the pre-cooler to avoid dehydration during cooling.
- ✓ This system can be applied to all crops particularly berries, ripe tomatoes, bell peppers and many other fruits, cabbage, green peas, cucumber, brinjal, muskmelon, watermelon and mushroom.
- ✓ Leafy vegetables: 1 – 2 hrs. cooling at 6 - $8^0$C (too low temperature causes chilling injury)

Fig. Forced air cooling (High humidifier)

Difference between Forced air cooling and Vacuum cooling

| Forced air cooling | Vacuum cooling |
|---|---|
| The air passes over the surface of the crop, cooling the outside while the inside is cooled by heat transfer from inside to the outside for the crop. | In cooling chamber, pressure (reduced) is exactly the same around the produce and in the centre of the produce. This means the cooling is very even and quick throughout the crop. |

Crops usually pre-cooled by forced air (See table below)

| | | | |
|---|---|---|---|
| Anona | Citrus | Litchi | Plantain |
| Avocado | Coconut | Mango | Pomegranate |
| Banana | Cucumber | Mangosteen | Prickly pear |
| Barbados cherry | Eggplant | Melons | Pumpkin |
| Berries | Fig | Mushrooms | Rhubarb |
| Breadfruit | Ginger | Okra | Sapota |
| Brussels sprouts | Grape | Orange | Snap beans |
| Cactus leaves | Grapefruit | Papaya | Strawberry |
| Capsicum | Guava | Passion fruit | Summer squash |
| Carambola | Kiwifruit | Persimmon | Tomato |
| Cassava | Kumquat | Peas | Tree tomato |
| Cherimoya | Lima bean | Pineapple | Yam |

**E. Top icing**

- ✓ This is one of the oldest ways to reduce field temperature.
- ✓ It is commonly applied to boxes of produce by placing a layer of crushed ice directly on top of the crop.
- ✓ It can also be applied as an ‘ice slurry’ made from 60% finely crushed ice, 40% water and

- ✓ 0.1% sodium chloride to lower the melting point of the ice.
- ✓ Ice slurry give greater contact between produce and ice compared only top icing, and therefore result in quicker cooling.
- ✓ The main use for top icing is for road transport and it can be applied shortly after harvest.
- ✓ Top-ice on loads should be applied in rows rather than a solid mass. It is important not to block air circulation inside the transport vehicle. Ratios of water to ice may vary from1:1 to 1: 4.
- ✓ Direct contact between the produce and the ice provides fast, initial conduction cooling.

However, as the ice melts, an air space is created between the ice and the produce and the conduction cooling stops. Subsequent cooling is by radiation and convection, both of which are slower processes than conduction.

Package ice can be used only with:

- ✓ during transport to maintain a high relative humidity for certain products
- ✓ water tolerant, non-chilling sensitive products
- ✓ with water tolerant packages such as waxed fiberboard, plastic or wood.

It also increases costs because of the heavier weight for transportation and the need for oversized packages. In addition to this, as water melts, storage areas, containers, and shelves become wet.

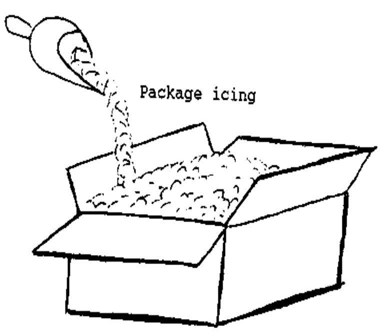



Fig. Package icing of vegetables

Crops suitable for ice cooling

| | | | |
|---|---|---|---|
| Belgian endive | Chinese cabbage | Leek | Sweet corn |
| Broccoli | Carrot | Parsley | |
| Brussels sprouts | Green onions | Pea | |
| Cantaloupe | Kohlrabi | Spinach | |

**F. Vacuum cooling**

- ✓ Vacuum cooling takes place by water evaporation from the product at very low air pressure (At a normal pressure of 760 mmHg, water evaporates at 100ºC, but it does at 1ºC if pressure is reduced to 5 mmHg.).
- ✓ Most rapid and uniform methods of cooling. Products that easily/rapidly release water may cool down rapidly.

Eg.: Most suitable - Leafy vegetables, cabbage

Not suitable - Tomato with low ratios between mass and surface area and effective water barrier like wax on surface is not suitable.

- ✓ Produce is placed in a strong, airtight, steel chamber. Moisture loss is achieved by pumping air out of the chamber containing the product and reducing the pressure of the atmosphere around the product. It causing the water in the produce to vapourize. Cooling occurs because the heat energy for vapourization comes from the produce.
- ✓ Vacuum cooling causes about 1% product weight loss for each 50 of cooling.
- ✓ This method is also used to cool the products like beans, carrots, capsicum, celery, corn, lettuce, mushrooms, spinach, sweet etc.
- ✓ High cost and sophistication operation needed.

Crops that can be vacuum cooled (see table below)

| | | | |
|---|---|---|---|
| Belgian endive | Celery | Mushrooms | Swiss chard |
| Brussels sprouts | Escarole | Snap beans | Watercress |
| Carrot | Leek | Peas | |
| Cauliflower | Lettuce | Spinach | |
| Chinese cabbage | Lima bean | Sweet corn | |

Fig. View of room cooling Forced air cooling Vacuum cooling

Tips to increase pre cooling- efficiency

- ✓ Pre cooling should be done as soon as possible after harvest.
- ✓ Harvesting should be done in early morning hours to minimize field heat and the refrigeration load on pre cooling equipment.
- ✓ Harvested produce should be protected from the sun with a covering until they are placed in the pre cooling facility.

Precautions

- ✓ Since most tropical produce are sensitive to chilling injury, care must be taken not to precool or store the produce below the recommended temperature.
- ✓ All produce is sensitive to decay. Precooling equipment and water should be sanitized continuously with a hypochlorite solution to eliminate decay producing organisms.
- ✓ Care also must be taken not to allow produce to warm up after precooling.

Condensation on pre cooled produce surfaces at higher air temperatures also spreads decay.

### 9. 3. Fruit coating - waxing

Fruits and vegetables have a natural waxy layer on the whole surface (excluding under- ground ones). This is partly removed by washing. Waxing is especially important if tiny injuries and scratches on the surface of the fruit or vegetable are present and these can be sealed by wax.

Waxes - are esters of higher fatty acid with monohydric alcohols and hydrocarbons and some free fatty acids.

Waxing generally reduces the respiration and transpiration rates, but other chemicals such as fungicides, growth regulators, preservative can also be incorporated specially for reducing microbial spoilage, sprout inhibition etc. However, it should be remembered that waxing does not improve the quality of any inferior horticulture product but it can be a beneficial in addition to good handling.

A protective edible coat on fruit and vegetable which protect them from transpiration losses and reduce the rate of respiration is called 'waxing'.

Skin coating (Protective coating) - is defined as artificial application of a very thin film of wax or oil or other material to the surface of the fruits or vegetables as an addition to or replacement for the natural wax coating.

**Advantages of wax application are:**

- ✓ Improved appearance
- ✓ Reduced PLW - reduced moisture losses and retards wilting and shriveling during storage
- ✓ Reduced weight loss
- ✓ Prevents chilling injury and browning
- ✓ Protect produce from bruising
- ✓ Reducing respiration rate - by creating diffusion barrier between fruit and surrounding as a result of which it reduces the availability of O2 to the tissues.
- ✓ Protects fruits from micro-biological infection
- ✓ Considered a cost effective substitute in the reduction of spoilage when refrigerated storage is unaffordable.
- ✓ Carrier agent - used as carrier for sprout inhibitors, growth regulators and preservatives.
- ✓ Increase in the shelf life

  Eg. Mango fruits treated with wax emulsion containing 8 to 12% solids have one or two week's.

- ✓ longer storage life than the untreated ones.

**Disadvantage:**

- ✓ Development of off-flavor if not applied properly.
- ✓ Adverse flavor changes have been attributed to inhibition of $O_2$ and $CO_2$ exchange thus, resulting in anaerobic respiration and elevated ethanol and acetaldehyde contents.

**Specifications of a desirable wax**

- ✓ The selected wax material should provide a lasting shine
- ✓ Must be manufactured from food grade materials
- ✓ It should not develop any off-flavor and resistant to chalking. This can be determined by cooling waxed fruit to 0°C and allowing moisture to condense on fruit on removal from cold room
- ✓ It should reduce weight loss of commodity by 30% to 50%
- ✓ Rapid drying, competitive price and easy clean up

**How fruit coating works?**

Fruit coating results in the restriction of the gas exchange between the fruit and surrounding atmosphere. This causes a builds up of $CO_2$ and a depletion of $O_2$ with in the fruit, thus causing an effect similar to CAS (controlled atmosphere storage).

If surface coatings and their concentration are not selected properly, the respiratory gas exchange through fruit skins is excessively impaired leading to development of off-odours and off-flavours. Over waxing also results in abnormal ripening and softening that affects the marketing of such fruits.

Fruit coatings can be formulated from different materials including lipid, resins, polysaccharides, proteins, and synthetic polymers. Most coatings are a composite of more than one film with the addition of low molecular weight molecules such as polyols, that serve as plastisizers (increase the plasticity or fluidity of the material). Otherwise, coatings can be too brittle and will flake or crack on the coated product. Surfactants, antifoaming agents, and emulsifiers are also often used in coatings.

**Fruits suitable for waxing:**

***Immature fruit vegetables -*** cucumbers and summer squash

***Mature fruit vegetables -*** eggplant, peppers and tomato, potato, pumpkin, carrot, snake gourd, coccinia and capsicum

***Fruits*** – apple, avocado, banana, citrus (orange, mandarin, lemon, grapefruit), guava, mangoes, melons, papaya, peaches, pine apple etc.

Food grade waxes are used to replace some of the natural waxes removed in washing and cleaning operations, and helps in reducing loss during handling and marketing. If produce is waxed, the wax coating must be allowed to dry thoroughly before further handling.

**Types of Waxing:**

***A. Natural waxing***

On the plant when fruit attains desired stage of maturity, nature provides them with thin coat

of whitish substance, which is called bloom or natural waxing. Natural coat is clearly visible on fruits and disappears after harvest due to repeated handling of fruit.

Ex: apple, pear, plum, mango and grapes.

***B. Artificial waxing***

To Prolong the shelf life of produce some of the fruit and vegetables are dipped in a wax emulsion and then dried for few minutes. This process provides thin layer (<1 μ) of artificial wax on skin of the produce by which the small pores present on the skin are fully covered and reduce the transpiration and respiration process resulting in increased shelf life. Artificial wax also provides good shining and luster to the produce, which increases its market value. Artificial waxes like solvent waxes, water waxes and paste or oil waxes are used.

**List of commercial waxes**

| | **Waxes** | |
|---|---|---|
| 1 | Shellac | |
| 2 | Carnauba wax | |
| 3 | Bee wax | |
| 4 | Polyethylene | 12% used in Israel for Mango |
| 5 | Wood resins | |
| 6 | Paraffin wax | |

**Methods of wax application**

Performance of waxing depends on method of application. Amount of wax applied and uniformity of application are extremely important. Fruits should be damp dry prior to wax application to prevent dilution. Waxes should never be diluted with water. The following methods are commonly used.

1**. Spray waxing:** This is most commonly used method. Fruits and vegetables which move on the roller conveyor are sprayed with water-wax emulsion. The waxed produce is dried in a current of air at 55°C. There are two types of spray waxing namely low pressure spraying and high pressure atomizing.

**2. Dipping:** Here fruits are dipped in water wax emulsion of required concentration for 30 to 60 seconds. The fruits or vegetables could be waxed by keeping them in wire boxes holding about 100 fruits (30 kg) and dipping in 30 litre capacity tank containing wax emulsion. The fruits are then removed and allowed to dry under electric fan or in the open air or with warm air at 54 to 55°C. The produce should be turned periodically while drying.

**3. Foam waxing:** Foaming is a satisfactory means of application because it leaves a very thin coating of wax on the fruit after the water has evaporated. A foam generator is mounted over a suitable brush head, and water is applied to the fruit or vegetable in the foam of foam. Spraying tends to waste wax, but it can be recovered in catch pans.

**4. Flooding:** Flooding is similar to dipping and is a safe and convenient method of application.

***Trade name of some extensively used waxes***

- ✓ Citrashine@ from DECCO, India UPL
- ✓ Waxol -12 – Oil/ water-emulsion wax containing 12% solids
- ✓ Tal-Prolong
- ✓ Semper fresh
- ✓ Frutox - Emulsion of different waxes with 12 % solids.

**Table:** Use of wax concentration on the fresh produce

| Conc. Wax (%) | Commodity |
|---|---|
| 12 | Carrot, brinjal, snake gourd, potato, cucumber, coccinia, capsicum, ribbed gourd, pine apple, guava and papaya |
| 09 | Tomato, lime, orange |
| 08 | Apple |
| 06 | Mango and musk melon |

**Table:** Quantity of wax emulsion at 12% concentration required for one mt. of commodity

| Item | Wax emulsion (12%) in L |
|---|---|
| Orange | 3.6 |
| Mosambi | 5.4 |
| Mango(300-350gm) | 3.6 |
| Potato | 7.9 |
| Apple | 5.4 |
| Guava | 5.7 |
| Tomato | 5.0 |
| Banana | 3.0 |
| Lime | 9.0 |

**Coloring waxes -** Dyes are sometimes added to waxes for greater consumer appeal, it is being used on red variety of Irish potatoes, sweet potatoes, and other vegetables.

They enhance the color to give the same shade or tint as when the roots were freshly dug.

In citrus fruits, dye has been approved for general use. Eg. 1-2 (2,5-dimethoxy phenylazo)-2-napththol with an established tolerance of 2 ppm.

**Astringency removal:**

Astringency is the dry, puckering (to gather something around the lips) mouth feel caused by tannins found in many fruits such as red grapes, blackthorn, quince, persimmon fruits, and banana skin.

**Why we feel astringent?**

The tannins denature the salivary proteins, causing a rough sand papery sensation in the mouth. It coagulates the viscous protein on the surface of our tongues, we feel its astringency. Astringency tastes unpleasant to many which tend to avoid eating astringent fruits.

Astringent is Latin word meaning ‘to bind fast’.

Astringency occurs in many fruits due to the presence of tannins. These can impart an unpleasant flavor and are associated with immature fruit. In banana, tannins polymerise as the fruit ripen and lose their astringency.

Varieties of fruits high in phenolics (phenols have no particular taste charterstics, except astringency of condensed flavor and bitterness in some of the citrus falvonoids) are more astringent than varieties with low in phenolics.

Eg. Red grapes (var. Cabernet Sauvignon) have high astringency than white grape.

During maturation, the condensation of phenolics continuously increases and at the same time the astringency decreases, perhaps because highly condensed flavans are less soluble and tightly bound to other cell components.

How to reduce astringency?

Treatment with high levels of $O_2$ and spraying with alcohol (ethanol) is used to reduce the astringency.

Eg.

1. Storage of persimmon in 4% $CO_2$ at -10C for about 2 weeks before removal from the storage followed by 6-18 hours in 90% CO2 at 170C removes the astringency.

2. Spraying persimmon fruit with 35 - 40% ethanol @ 150-200 ml per 15 kg of fruit is known to remove the astringency 10 days later in the ambient storage. This treatment takes much longer time than CO2 treatment, but fruits quality is better.

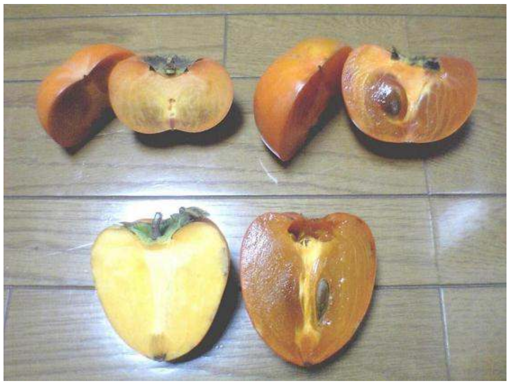


Fig. Cut persimmon fruits (the upper left and right cut pieces are non-astringent as for an unripe persimmon and a mellowed persimmon, and lower left and right are the astringent of an unripe persimmon and a mellowed persimmon).Source-http://en.wikipedia.org/wiki/Persimmon

**9.4. Irradiation**

Radiation can be applied to fresh fruits and vegetables to control microorganism/insects/parasites and inhibit or prevent cell reproduction and some chemical changes. It can be applied by exposing the crop to radioisotope in the form of gamma-rays but X-rays can also be used from the machine which produces a high energy electron beam.

**Unit of measurement**

Radiation doses are measured in Grays (Gy). One Gray = 100 rads.

One Gy dose of radiation is equal to 1 joule of energy absorbed per kg of food material. In radiation processing of foods, the doses are generally measured in kGy (1,000 Gy).

Radiation helps in breaking the chemical bonds in the produce or microorganism.

***Ionizing radiation*** involves damage to DNA, the basic genetic information for life. Microorganisms can no longer proliferate and continue their harmful or pathogenic activities. Insects do not survive, or become incapable of proliferation. Plants cannot continue the natural ripening or aging process.

**Cobalt 60** is commonly used as a source of gamma-rays in food irradiation. Radioisotopes cannot be switched on or off so they are immersed in a pool of water to allow operators to enter the processing area. When food is to be irradiated the radioisotopes is raised out of the water and material to be irradiated is usually passed through radiation field on the conveyer belts. The whole processing area is surrounded by thick concrete to prevent the radiation out.

**Advantages of Irradiation**

- ✓ Reduce the spoilage
- ✓ Slowing down the rate of metabolism in the produce
- ✓ Delay ripening and senescence
- ✓ Controlling sprouting in potato, onion, garlic and yams – 0.05-0.3 kGy
- ✓ Extend shelf life of fresh produce
- ✓ Insect and parasite disinfestations- egg phase is most sensitive followed by larval, pupal and adult stages. Most insects are sterilized at doses of 0.1 -1.0kGy. And survived adults progeny are sterile.

Eg. Irradiation is being is used in Australia to produce sterile male Queensland fruits flies and in Hawaii it is being used in papaya for papaya fruit fly

**Factors effecting radiation of the produce**

Moisture content in foods and the surrounding environment during treatment influence the sensitivity of microorganisms to irradiation.

Eg. high RH and high water content in foods reduce the effectiveness of irradiation. Ultraviolet lamps are sometimes used in refrigerated storage for the control of bacteria and moulds.

**Dosage**

In general, most vegetables can withstand irradiation dosages up to a maximum of 2.25 kGy; higher doses can, however, interfere with the organoleptic properties of food products. Combining irradiation + temperature control + gaseous environment + adequate processing conditions is one of the most effective approaches to vegetable preservation.

N.B. The maximum absorbed dose delivered to a food should not exceed 10 kGy.

Fig. Logo used to show a food has been treated with ionizing radiation

Table.: Desirable effects and dose of irradiation on fresh produce

| Commodities | Dosage (kGy) | Effect |
|---|---|---|
| Apple | 1.5 | Control scald and brown core |
| Apricot and peach | 2.0 | Inhibit brown rot |
| Asparagus | 0.05 - 0.1 | Inhibit growth |
| Avocado, banana, | 0.025 - 0.75 | Delay ripening |
| Avocado, banana, | 1-3 | Inhibit mould |
| Mushroom | 2.0 | Inhibit stem growth and cap |
| Papaya | 0.25 | Disinfect fruit fly |
| Potato, onion, yams | 0.05 - 0.3 | Controlling sprouting |
| Strawberries, mushrooms, onion | 2 - 3 | Reducing the decays |
| Shredded carrots | 2.0 | Inhibited the growth of aerobic |
| Grapes | 0.25-0.50 | Inhibit grey mould |
| Tomato | 3.0 | Inhibit Alternaria rot |
| Mango, dried fruits | 0.25 - 0.75 | Insect disinfestation |
| Garlic, Ginger | 0.03 - 0.15 | Sprout inhibition |

**9.5. Dressing**

- ✓ Removal, trimming and cutting of all undesirable leaves/ stem/ stalks/ roots/ other non-edible or unmarketable parts is called dressing. Dressing makes vegetables attractive and marketable.
- ✓ Trimming is done especially in vegetables and flowers to remove unwanted, discoloured, rotting and insect damaged parts (e.g., cabbage, cauliflower, spinach, lettuce, rose, chyrysanthemum, gladiolus, tuberose etc.) or parts that may favour deterioration or damage during later handling.

In case of grapes, trimming of bunches is done to remove the undersize, immature, dried, split and damaged berries. Trimming and removal of decaying parts are preferably done prior to washing. Trimming enhances visual quality, minimizes water loss and other deteriorative processes. Trimming reduces the likelihood of diseases or their spread, facilitates packaging and handling, and reduces damage for other produce.

**9.6. Sorting sizing and grading**

***Sorting***

Sorting is done by hand to remove the fruits and vegetables which are unsuitable to market or storage due to damage by mechanical injuries, insects, diseases, immature, over-mature, misshapen etc. This is usually carried out manually and done before washing. By removing damaged produce from the healthy ones, it reduces losses by preventing secondary contamination. Sorting is done either at farm level or in the pack-houses. In sorting, only sensory quality parameters are taken into consideration.

***Sizing***

Before or after sorting, sizing is done either by hand or machine. Machine sizers work on two basic principles; weight and diameter. Sizing on the basis of fruit shape and size are most effective for spherical (oranges, tomato, certain apple cultivars) and elongated (Delicious apples and European pears are of non-uniform shape) commodities,

respectively.

**Mechanisms/Types of sizing**

***A. Diverging belts/rope grader -*** the different speed of belts makes produce rotate besides moving forward to a point where produce diameter equals belt/rope separation. Eg. cucumbers, gherkins, pineapples and large root vegetables

***B. Sizing rollers -*** with increased spaces between rollers Eg. Citrus

***C. Hand held template-*** Sizing can be performed manually using rings of known diameter
***D. Sizing by weight -*** sorting by weight is carried out in many crops with weight sensitive trays. These automatically move fruit into another belt aggregating all units of the same mass. Individual trays deposit fruit on the corresponding conveyor belt.

Eg. Citrus, apples and pear and irregular fruits E. Mesh screens - eg, potato, onion, anola etc.

## *Grading*

The produce is separated into two or more grades on the basis of the surface colour, shape, size, weight, soundness, firmness, cleanliness, maturity & free from foreign matter /diseases insect damage /mechanical injury.

Eg. : Apple:

I. Extra Fancy; II. Fancy; III. Standard; IV. Cull (for processing).

Grading may be done manually or mechanically. It consists of sorting product in grades or categories based on weight/size.

**Systems of grading**: Static and Dynamic.

***A. Static systems -*** are common in tender and/or high value crops. Here the product is placed on an inspection table where sorters remove units which do not meet the requirements for the grade or quality category.

***B. The dynamic system -*** here product moves along a belt in front of the sorters who remove units with defects (fig.13). Main flow is the highest quality grade. Often second and third grade quality units are removed and placed onto other belts. It is much more efficient in terms of volume sorted per unit of time. However, personnel should be well trained. This is because every unit remains only a few seconds in the worker's area of vision. Eg. Onion grading

There are two types of common mistakes: removing good quality units from the main flow and more frequently, not removing produce of doubtful quality.

**New Innovation in grading systems**

***1. Computerized weight grader –*** operate on the basis of tipping buckets that drops to release the pre weighed item at a particular position. – Apples, citrus

***2. Video image capture &analysis–*** used for size, color & external defect grading-coffee bean

### 9.7. Sprout Suppressants

Root and tuber type vegetables have dormant period after harvest and then re-grow under favorable conditions.

In potatoes, garlic, onion and other crops, sprouting and root formation accelerate deterioration. This determines the marketability of these produce as consumers strongly reject sprouted or rooted produce.

**Disadvantage of Sprouting**

- ✓ Sprouting makes the produce to lose moisture quickly, shrivel
- ✓ Become prone to microbial infection
- ✓ The quality of sprouted tubers becomes poor due to high respiratory utilization of reserved food.
- ✓ Due to above factors because consumers strongly reject sprouting or rooting products.

**Physiological basis for sprouting**

- ✓ After development, bulbs, tubers and some root crops enter into a rest period.
- ✓ This is characterized by reduced physiological activity with non-response to environmental conditions. In other words, they do not sprout even when they are placed under ideal conditions of temperature and humidity.
- ✓ During rest, endogenous sprout inhibitors like abscisic acid predominate over promoters like gibberellins, auxins and others. This balance changes with the length of storage to get into a dormant period. They will then sprout or form roots if placed under favorable environmental conditions. There are no clear-cut boundaries between these stages. Instead, there is a slow transition from one to the other as the balance between promoters and inhibitors change. With longer storage times, promoters predominate and sprouting takes place.

***Methods of sprout suppression***

**A. Physicals method**

Refrigeration and controlled atmosphere reduces sprouting and rooting rates but because of their costs, chemical inhibition is preferred. Sprouting of potatoes is suppressed at and below 50C and enhanced at higher temperature storage, and in yam no sprouting was observed during 5-month storage at 130C, but tubers sprouted during that period at 150C.

**B. Chemicals methods**

Sprouting can be suppressed by application of growth regulators on the crop. In bulbs, such as onion, this is not possible because the meristematic region where sprouting occurs is deep inside the bulb and difficult to treat with post-harvest chemicals. Therefore, chemicals like Maleic Hydrazide (MH) is applied to the leaves of the crop at least 2 weeks before harvesting, so that chemical can be translocated deep into the middle of the bulb in the meristematic tissue where sprouting is initiated.

***Potatoes*** **-** commercially CIPC (3-chloro –iso-propyl-N phenylcarbamate is also called chloropropham) is applied prior to storage as dust, immersion, vapor or other forms of application as sprout suppressant. CIPC inhibits sprout development by interfering with spindle formation during cell division. However, cell division is extremely important during wound healing or curing period after potatoes have been placed onto storage. Wound healing requires production of 2-5 new cell layers by cell division. CIPC should be applied after wound healing process/suberisation is complete, but before periderm formation. Hence, it must be applied after curing is completed.

Care must be taken not treat seed potato with CIPC and also avoid storing same in place where, already CIPC treated potato has been stored. CIPC is mainly used for the potato stored for processing purpose.

**Ionization methods**

Sprout suppression can also be achieved by irradiating onion bulb, potato and yam tubers.

**Mineral Application**

Deficiencies of certain minerals result in physiological disorders, loss of storage life or quality. Calcium is the nutrient most commonly associated with post-harvest disorders and can be overcome by external application of fruits after harvest by spraying or dipping, vacuum infiltration and pressure infiltration. Advantages of minerals application

Reduce physiological disorder - internal break down/ pitter pit, storage scald etc

- ✓ Calcium chloride (4-6%) dips or sprays for bitter pit in apples.
- ✓ Reduced chilling injury
- ✓ Increase diseases résistance
- ✓ Delaying ripeness - tomatoes, avocados, pear and mango
- ✓ Reduces chilling injury and increase disease resistance in stored fruits
- ✓ Low concentrations of 2.4-D to waxes assists in keeping citrus peduncles green

**Disadvantages**

- ✓ Skin discoloration (at higher concentration)
- ✓ Rotting (at higher concentration)

The pre-harvest spray problem can be overcome by dipping the apple fruit in solution containing calcium salts. Uptake can be enhanced by pressure infiltration to force calcium solution into apple flesh. The best results are obtained with apples that have a closed calyx so that the calcium solution is forced through lenticels and thus spread around the peripheral tissue where the disorder occurs. With open –calyx fruit, the uptake of solution is difficult to control as it readily enter the fruit via the calyx and excess solution accumulates in the core area, often lading to injury or rotting. Vacuum infiltration (250mmHg) of calcium chloride at concentration of 1- 4% is beneficial.

**Guava -** Fruit dipped in 1% solution of calcium nitrate reduces weight loss, respiration, disease occurrence and increased the shelf life for more than 6 days as compared to 3 days in the control at room temperature.

Chemicals used to extend the shelf life and quality of produce

| Commodity | Chemicals | Conc. % |
|---|---|---|
| Apple | Ca | 1 - 4 |
| Mango | Ca nitrate | 1.0 |
| | Ca chloride | 0.6 |
| Ber | Ca | 0.17 |
| Banana | GA3 | 50 ppm |
| | Kinetin | 20 ppm |
| Guava | Ca nitrate | 1.0 |

## 9.8. Growth Regulators

Growth regulators like GA3 are useful in extending the shelf life of some climacteric fruits for short duration and retention of green colour of non- climacteric fruits for longer periods. 2, 4-D is widely used herbicide and can be used to prevent stem end rot development in citrus.

As a postharvest treatment, 2,4-D induces healing of injuries, retard senescence and control post-harvest decay of fruits and vegetables.

### 9.9. Chemical treatment of harvested produce - disinfestation

Succulent nature of fruits and vegetables make them easily invaded by these organisms. The common pathogens causing rots in fruits and vegetables are fungi such as Alternaria, Botrytis, Diplodia, Phomopsis, Rhizopus, Pencillium and Fusarium and among bacteria, Erwinia and Pseudomonas cause extensive damage.

Losses from post-harvest disease in fresh produce can be both quantitative and qualitative. Loss in quantity occurs where deep penetration of decay makes the infected produce unusable. Loss in quality occurs when the disease affects only the surface of produce causing skin blemishes that can lower the commercial value of a crop.

**Disinfestation**

Postharvest diseases of fruits, vegetables and flowers are caused by fungi and bacteria but viruses are rare. These exist either as parasite (on living matter) or saprophytes (dead produce). Most fungi require acidic pH (2.5 – 6) condition in which they grow and develop, while bacteria thrive best at neutral and few can grow at levels below pH 4.5. Bacteria therefore doesn't usually infect fruits, normally but only vegetables and flowers.

Chlorine and sulfur dioxide are most widely used chemicals. Chlorine is probably the most widely used sanitizer. It is used in concentrations from 50 to 200 ppm in water to reduce the number of microorganisms present on the surface of the fruit. However, it does not stop the growth of a pathogen already established.

**Mode of infection of micro organism**

Fungal and bacterial infection can occur through mechanical injuries and cut surfaces of the crop, growth cracks and pest damage. They also infect through natural opening on the surface of the crop such as stomata, lenticels, cuticles and hydrathodes. Most fungi are able to penetrate the intact healthy skin of the fruits and vegetables. Many pathogens remain dormant on the surface of the produce for many weeks before visible symptoms of the infection occur.

**Damage by micro organism**

It mainly causes physical loss of the edible matter, which may be partial or total. Also affects marketability, particularly where mold growth is obvious on the produce surface. In some cases the superficial infection also make the produce either entirely unmarketable or at least reduce its economic value.

Example: Fungi Aspergillus flavus and A. parasitica which produce aflatoxin like mycotoxin on ground nut kernels, coconut, dry beans and some leafy foods. The apples juice is also affected by mycotoxin "patulin" produced by Penicillium patulum and P. expansum, P.urticae, Aspergillus clavatus when stored for too long before being processed. This mycotoxin is carcinogenic and has maximum permitted levels of 50 ppb in fruit juices.

**Disinfestation process can be carried out by:**

***Physical methods -*** low temperature, vapor heat, and irradiation.

**Disinfestation methods:**

**A. Field management:** Growing fruits and vegetable adopting scientific standard and recommended practices can reduce the field inoculum of disease causing pathogens. Adopting standard cultural practices in terms of sanitation, proper nutrition, irrigation and appropriate harvesting time and methods, etc. are known to reduce postharvest diseases.

Use of wind breaks can reduce spread of field infection where wind is the carrier of pathogen. Other practices like cultivation of crops in regions free from diseases, cultivation of disease resistant cultivars, care in harvesting and handling to avoid wounding fruit, fruit bagging for reducing surface wetness and deposition of inoculum will all help in reducing post harvest diseases.

**B. Pre-harvest spraying:** Field sprays with fungicides are known to prevent spore germination and the formation of deep seated infections in the lenticels or in the floral remains of the fruits.

**C. Post-harvest chemical treatments:** Post harvest treatments with fungicides like Thiobendazole and Benomyl have rendered good control of stem end rot in many citrus fruits, anthracnose of banana and mangoes despite the fact that infection occurred long before the treatment was applied.

Safer and less toxic chemicals grouped under the category of GRAS (generally regarded as safe) can be used for the control of post-harvest diseases of fruit and vegetables. These compounds mostly include week organic acids, inorganic salts and neutralized compounds.

It has been reported that extracts of Eucalyptus globula, Punica granatum, Lawsonia inumis, Datura stramonium and Ocimum sp. extracts are effective against various fruits rots. Some vegetable and other oils are also effective against fruit rots. Mustard, castor and paraffin oils have been found effective against Rhizopus rot of mango.

***Disinfection of all handling equipment in pack-houses*** with 1-3% formaldehyde solution, hypochlorite or SOPP (Sodium ortho phenylphenate) will help in prevention of secondary infection. Washing with water alone reduces many disease of fruits and vegetables.

**Methods of Chemical Application**

1. **Dipping –** for effective control of diseases chemical may be used with hot water at 550C

for about 10 min. The crop may be passed below shower of the diluted chemicals. This is

called 'cascade' application. Use of chemical like citric acid to lower the pH of the solution along with fungicides seems more effective.

In pineapple, infection occur commonly through the cut fruit stalk, therefore dipping cut end was found sufficient to control the disease, save pesticides solution and lower residues on the fruits.

Eg. Citrus, apples, pineapple, root vegetables.

2. **Spraying -** Spraying is more effective than dipping, because fungicide effectiveness is reduced if the crop has been washed and is still wet and many pesticide chemicals are formulated so that they are not in a solution , but rather in a fine suspension. This results in a concentration gradient in the tank between top(less concentration) and bottom (more) of the tank unless suspension frequently agitated.

Eg. Citrus, apple

3. **Electrostatic Sprays / Thin film of Coating –** breaking up the pesticides solution into fine droplet and then giving them an electric charge to obtain uniformity of application. Principle is that the particle all have the same electrical charges hence, thus repel each other. These charges are attracted toward the crop and form uniform coating on the produce.

Eg.: Potato and crown rot of banana

4. **Dusting –** with wood ash and lime in case of yam. Fungicides along with talc on potato.

**5. Fumigation / Vapour treatment –** Fumigation is to eliminate insects, either adults, eggs, larvae or pupae and pathogen inoculum. Fumigant such as sulphur dioxide ($SO_2$) is used for controlling post-harvest disease in grapes. This is achieved by placing the boxes of fruit in a gastight room and introducing the gas from the cylinder to the appropriate concentration. This treatment results in a residue of 5-18 ppm $SO_2$ in the grapes is sufficient to control decay.

Its toxicity to Botrytis cinerea was found to be proportional to temperature over the range of 0-300C, where the toxicity of $SO_2$ increased about 1 ½ times for every 100C rise in temperature. In general treatment with 0.5- 1% $SO_2$ for 20 min is found to be effective fallowed by ventilation. During storage, periodic (every 7-10 days) fumigations are performed in concentrations of 0.25%.

**Disadvantages-**

**a.** $SO_2$ can be corrosive, especially to metals, because it combines with atmospheric moisture to form sulphurous acids. Hence, special sodium met- bisulphate impregnated pads are available which can be packed into individual boxes of fruits to gives a slow releases of SO2. Eg Grape guard used in grapes fruit packing.

**b.** At higher concentration it has bleaching effects on black grapes.

**c.** Some people are allergic to $SO_2$, particularly those who have chronic respiratory problems.

**Litchi fruits -** $SO_2$ fumigation at 1.2% for 10 min. is used to prevent discolouration of the skins of fresh litchi fruits caused by fungal infection, followed by 2 min. dip in 1 N HCL stabilizes the red colour and reduces the skin browning.

**Snap beans -** Exposing the beans to $SO_2$ at 0.7% for 30 seconds reduced the broken end dis-coloration due to mechanical injury.

**Other chemicals -**

- ✓ Acetaldehydes fumigation in Sultana grapes @500 ppm for 24hr. control postharvest diseases.
- ✓ Paper pad impregnated with diphenyl fungicides are commonly applied to citrus fruit.
- ✓ Tecnzane, 2-aminobutane(potato) and 2-AB (orange) are the chemicals used.

Fumigation with gaseous sterilants is the most effective techniques for disinfesting produce. However, these are becoming increasingly unpopular or banned because of high mammalian toxicity (hydrogen disulphide), flammability (carbon disulphide) and damage to the atmospheric ozone layer (methyl bromide).

Fumigation with methyl bromide has been replaced by temperature (high and low) treatments, controlled atmosphere, other fumigants or irradiation.

**6. Absorbent paper –** chemical may be absorbed into a pad made of suitable material like paper. This absorbent pad soaked in fungicides like thiabendazole and dried, is placed over cut surfaces, such as cut crown end to control the crown end rot of banana. Here pad absorbs latex from the cut surfaces, which also helps to keep the pad in the position and prevents staining the banana. Potassium aluminum sulphate may be added to the pads, which helps to coagulate the latex. This method is used when banana is dehanded in the field and packed directly into export cartoon, where no washing, spraying or dipping take place. Insecticides like dichlorovos has limited vapour phase activity, therefore dichlorovos based pest strip have been included in cartoon packed with flowers to effects ongoing disinfestations during export.

**6. Cold storage –** many insect pests do not tolerate prolonged exposure to low temperature. Storing the produce at <1.60C for 16 days has been shown to be effective for disinfesting fruits against Mediterranean and Queensland fruit fly. But chilling susceptible fruits are not suitable for this method.

**7. High temperature –** Heat treatments like hot water dips or exposure to hot air or vapor is employed for insect control (and for fungi, in some cases). Using high temperature of about 40-550C for about 15 minutes can be easily disinfected. Generally, high temperatures can cause softening of tissues and promote bacterial diseases.

- ✓ Dipping temperature depends on commodity, insect to be controlled and its degree of development.
- ✓ Dipping in hot water also contributes to reduced microbial load in plums, peaches, papaya, cantaloupes, sweet potato and tomato but does not always guarantee good insect control.
- ✓ Heat treatments is reconsidered as quarantine treatments in fruits such as mango, papaya, citrus, bananas, carambola and vegetables like pepper, eggplant, tomato, cucumber and zucchinis.
- ✓ Temperature, exposure and application methods are commodity specific and must be carried out precisely in order to avoid heat injuries, particularly in highly perishable crops. On completion of treatment, it is important to reduce temperature to recommended levels for storage and/or transport.
- ✓ Many tropical crops are exposed to hot and humid air (40-50 °C up to 8 hours) or water vapor to reach a pulp temperature which is lethal to insects. Hot air is well tolerated by mango, grapefruit, Navel oranges, carambola, persimmon and papaya. Similarly, vapor

treatments have been used for grapefruits, oranges, mango, pepper, eggplant, papaya, pineapple, tomatoes and zucchinis.

- ✓ A common mango fruits disease, anthracnose can be successfully controlled by dipping at 550C for about 5 min.

**8. Biological control –**

- ✓ The yeast Candida guilliermondii is used against Penicillium spp. incorporated into citrus waxes
- ✓ Bacillus subtilis is used against mango anthracnose and stem end rot

Table: List of postharvest diseases of fruits

| Fruit | Disease | Casual organism |
|---|---|---|
| Banana | Crown rot | *Acremonium sp, Curvularia sp, Colletotrichum musae, Fusarium semitectum, Verticillium sp* |
| Ber | Fruit rot | *Alternaria sp, Phomopsis sp, Colletotrichum sp.* |
| Citrus | Black rot | *Alternaria citri* |
| | Grey mold | *Botrytis cinerea* |
| | Green mold | *Penicillium digitatum* |
| | Stem-end rot | *Diaporthe citri, D. medusae, D. natalensis.* |
| Guava | Anthracnose | *Colletotrichum gloeosporioides* |
| Kiwifruit | Stem rot | *Botrytis cinerea* |
| | Ripe rots | *Botryosphaeria dithodea* |
| Litchi | Skin injuries | *Aspergillus sp., Penicillium sp., Rhizopus sp.* |
| Mango | Anthracnose | *Colletotrichum gloeosporioides* |
| | Stem-end rot | *Botryodiplodia theobromae* |

| | | |
|---|---|---|
| | Alternaria rot | Alternaria alternata |
| | Black mold | Aspergillus niger |
| Papaya | Chocolate spot | C. gloeosporioides |
| | Dry rot | Mycosphaerella sp. |
| | Wet rot | Phomopsis sp. |
| | Alternaria spot | Alternaria alternata |
| | Fusarium rot | Fusarium solani |
| | Internal yellowing | Enterobacter clocae |
| | Anthracnose | C. gloeosporioides, C. dematium, C. capsici, C. |
| Pear | Blossom-end rot | Alternaria sp., Botrytis sp., Penicillium sp. |
| Pineapple | Black rot | Chalara paradoxa |
| | Fruitlet core rot | Penicillium funiculosum, Fusarium moniliforme, |
| Pomegranate | Heart rot | Aspergillus niger, Alternaria sp. |
| Stone fruits | Brown rot | Monilinia fructicola |
| Onion | Black mold | Aspergillus spp. Botrytis allii |

Table. Chemicals used to control spoilage and quality in fruit and vegetables

| **Item** | **Chemicals** |
|---|---|
| Apple | Sodium-phenyl phenate |
| Banana | Thio bendazole, Benomyl |
| Citrus | Sodium carbonate, Borax, SOPP, Biphenyl, |
| Mango | Hot water, Benomyl |
| Grapes | SO2 fumigation |
| Papaya | Hot water |
| Pomegranate | Ethyl oleate |
| Potato | Hypo chlorite |
| Carrot & cabbage | Thiobendazole , Benomyl |
| Onion | Benomyl |
| Sweet potato & tomato | 2,6-dichloro-4-nitroaniline |

### 9.10. Post-harvest pests

Although relatively few post-harvest losses of fresh produce are caused by attacks of insects or other animals, localized attacks by these pests may be serious.

- ✓ Insect damage is usually caused by insect larvae burrowing through produce, e.g. fruit fly, stone weevil, sweet potato weevil, potato tuber moth and infestation usually occurs before harvest.
- ✓ Rats, mice and other animal pests again are sometimes a problem when produce is stored on the farm.

Almost all postharvest pests originate from field infestations. Wounds and punctures caused by insect pests not only adversely affect visual quality but also serve as entry points for pathogens, leading to secondary infection and spoilage.

**Table.: List of insect pests affecting postharvest quality**

| Pests | Common name | Common host |
|---|---|---|
| Fruit flies | | |
| *Dacus ciliatus* | Lesser pumpkin fly | Cucurbits |
| *D. cucurbitae* | Melon fly | Cucurbits and tomato |
| *D.dorsalis* | Oriental fruit fly | Most fleshy fruits and vegetables |
| Mites | | |
| *Halotydeus destructor* | Red legged earth mite | Leafy vegetables |
| *Panonchus ulmi* | European red mite | Apple and other deciduous fruits |
| *Phthorimaea operculella* | Potato tuber moth | Potato, tomato, brinjal |
| Mealy bugs | | |
| *Planococcus citri* | Citrus mealy bug | Citrus, grape |
| *Dysmicoccus bevipes* | Pineapple mealy bug | Pineapple |
| Moths | | |
| *Cydia pomonella* | Codling moth | Apple,pear,peach,quince,prunus,walnut |
| *Maruca testulalis* | Beam pod borer | Legumes |
| Scale insects | | |
| *Aonidiella aurantii* | Red scale | Citrus |
| *Lepidosaphes beckii* | Purple scale | Citrus |
| *Quadraspidiotus preniciosus* | San Jose scale | Deciduous fruits |
| weevils | | |
| *Cylas formicarius* | Sweet potato weevils | Sweet potato |
| *Sternochaetus mangiferae* | Mango seed weevils | Mango |

## 9.11. How to set quality standards for fresh produce?

***Procedures of SI (international standards)***

Eg. Quality Standards for Melons.

Regulation 1093/97 of 16 June 1997 for marketing into the European Community.

**I. Definition of produce**

This standard applies to melons of varieties (cultivars grown from *Cucumis melo* L. to be supplied fresh to the consumer, melons for industrial processing being excluded.

**II. Provisions concerning quality**

The purpose of this standard is to define the quality requirements for melons after preparation and packaging.

**A. Minimum requirements**

In all classes, subject to the special provisions for each class and the tolerances allowed, the melons must be:

1. intact,

− sound, produce affected by rotting or deterioration such as to make it unfit for consumption is excluded.

- clean, practically free of any visible foreign matter
- of fresh appearance
- practically free from pests
- practically free from damage caused by pests
- firm
- free of abnormal external moisture
- free of any foreign small and/or taste

The melons must be sufficiently developed and display satisfactory ripeness

2- The development and condition of the melons must be such as to enable them:

- to withstand transport and handling, and
- to arrive in satisfactory condition at the place of destination

**A. Classification**

Melons are classified into two classes defined below:

**Class I**

Melons in this class must be of good quality. They must be characteristic of the variety or commercial type.

The following slight defects however may be allowed provided that these do not affect the general appearance or the produce, the keeping quality, and presentation in the package:

- a slight defects of shape
- slight defects of coloring (a pale coloring of the rind at the point where the fruit touched the ground while growing is not regarded as a defect)

- slight skin blemishes due to rubbing or handling
- slight healed cracks around the peduncle of less than 2 cm in length that do not reach the pulp
- The length of the peduncle, in the case of fruit belonging to varieties that do not separate at the time of ripening may not exceed 2cm for the varieties of Charente's, Ogen and Galia type melons and 5cm for other melons, but must in any case be present and intact.

**Class II**

This class includes melons which do not qualify for inclusion in Class I but satisfy the minimum requirements specified above.

The following defects may be allowed provided the melons retain their essential characteristics as regards the quality, the keeping quality and presentation:

- defects of shape
- defects of coloring (a pale coloring of the rind at the point where the fruit touched the ground while growing is not regarded as a defect)
- slight bruising
- slight cracks or deep scratches that do not affect the pulp of the fruit and are dry
- skin blemishes due to rubbing or handling

**III. Provisions concerning sizing**

Size is determined by the weight of one unit or by the diameter of the equatorial section.

When the size is expressed in terms of weight, the largest melon in each package

may not weigh over 50% more than the smallest.

When the size is expressed in terms of diameter, the diameter of the largest melon may not be over 20% more than the diameter of the smallest.

Sizing is compulsory for both classes.

## IV. Provisions concerning tolerances

Tolerances in respect of quality and size are allowed in each package for produce not satisfying the requirements of the class indicated.

### A. Quality tolerances

**Class I**

10% by number or weight of melons not satisfying the requirements of the class but meeting the requirements for Class II, or, exceptionally, coming within the tolerances for that class. (sometimes 10~ 15%)

**Class II**

10% by number or weight of melons satisfying neither the requirements for the class nor the minimum requirements , with the exception of produce affected by rotting, or any other deterioration rendering it unfit for consumption. (sometimes 10~ 15%)

### B. Size tolerances

For all classes 10% by number or weight of melons not satisfying the size immediately below or above that specified on the package.

## V. provisions concerning presentation

### A. Uniformity

The contents of each package must be uniform and contain only melons of the same origin, variety or commercial type, quality and size and which have reached appreciably the same degree of development and coloring.

The visible part of the contents of each package must be representative of the entire contents.

### B. Packaging

Melons must be packed in such a way as to ensure proper protection of the produce. The materials used inside the package must be new, clean and of a quality such as to avoid causing any external or internal damage to the produce. The use of materials and particularly of paper or stamps bearing trade specifications is allowed provided that the printing or labelling has been done with a non-toxic ink or glue.

The package must be free of all foreign matter.

**VI. Provisions concerning marking**

Each package must bear the following particulars in letters grouped on the same side, legibly and indelibly marked and visible from the outside:

**A. Identification**

Packer and or dispatcher. Name and address or officially issued or accepted code mark

**B. Nature of produce**

"Melons" if the contents are not visible from the outside. Name of the variety or commercial type (e.g. Charentais)

**C. Origin of produce**

Country of origin and, optionally district where grown or national, regional or local place name.

**D. Commercial specifications**

Size expressed either by minimum or maximum weight or minimum and maximum diameter

Number of units (optional)

**E. Official control mark (optional)**

(1) However, a small healed scar caused by automatic measurement of the refractometric index is not regarded as a defect.

(2) The refractometric index of the pulp must be at least 8% measured at the middle point of the fruit flesh at the equatorial section.

**WORKING MANUAL ON POSTHARVEST ASPECTS OF SOME COMMON FRUITS , VEGETABLES, ROOTS AND TUBERS.**

**A PRACTICAL EXAMPLE**

## HARVEST AND POST-HARVEST HANDLING FOR SELECTED FRUITS, VEGETABLES ROOTS AND TUBERS

## 1. Avocado

Latin name: *Persea mericana* L.

The fruit is pear shaped, oval or nearly round. It has a skin which may be yellow-green, deep green or reddish-purple, depending on the variety. Avocadoes will not ripen while they are still attached to the tree; flesh rancidity and browning may develop if they are left too long on the trees. Homeowners usually consider the crop pickable when a few mature (fully grown) fruits have fallen. This is not a dependable guide because the prolonged flowering of the avocado results in fruits in varying stages of development on the tree and at the same time.

### 1.1. Harvesting

**Harvesting maturity**. Avocadoes ripen only after they are picked and may need up to 10 days to ripen at room temperature. Indication of maturity, depending on variety, is a combination of size, smoothness of the skin and loss of sheen. Determining the proper harvest maturity is difficult: experience is necessary. Fruits grown on the same tree vary in expected maturity dates. Ready fruits are usually picked at weekly intervals for a month or more, the largest fruits being selected each time. Harvested immature fruits will fail to ripen, shrivel rapidly and show rapid decay.

**Harvesting method.** Harvest carefully as even small cuts, scratches and abrasions can spoil appearance and lead to decay. Harvest with the stalk attached, preferably by hand and place in a bag or pouch worn on the body for lowering to the ground at intervals. Many varieties have big size trees and when the fruit cannot be reached by climbing or positioning a ladder for hand picking, picking poles (preferably with cutter bars or clippers) with attached pouches to catch the fruit, should be used.

**Field assembly.** Place the fruits in lined field crates or baskets. Position the latter in a shaded area of the field, because exposure to the sun will raise the temperature of the fruits and cause earlier ripening and shorter self life.

## 1.2. Post-harvest

**Treatment.** Trim stalk to approximately 1 cm in length to reduce the risk of injuries (punctures and scratches) among the fruits after ripening. If the stalk is completely removed at the mature green stage it predisposes the fruit to stem-end rot.

**Selection/Grading.** Remove soil or field debris with clean soft cloth, containing a mild solution of bleach. Select out damaged, malformed, immature and scarred (e.g. fruit with growth cracks and healed abrasions injuries) fruit. Grade, according to size. A post-harvest dip treatment in a solution of 0.05 % Thiabendazole may assist in reducing disease development.

**Packaging.** Place large fruits in single layers in strong cardboard cartons with separators. Smaller fruit should be placed in cardboard cartons with or without separators in two or three layers as indicated. Lined wooden crates may also be used.

## 1.3. Storage

Most varieties ripen between 2 to 10 days after harvesting, depending on variety and the storage temperature; ripe fruits have a shelf life of 1 to 2 days. Avocadoes are susceptible to bruising and disease incidence, but if handled correctly and stored under the appropriate conditions, a storage life of up to four weeks, depending from the variety, can be achieved. Storage refrigeration can be the following:

- 5 to 13° C, depending on the variety and duration, for mature-green fruits;
- 2 to 4° C for ripe avocados; and
- 90-95 % is the optimum relative humidity.

## 1.4. Post-harvest losses.

- Chilling injury. Skin pitting, scalding and blackening develop on mature-green avocadoes kept at low temperature (0-2° C) for more than 7 days; internal flesh browning develop when fruits are stored to 3-5° C for more than 2 weeks.
- Anthracnose. Provoked by a fungus, this consists of circular

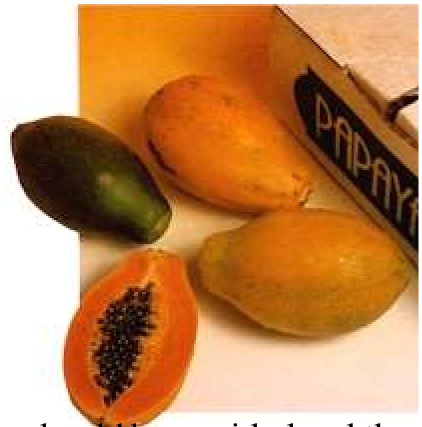
black spots on the skin, which can penetrate into the flesh when the fruits begin to soften. Can be partially controlled or delayed with prompt cooling; and

- Stem-end rot. Provoked by a fungus and appears as dark-brown-black discolorations starting at the stem and advancing toward the blossom. Control method includes good orchard sanitation and careful handling to minimize physical injuries and prompt cooling.

## 2. Papaya

Latin name: *Carica papaya* L.

### 2.1. Harvesting



Papaya is one of the most susceptible fruits to skin damage. Papaya handlers can minimize fruit damage by taking protective measures throughout all handling stages: use the harvesting tools properly, and avoid dropping the fruits into the boxes and overfilling, latex stains should be avoided and the fruits transported carefully.

**Harvesting maturity.** Papayas are ready for harvesting when most of the skin is yellow-green, called the "one yellow stripe" If harvested before this stage papayas will fail to ripe completely. For the local market, particularly in the winter months, papaya should be allowed to color fairly well, before picking; in this case the fruits are more susceptible to damage and bruising during handling.

**Harvesting method.** Home growers usually twist the fruit to break the stem. In commercial operations it is preferable to use a sharp knife to cut the stem and then trim it to the base of the fruit. Harvesting of high fruits can be done with a harvesting pole with a small hoop and a small mesh bag at the end. Above the hoop is a horizontal blade, which cuts the fruit which will fall into the bag below. Another system consists of a harvesting pole with a cup attached held against the lower end of the fruit and twisting it. In this case the picker will then need to catch the falling fruits. Latex can irritate the skin of the pickers: protection with gloves is advisable.

**Field assembly.** The fruit must be handled with extreme care to avoid scratching and licking of latex which provokes stain on the fruit which may burn the skin.

After harvest fruits are placed gently in plastic or wooden field crates, preferably with a foam layer as cushioning.

## 2.2. Post-harvest handling

Post-harvest handling of papaya requires care and attention to detail. The fruit is susceptible to several factors (fluctuating temperature, moisture, diseases and mechanical damage) which reduce its commercialization.

**Treatments.** Fruits could be held at 30° C and high humidity for 48 hours to enhance coloring before packing. The standard decay control consists of 20 minutes submersion of the fruits in water at 49° C, followed by a cool rinse. Application of fungicide as thiabendazole (TBZ) or a similar one has proven to be satisfactory also to control the pathological diseases. Heat treatment can help to control insects present on the skin of the fruit.

**Selection/Grading/Packing.** Grading and packing should be carried out as soon as possible after harvest. Fruits, after separation of broken or heavily diseased ones, are graded according to size and stage of ripeness.

Papaya should be packed in single layer cartons. Internally, packaging material could include shredded paper. Papayas are best packed on their sides in rows with the stem end at an angle.

## 2.3. Storage

Fruits harvested at the proper harvesting stage (one yellow stripe) will ripen to 60-70% yellow within 4 to 6 days under ambient tropical conditions (25-28° C). Fruits harvested at "one strip stage" and stored at low temperature (10 to12° C) will last from 14 to 21 days, if post-harvest disease incidence can be controlled.

## 2.4. Post-harvest losses

They may include:

- Chilling injuries. They include pitting, uneven ripening, skin scald, hard core and increased susceptibility to diseases; and
- Anthracnose. It is the major cause of post-harvest losses. It can be partially controlled with the heat treatment.

## 3. Mango

Latin name: *Mangifera indica* L.

Mango is considered the apple of the tropics and one of the most commonly eaten fruits in tropical countries around the world.

### 3.1. Harvesting

**Harvesting maturity.** Mangoes normally reach maturity in 4 to 5 months after flowering. When the first large fruits start showing a yellow-pink color on the tree, all the fruits of the same size or larger are ready and have to be picked. Harvesting must be repeated when the remaining fruits, which in the meantime have grown in size, start coloring. When the fruit is fully grown and ready for picking, the stem will snap easily with a slight pull. If a stronger pull should be needed, it means that the fruit is still immature and should not be harvested. In the red varieties an additional indicator of maturity is the development of a purplish-red blush at the base of the fruit.

**Harvesting method.** When harvesting by hand from the ground is not possible the picker should use a long pole with a cutting blade and a small bag under the blade which holds only a few fruits. For bigger trees the pickers should climb the branches with cotton or fiber bags that they fill and lower to the ground. Fully mature fruits will detach easily at the natural abscission point, whereas half-mature fruits will not. Optimum picking should be done with shears and cutting the stem 1 to 2 cm away from the fruit. This technique permits the reduction of latex exudation and staining of the skin and the entrance of fungus diseases.

The quantity of latex flow depends on:

- Fruit maturity: younger fruits exude more latex;
- Time of the day of harvest: in early morning harvest more exudes;
- Level of rainfall: more latex flows when harvesting after rain;
- Length of stem at harvest: if fruit is picked with the stem, latex flow is minimal.

Unfortunately many pickers harvest mangoes by simply knocking them from the tree, dropping or throwing to the ground; this causes bruises, punctures and cracks and later the fruits spoil. When low fruits are harvested with clippers, it is desirable to leave aprox.1 to 2 cm of stem to avoid the spurt of the milky sap that exudes if initially the stem is cut close.

**Field assembly.** Place the field crates with no more than two to three layers of fruits (separating each layer with sponges to avoid bruises and scratches) and baskets with liners in a sheltered or shaded area of the field or under the shade of the tree. Exposure to the sun of fruits with stains provoked by the latex may be corrosive for the skin. After harvest, latex should be allowed to drain away from the fruit by placing the mangoes with the stem downward on grass below the tree, cutting the stem 1 to 2 cm away from the fruit.

When quality of the harvested fruits is very good, in field selection, grading, sizing and packing can be done. Fruits should be freed from debris, and cleaned of soil and eventual leaked latex separated with a clean and soft cloth.

### 3.2. Post-harvest

**Treatments.** Wash/clean the fruits or use a clean soft cloth if latex stains and/or residues of chemical treatments are present on the surface of the fruit. In India, it is a habit at the beginning of the harvesting season to artificially ripen mangoes. In the south of the country mangoes are picked at a quite green stage to avoid bird damage and reduce damage during long transport of badly packed produce, on roads which are in a bad condition. On arrival in the final market dealers layer them with paddy straw, covered with plastic, often burning calcium carbide to increase underneath the quantity of acetylene and induce surface color and ripening, which will take place within 5 to 7 days at15 to 20$^{o}$ Celsius.

In developed countries ripening of mangoes prior to shipment is conducted in ripening rooms with controlled atmosphere, temperature and humidity. Treatments with chemicals
(such as ethephon which produces ethylene and calcium carbide which produces acetylene) are used in a air tight rooms for 24 hour at 20 to 25° C and 90 - 95% of relative humidity and an adequate air circulation. The treatment causes green mangoes to develop full color in 7 to 10 days, depending on the degree of maturity, whereas untreated fruits require 10 to 15 days.

**Selection/Grading.** Select out all immature, ripe, damaged, scarred or otherwise damaged fruits. In accordance with quality specifications required by the purchaser fruits should be graded in each carton according to variety, size and maturity.

**Packaging.** Mangoes for export or sophisticated internal markets such as supermarkets should be packed in cardboard boxes in single layer and the stem end facing downward or slightly on one side to avoid the latex contamination and with separators Ventilation holes are recommended to improve air circulation.

### 3.3. Storage

Mangoes ripen within 4 to 6 days, after harvest at the mature green stage. The ripe fruits have a shelf life of 2 to 4 days. Storage at 10 to 12° C and 85 to 90 % of relative humidity, will maintain fruits in acceptable conditions for up to 4 weeks and fruits will then ripe satisfactorily at higher temperature. These conditions will however depend on the variety, maturity at harvest and tome of harvest.

### 3.4. Post-harvest losses

- Chilling injuries. Storage below 10° C for a few days will result in this damage.
- Anthracnose. Consists of small, black, circular spots on the skin which increases with the ripening of the fruits. Post-harvest applications of specific fungicides (imazalil or thiabendazole) may assist in disease control. Dipping in hot water (at 50° C for 5-10 minutes, depending from the fruit size in combination with the fungicide) is also utilized.

## 4. Watermelon

Latin name: *Citrullus Lanatus* T.

### 4.1. Harvesting

**Harvesting maturity.** Ripeness in watermelons is difficult to determine because the fruit remain attached to the wine, rather then 'slipping off". Harvesting generally begins about 30 days after full bloom and continues with periodical cuts at 3 to 5 days intervals. The most recommended method for timing the harvest of watermelons is to cut a few representative fruits in the field. However, also the following indicators of ripeness will help:

- The tendrils of the leaf closest to the fruit attachment become dry;
- Change in ground spot colour from greenish-white to pale yellow;
- The rind becomes hard to pierce with the fingernails;
- Blossom end "fill out'; and
- The sound of a fruit, when thumped with a finger, is a muffed, dull tone if it is ripe.

**Harvesting method**. Watermelons are harvested in the afternoon by cutting the stem with a sharp knife rather than pulling the fruit out. Afternoon harvest may reduce the risk of cracking if the field has received abundant water during the previous night. If plants are not too turgid field heat can be minimized by harvesting in the morning. Watermelons do not ripen off the vine. However holding them for 7 days and over at room temperature will improve flavour and colour in seeded varieties. Take care of the wet and dirty soil; if watermelons get dirty clean them with a wet and clean cloth.

**Field assembly and packaging**. After harvesting, watermelons are stacked in the field itself, on the side rather than on end to reduce the risk of cracking. Placing them in a shaded area will allow to minimize the build up of heat and avoid quality reductions. Packaging in fibreboard boxes or bulk loaded in bins in the field itself taking care to load only dried rather than dew-covered fruits.

## 4.2. Post-harvest

Cleaning and packing is done in the field itself, when the field is easily accessible.

## 4.3. Storage

At 10 to 15° C and 90% relative humidity the fruits can be kept for 2 to 3 weeks after harvest. Prolonged storage will be responsible for reduction in crispness and colour.

## 4.4. Post-harvest losses

Chilling injuries (the pit in the ring will be invaded by micro organisms) will take place after storage below 5° C.

# 5. Bananas and plantains

Latin name: *Musa spp.*

Include: Plantains; traditionally grown for cooking as part of the staple diet, or for processing into more durable products, such as flour, which can be stored for later food use. Bluggoe ; uses are similar to plantains as a locally consumed staple food. Dessert; includes Gros Michel and Cavendish types, widely grown for export to temperate countries. The ripe fruit is also eaten where it grows, but in some countries it is cooked in the immature stage or in the mature green but unripe stage as a starchy staple.

## 5.1. Harvesting

**Harvesting maturity.** Published recommendations of maturity standards for export dessert bananas do not generally apply to bananas grown for local consumption. Many types of bananas are grown for local use in different countries.

When bananas are to be sent to distant urban markets they are best harvested in hard mature but unripe green state, which reduces the risk of deterioration during transport.

**Harvesting method**. The method of harvesting will depend on the height of the plant. Low-growing varieties can be harvested by cutting through the bunch stalk about 30 to 35 cm above the top hand. With taller varieties, the stem of the plant will be partly cut through to bring the bunch down within the harvester's reach, and then the bunch stalk can be cut through. Harvested bunches are best carried on a foam-padded tray to reduce damage during carrying.

**Field assembly**. It is customary in most banana-growing countries to transport the fruit to market on the bunch. This practice injures the fruit during handling and transport, and it is not recommended. Bananas for urban markets will suffer less damage and look better if they are de-handed and packed in suitable boxes.

### 5.2. Post-harvest

**Selection and grading.** Bananas which are very immature and small, badly damaged or decaying should be discarded. Size and quality grading will depend on the demands of the market. In the more sophisticated urban markets (e.g. supermarkets), size-graded and good-looking fruit may command a higher price.

**Packing**. All harvested bananas should be kept dry and in the shade before and after packing. Packing is best done in or as near to the field as possible. There must be facilities for keeping the fruit and packaging dry.

As soon as the hands of bananas are cut from the stem, they should be laid, curved side uppermost, across the midribs of fresh banana leaves. This will prevent latex from the cut crown contaminating the fruit. Latex flow should stop in 12-15 minutes, after which the banana may be packed into wooden or, preferably, cardboard boxes, which can be of the slotted or telescopic type. Whole hands of bananas can be divided into clusters of four or more fruit which can be packed more compactly to give a greater weight of fruit per box.

The hands or clusters should be packed in the boxes with the curved side uppermost, making sure that the crowns of the upper hands do not damage the bananas underneath. Boxes should be full but not over-packed, otherwise the bananas will be damaged because the fruit itself and not the walls of the boxes will be supporting the upper boxes of the stack.

**Post-harvest treatments**. No special post-harvest treatments should be necessary for bananas sold locally or for those which will be sold to consumers in urban markets within four or five days. If sales are to be delayed for a greater time and the fruit sold in a ripening condition, it may be necessary to wash and then dip or spray them with a fungicide before packing.

## 5.3. Storage

Bananas have a very short post-harvest life at ambient conditions. This is four to ten days when mature green and two to four days when ripe. Both green and ripe bananas are sensitive to cold and are damaged by temperatures less than 13° Celsius.

## 5.4. Ripening

Bananas harvested in the mature green stage will normally ripen under the local ambient conditions in which they are grown, but some types will not develop their full ripe skin color. Where urban high-value markets demand fully colored fruit, ripening under controlled conditions is best carried out on a large scale at the urban distribution point. The operation requires special equipment, good management and technical skills. Where the ripening operation is to be undertaken locally, advice should be sought from specialists.

## 6. Citrus

Latin name: *Citrus spp***.**

**Includes**: Oranges, grapefruit, mandarins; used ripe as fresh fruit and for juice. Lemons and limes; used mature green or ripe for culinary purposes and for drinks.

### 6.1. Harvesting

**Harvesting maturity.** The assessment of the readiness of citrus fruit for harvest presents some problems for small-scale producers because:

- citrus fruits do not ripen further after harvest. To reach their full flavour and sweetness they must be left on the tree to ripen;
- in the tropics citrus often remain green when they are fully ripe internally and do not develop an orange-yellow colour on the tree. The development of the orange-yellow skin colour can be artificially induced after harvest (de-greening).

These facts make it very difficult to assess harvest maturity just from the appearance of the fruit on the tree. Small-scale producers marketing their own fruit will be able to assess the readiness of their fruit on several counts, which will vary in different situations, for example:

- **Skin colour**: where it develops normally, this will be a good guide to ripeness; if normal skin colour does not develop, maturity may be indicated by a change in the shade of green shown by the skin; lemons change from dark green to a silvery-green appearance at maturity;
- **Size**: experienced growers may evaluate maturity by considering size as well as with other characteristics, such as slight changes in skin colour; and

- **Internal condition of fruit**: if a few typical fruit thought to be mature are cut in two, they can be considered ripe if:

    1. The juice has developed full flavour and is sweet;
    2. The fruit pulp has developed to the normal colour; and
    3. Juice drips from the half-fruit when the cut surface is held vertically.

**Harvesting method.** Although the skin of citrus fruit is relatively tough and can tolerate some degree of pressure, it is easily cut or punctured, providing access to the serious post-harvest decay diseases: blue and green mould. Every care must be taken to avoid cutting or puncturing the skin of citrus fruits at all times. Clippers or secateurs should be used to remove the fruit from the tree. Fruit may be pulled by hand, but there is danger that the stem may be pulled out of the fruit, damaging the skin, or of damage to the tree providing an entry point for field diseases. Not more than 0.5 cm of stem should be left attached to the fruit. If the fruit is mature or ripe this piece of stem will dry up and fall off, leaving only the flower calyx (button) attached to the fruit. As it is harvested, citrus fruit should be placed in picking bags worn by the harvester or in plastic buckets.

**Field handling**. Harvested fruit is taken in the harvesting container either directly to the packing facility or to the field assembly point, where it is emptied into field containers. At either point the fruit should be protected from exposure to sunlight and rain while awaiting packing or movement to the packing house.

### 6.2. Post-harvest

**Selection**. Before it is packed the fruit should be sorted to eliminate all foreign material, such as leaves and twigs. The fruit is then inspected and pieces which are unripe, immature, undersized, damaged or decaying should be discarded. The extent to which superficial skin damage can be tolerated will depend upon the market. Local consumers may be more concerned about the eating quality of produce than its external appearance.

**Size grading** Where citrus fruits are to be pattern-packed in custom-made cardboard boxes it is usually an advantage to grading it into size categories. The differences between categories will depend on the type of fruit. Suggested minimum sizes and grade category differences for different commodities are:

| Commodity | Minimum (mm) | Grade difference (mm) |
|---|---|---|
| Oranges, lemons, mandarins | 50 | 5-10 |
| Grapefruit | 70 | 15-20 |

Limes are not normally size-graded. Citrus sent to local markets in wooden crates will usually be size-graded by the retailer at the point of sale.

**Packing**. Citrus for sale in local and internal urban markets is packed in a variety of containers. Baskets, wooden boxes, sacks, bags, factory-made wooden crates and cardboard boxes are all used. Most citrus from large scale commercial production are now packed in telescopic cardboard boxes. The recommended outside dimensions for the boxes are 50x 30x 30 cm. These can be stacked eight boxes per layer on standard 1 x 1.2 m pallets. The capacity of these boxes is about 18-20 kg. Wooden crates can also be used for citrus provided they do not have sharp edges or splinters which will damage the skin of the fruit. Wooden crates should not exceed 25 kg capacity. Larger crates are difficult to handle and if dropped can severely damage the contents. Citrus fruits can be packed a little above the top of the box so that they are under slight pressure when the box is closed. This prevents movement of fruit within the box during transport and handling and allows for natural shrinkage.

**Post-harvest treatments**. Citrus produced for local and other internal markets should not require specific post-harvest treatments provided it is handled carefully and packed properly. Commercially grown citrus for export is normally washed, treated with fungicide and wax-coated on highly automated packing lines. There may be occasions where citrus for internal urban markets requires fungicide treatment. Where this is necessary, the fruit should be washed and dried after sorting, then treated with fungicide and dried before packing. In those countries where some types of citrus remain green when ripe it is not usually necessary to de-green them for market. De-greening will only change the color of the skin of citrus fruits. It will not ripen them internally. De-greening is carried out by exposing the fruit to ethylene gas under controlled environmental conditions. It can only add to the cost of the fruit to the consumer, without any compensation in eating quality. However, we are aware that most consumers purchase with the eyes, therefore yellow/orange color is preferable to the green one.

### 6.3. Storage

Citrus fruits can be held up to three weeks under ambient conditions, depending upon the temperature and moisture content of the air. In dry air they may lose moisture and shrink after a few days. Damaged fruit may become infected and decay quickly after harvest. Depending on the variety citrus can be stored in refrigerated rooms as follows:

- Grapefruits: at 10 to 15° C,85-90% Relative Humidity, for 6 to 8 weeks.
- Lemons: at 10 to 13 ° C, 85-90% Relative Humidity, for 1-6 months.
- Limes: at 9 to 10° C, 90-9656% Relative Humidity, for 6 to 8 weeks.
- Oranges: at 0 to 9° C, 90-95% Relative Humidity, for 3 to 8 weeks.

## 7. Pineapple

Latin name: *Ananas comosis sp.*

**Harvesting maturity.** It is difficult to tell when pineapples are ready to be harvested. Some people judge ripeness and quality by snapping a finger against the side of the fruit. A good, ripe fruit has a dull, solid sound. Immaturity and poor quality are indicated by a hollow thud. However harvesting should be started when the base of the fruit has changed from green to yellow or light brown. An acceptable quality may also develop before color changes may occur. Often pickers select fruits by size.

**Harvesting method and handling.** Fruits are harvested manually by cutting the stalk using a sharp knife or twisting the fruits from the stalk. The harvested fruits are put inside gunny bags, bamboo or other kind of baskets or field crates and sent to the collecting point for grading. Grading and packing can also be done in the field itself. Fruits, after separation of broken and heavily diseased or defective ones, are graded according to size and stage of ripeness and packed in single layer cardboard boxes, on their side.

**Storage.** The fruits should be stored, depending from the variety, at 7 to 13° C (45 to 55 ° F), 85-95% Relative Humidity for up to 24 weeks. However it is advisable to store pineapples for no more than 4-6 weeks, because the fruit is chilling injury sensitive, like most of the tropical fruits.

**8. Soursop**

Latin name: *Annona muricata*.

The skin is dark green in the immature fruits, becoming slightly yellowish-green before the mature fruit is soft to the touch.

**Harvesting.** The soursop flowers more or less continuously but in every growing region there is usually one principal harvesting period. The fruit is picked when fully grown and still firm but slightly yellow-green. If it is allowed to soften on the tree, it will fall to the ground and splatter. It is harvested by hand using a large bamboo pole with an attached pouch.

**Handling**. Firm fruits are kept a few days at room temperature. The skin will blacken and become unsightly while the flesh is still unspoiled and usable. Studies of the ripening process have determined that the optimum stage for heating is 5 to 6 days after harvest, at the peak of ethylene production. Thereafter, the flavor is less pronounced and some off-odor may develop. The fruit is very sensitive to packing if harvested at the proper maturity stage. One single layer should be packed in cardboard boxes with cushioning material.

**Storage**. The soursop can be stored under refrigeration at 13° C, 85-90% Relative Humidity for 1 to 2 weeks.

**9. West Indian Cherries**

Latin name: *Malpighia sp.*

**Harvesting.** For home use, as a dessert, the fruits are picked when fully mature. For processing or preserving, they can be harvested when still slightly immature, when they are turning from green-yellow to red. As there is continuous fruiting over long periods, picking is done by hand, in the cool of the early morning, every day or every 3 days to avoid losses by falling. They are extremely short shelf-life and must be handled gently to reduce bruises and oxidation. For immediate processing some growers shake the tree and allow the ripe fruits to fall into sheets spread on the ground.

**Handling**. Fruits should be packed directly in the field into 5 kg cardboard boxes or wooden or plastic trays, often being sorted based on color and size. Harvested produce should be kept in the shade until transferred from the field, which should be done within 2-3 hours. Boxes, if not shaded, should be covered with canvas.

**Storage.** Ripe cherries bruise easily and are highly perishable. They can be stored for no more than 3-4 days at 7° C and 90-95% Relative humidity. Half ripe fruits can be stored for a few more days.

## II. HARVEST AND POST-HARVEST HANDLING FOR SELECTED VEGETABLES

### 1. Bulb onions and garlic

**Latin name:** *Allium cepa, A. sativum* and other species.

Onions and garlic of different types are grown worldwide for the flavor they contribute to food. They are also commonly regarded as having medicinal properties. In many countries onions are used in the immature green state. In others, where the crop is seasonal, cultivars which produce bulbs that can be stored in a dry state are grown.

### 1.1. Harvesting

**Harvesting maturity**. When the bulbs developing from the leaf bases of both garlic and onions are fully formed, the leafy green tops begin to yellow and eventually collapse at a point a little above the top of the bulb, leaving an upright short neck. When the tops "go down" in this way, the bulbs are ready for harvesting. Because all the onions or garlic in a crop do not mature at the same time, large-scale commercial growers harvest them when about half the tops have gone down. Small-scale growers can, if they wish, harvest their crops progressively as the tops go down, especially so if they intend to store the dry onions for sale or use at a later date.

**Harvesting method.** Since onion bulbs are normally formed at the soil surface, it is sometimes possible in sandy soils to pull the mature bulbs by hand. Where conditions make hand-pulling impossible, and with garlic where the bulbs develop below ground, harvesting is done by loosening the bulbs with a fork or hoe before lifting them. In dry, sunny weather the harvested crop is left in windrows in the field for a few days until the tops are dry. Where the harvested bulbs are exposed to high-intensity sunlight (e.g. at high altitudes in the tropics), the windrows should be made so that the green tops cover the bulbs to protect them from sunburn.

## 1.2. Post-harvest

**Selection and grading**. All damaged or decaying onion and garlic bulbs should be discarded. Onions with thick necks should be put aside for immediate use because they will not store well. Market requirements will determine whether onions need to be size graded or not. Retailers in local markets will normally do their own grading when making up lots for sale. If the onions or garlic are to be made up into strings for storage or sale, as described below, it is an advantage to separate them into sizes so that the bulbs will be more or less uniform in size in any string. This makes the stringing operation easier and gives a better appearance to the finished product.

**Post-harvest treatment**. The only post-harvest treatment required for the long storage of bulb onions is a thorough curing of the bulbs. Curing is a drying process intended to dry off the necks and outer scale leaves of the bulbs to prevent the loss of moisture and the attack by decay during storage. It can be carried out in the field under dry conditions by windrowing the bulbs. The essentials for curing are heat and good ventilation, preferably with low humidity. This dries out the neck and the two or three outer layers of the bulb. The outermost layer, which may be contaminated with soil, usually falls away easily when the bulbs are cured. This results in exposing the dry under-layer, which should have an attractive appearance. If onions cannot be dried in the field, they can be collected in trays, which are then stacked in a warm, covered area with good ventilation. In cool, damp climates, onions in bulk ventilated stores are dried with artificial heat blown through the bulk at a duct temperature of 30$^{o}$ C. Garlic and onions can also be cured by tying the tops of the bulbs in bunches and hanging them on a horizontal pole in a well-ventilated situation.

**Packaging**. For bulk marketing, the tops of onions are removed when they are thoroughly cured and the necks are quite dry. The tops of garlic are cut off one cm above the bulb and only the loose outer skin rubbed off. Both onions and garlic may be made up into strings. These are of 2 kg for garlic or 5 kg to 10 kg for onions. This is, however, a labor-intensive operation suited to small-scale production using family labor. It is not cost-effective on a commercial scale.

### 1.3. Storage

The first requirement for successful storage of dry bulb onions is that the cultivar chosen should have the right characteristics for long-term storage. The principal needs are:

- the cultivar should have a long dormant period;
- it should be a cultivar which forms a strong outer skin when fully cured; brown- and red-skinned cultivars tend to be better in this respect;
- the bulbs put into storage should be disease-free; the most important storage disease is neck rot, which is controlled by dusting the onion seed before planting with benomyl fungicide at the rate of one gram active material per kilogram of seed.

The storage environment must be dry and well-ventilated. Optimum storage temperatures must be the lowest available under ambient tropical conditions. At temperatures between these, onions will sprout in storage. Onions stored in a damp atmosphere will develop roots. Onions can be stored in bulk in insulated stores, with fans for cooling the onions using cold night air. This method is used where large tonnages are to be stored. Small-scale growers can use naturally ventilated stores made from local materials. The onions can be stacked in trays or in layers on slatted shelves.

Where small amounts are to be stored, the stringing of onions in 5 kg to 10 kg lots and the hanging of the strings in a well-ventilated dry location is a very effective storage method. Dried onions can be stored in cold storage at $0^{o}$ C, 65-70% Relative Humidity for 1 to 8 months.

Garlic may be stored in trays, strings or bunches in the same manner as onions, except that with garlic strings are made by plaiting the dry top leaves of the garlic. Garlic can be stored in cold storage at $0^{o}$ C, 65-70% Relative Humidity for 6 to7 months.

## 2. Leafy vegetables and immature flower heads

**Latin names:** *Brassica spp, Beta sp., Spinacea sp., Apium sp., Lactuca sp., Allium.*

Include cabbage, Chinese cabbage, kale, rape, mustard, broccoli, chard, spinach beet, spinach, lettuce, celery, green onions.

### 2.1. Harvesting

**Harvesting maturity.** All are harvested in the immature state before the plant has developed to the point of seed production. The older parts of these commodities become fibrous or woody.

**Harvesting method.** The parts of the plant harvested vary with the crop:

- Cabbage, Chinese cabbage, lettuce, celery and green onions form more or less compact heads; the entire head is harvested at one time;
- Kale, rape, mustard. young shoots, with or without immature flower heads, are picked by hand-breaking; can usually be harvested over a period of time as long as new shoots continue to develop; and
- Chard, beet and spinach are harvested as individual young leaves; sometimes young shoots of spinach are harvested; harvesting is repeated as new leaves continue to develop.

Those crops forming a head, such as cabbage, are cut with a sharp knife. Young shoots and leaves are broken off by hand. Celery and green onions are either pulled by hand or dug from the soil. They should be harvested under dry conditions when soil can be readily shaken from the roots. The roots are then trimmed with a sharp knife.

**Field assembly**. All these commodities are damaged easily if subjected to pressure. They should be packed loosely in field containers, which must not be overfilled or the produce will be damaged when the containers are stacked. The harvested produce must be kept free from contamination by soil. Leafy vegetables and immature flower heads deteriorate very quickly after harvest because they lose water fast and produce a great deal of heat. The following care is necessary to keep losses to a minimum:

- They must be packed loosely in well-ventilated plastic field containers; if they are piled in a tight mass, the heat they generate cannot escape.
- They must be kept in the shade and not exposed to direct sunlight.
- They must not be exposed to drying winds or they will lose water quickly and become wilted and soft; at the same time there must be enough ventilation to disperse the natural build-up of heat.
- There must be the shortest possible delay between harvest and sale or consumption because leafy commodities have a very short post-harvest life under ambient conditions.

## 2.2. Post-harvest

**Selection, grading and handling**. All produce which is damaged, decaying wilted or infested by insects or other pests must be discarded. Size-grading is not normally necessary for local and internal marketing. Size-grading may be needed to supply supermarkets.

**Post-harvest treatment.** It is essential to keep these commodities free from contamination by soil or decaying plant material. Do not wash them. Washing them may remove gross soil contamination, but it will also spread any decay through the whole bulk and result in heavy losses. Shading the produce and keeping it in a moist atmosphere helps to keep it cool, reduces water loss, and delays wilting and yellowing of leaves.

Chemical treatments to control decay are not acceptable because they are not very effective and they leave high residue levels because of the characteristic high surface area of these products in relation to their volume.

**Packaging.** For local rural markets traditional containers are likely to remain in use. It is important, however, that containers should not be too large to be carried by one person. Rough handling of heavy packages results in damage to produce. Packaging of leafy vegetables and immature flower heads for urban markets will vary with the type of commodity.

The following are examples:

- Cabbages: woven sacks, net bags or field crates of 20-25 kg capacity are suitable.
- Lettuce: one layer wooden plastic crates or ventilated cardboard boxes each containing 24 heads of lettuce.
- Celery: wooden crates holding 20-30 heads of celery.
- Green onions: normally tied in bunches by the grower; they are best transported in small wooden crates holding 10-15 kg.
- Chard and spinach: crisp, brittle and easily broken by rough handling; they are best packed loosely in cardboard, wooden or plastic field boxes of 5-10 kg capacity; over-packing will cause crushing of leaves and bruising and rapid discoloration of stems.
- Kale, rape and leafy brassicas: may be tied in bunches or packed loose; they can be marketed in nets, cardboard or wooden or plastic field crates of 5-10 kg capacity.

## 2.3. Storage

Leafy vegetables and immature flower heads have a very short post-harvest shelf-life, especially under ambient conditions. Even under refrigeration most remain in good condition only up to two weeks. Ideally, they should reach the consumer within two days of harvest. For details on the single commodities.

## 3. Tomatoes

**Latin name:** *Lycopersicon esculentum*

### 3.1. Harvesting

**Harvesting maturity.** If tomatoes are to be used in the ripe condition, they should be picked at the earliest when they are at least mature green. Immature tomatoes do not ripen after harvest. The actual stage at which they should be picked depends upon local preference and custom in each country. Tomatoes have reached the mature-green condition when they are fully rounded and have changed from dark to medium or light green, and the skin develops a waxy gloss. As ripening is initiated, the fruit shows a pale pink or yellow tinge, which develops through a definite pink to full red. Most tomatoes are harvested at the early ripening or pink stage, depending on market preference and the time they take to reach the retailer. Tomatoes to be consumed immediately can be harvested when fully ripe.

**Harvesting maturity.** Tomato fruit stalks have a natural break-point. Mature fruit readily breaks away from the cluster when pressure is placed on this point while lifting the fruit upwards. Tomatoes are best harvested into plastic buckets (pails) and transferred if necessary to plastic field crates holding not more than 20 to 25 kg weight.

### 3.2. Post-harvest

**Selection and grading.** All decaying, damaged, undersized and sunburned tomatoes should be discarded. Size-grading for the local market is normally done by retailers. Internal urban markets, including supermarkets, may have differential prices for size grades as against un-graded fruit. Catering and institutional buyers do not normally demand size-graded fruit.

**Post-harvest treatments.** Only those tomatoes which are in good condition are marketed, there should be no need for any post-harvest treatments. Tomatoes produced on a large commercial scale may be subjected to artificial ripening; but in countries where production is mostly on a small scale, this is not necessary since tomatoes are normally harvested at maturity and ripen naturally.

**Packaging.** For local markets tomatoes can be packed in baskets or other traditional containers assuring careful handling, i.e. rigid enough to protect the contents from being crushed. For urban markets cardboard telescopic boxes or wooden or plastic trays with capacities of not more than 10 kg, should be used. Size-graded tomatoes can be pattern-packed in 2 layers for green produce and one layer for ripe red produce to make best use of the box. Un-graded tomatoes are jumble-packed to a given weight.

### 3.3. Storage

Tomatoes have a relatively poor storage capability. Green mature fruit can be held for up to two weeks at 18-20°C and 90-95% Relative Humidity, but for less time under ambient tropical temperatures. Fully ripe tomatoes have only 4 to 7 days' storage life, at 13-15°C and 90-95% Relative Humidity.

## 4. Eggplants

**Latin name:***Solanum melangela L.*

### 4.1. Harvesting.

**Harvesting maturity.** The harvest index is based principally on size and color. The fruits of eggplant should be harvested somewhat before they reach full maturity. The color should be dark purple, firm and glossy, with green calyx and stem. Browning of the calyx and shriveled skin are indication of aging and water loss.

**Harvesting method**. Harvesting should be done once or twice per week, depending on the variety. Secateurs are needed for hand-harvesting, taking care to handle nicely the fruits and leaving 2 to 4 cm long stem above the calyx. The harvesting of wet fruits should be avoided.

**Field assembly.** Ventilated field crates should be placed when full, in a shaded place to avoid over-heating. Sacks and bags should be avoided to reduce development of mechanical damage and heat build-up.

### 4.2. Post-harvest

Clean with a soft cloth to remove soil and residues from the fruits. Fruits showing yellowing of the skin are over-mature and should be separated, along with fruits presenting signs of decay, insect damage, cracks, sunscald and other mechanical damages. After size grading, the fruits of the same size are loose packed in cardboard boxes.

### 4.3. Storage

At optimal storage conditions of 7 to 12° C and 85-90% Relative Humidity, eggplants can be stored for 7 to 10 days. Stored below 7° C the fruits will develop chilling injuries such as surface pitting, decay internal breakdown and shriveling.

### 4.4. Post-harvest losses

- Stem puncturing;
- Crates overfilling;
- Microbial infections;
- Chilling injuries; and
- Shriveling.

## 5. Carrots

Latin name: *Daucus carota*.

### 5.1. Harvesting

**Harvesting maturity**. Carrots are ready to harvest about 90 days or more after seeding, but continue to grow and enlarge them. Size is the best maturity index. Harvest when the roots are of good size, but still tender.

**Harvesting method**. They may be harvested manually or mechanically. The crop is mowed or preferably the roots are pulled out. The root is separated from the green top with a sharp knife.

### 5.2. Field assembly and handling

Carrots should be cleaned by immersion in water tanks. Separation of the soil is facilitated by soft scrubbing with a brush. Final washing in clean water may be needed. If it is the case add chlorine at 1%o. Carrots should be packed in plastic or wooden field boxes. Sack should be avoided to reduce handling and transport damages.

### 5.3. Storage

If carrots are left too long in the soil or allowed to over-mature, the roots become tough, woody and start cracking. At optimal storage conditions mature carrots can be stored at 0° C and 95-98% Relative Humidity up to 6 to 9 months.

## 6. Pungent and sweet peppers

Latin name: *Capsicum Sp.*

### 6.1. Harvesting.

**Harvesting maturity**. Sweet pepper fruits usually are picked when they have stopped increasing in size, are firm to the touch and in the green turning yellow/red stage. Hot varieties are harvested either immature (green) or mature (yellow/red) stage for fresh use or processing.

**Harvesting method and field handling**. All peppers are harvested by hand, with approximately 1 to 2 cm of stem attached, and introduced into baskets that are then emptied into field boxes for delivery to the pack-house or in single layer cardboard boxes for the market. Harvesting of wet peppers should be avoided. Considerable mechanical damage can occur during picking and handling if care is not taken to minimize scuffing and impact.

### 6.2. Post-harvest handling

Harvested peppers should be placed in the shade immediately after harvest and cooled, if refrigeration is available, as soon as possible to lower the field-heat. The use of perforated film carton liners or perforated plastic bags increase storage life, although it may inhibit proper cooling and may encourage diseases. Before final packing for market peppers should be selected for uniform maturity, color, shape, size and for freedom from defects (sunscald, mechanical or insect damage or decay).

### 6.3. Cooling and storage

Immediately after harvesting, peppers should be cooled to 7° C. If they are allowed to remain at high temperature for more than 1 to 3 hours they will begin to show signs of shriveling, shrinkage, softening, accelerates ripening and color changes. Peppers are also sensitive to chilling injuries. If kept at temperatures below 4° C, they may show signs of softening, pitting and a predisposition to decay.

Peppers are sensitive to ethylene gas produced, as a natural by-product of ripening, by some fruits and vegetables (such as tomatoes, apples bananas and avocadoes) which never should be stored and shipped together with peppers.

## 6.4. Post-harvest losses

Peppers in addition to the chilling injuries described above, are subject to a number of problems: diseases, insects, weather and other environmental factors.

## 7. Sweet corn

Latin name: *Zea mays L.*

### 7.1. Harvesting.

**Harvesting maturity**. Sweet corn ears are generally ready for harvest approximately three weeks after the first silk emergency, depending on the temperature. Silk will start to turn brown about two weeks after emergence. Ears should be harvested when the kernels appear to be milky when punctured with a thumbnail. It is called the milky stage. The un- husked ears should feel firm, have full kernel to the top of the ear and have brown dry silk. Fully ripe kernels of super sweet varieties will still posses a clear, watery juice.

**Harvesting method and field assembly**. Ears of standard varieties will remain in prime condition for only a short time in warm weather when compared to cool weather. Harvest in the early morning when both the ears and the weather are cool. High temperature will quickly lower the eating quality of sweet corn. When harvesting, break the stem of the ear as close to the ear as possible without breaking the main stalk. Long shanks and flag leaves should be clipped to reduce moisture losses. Ideally, ears should be cooled to 0° C within an hour of harvesting. Use field plastic or wooden crates to handle the corn.

### 7.2. Post-harvest handling

If corn cannot be refrigerated immediately, it should be stored in the shade to reduce heating from the sun. When harvesting for direct market supply, harvest only a one-day supply and keep as cool as possible. Ears can be packed in field-crates topped with ice, and kept at 0° C. Ears, in these conditions will be marketable for 5 to 10 days.

### 7.3. Storage

Traditional sweet corn varieties are seldom stored for more than a few days, because of the resulting serious deterioration and loss of tenderness and sweetness. The loss of sugar (which is converted to starch) fastens with the increase of temperature. Prompt cooling at 0° C and high Relative Humidity will extend shelf-life.

**8.Broccoli and cauliflowers**.

**8.1. Harvesting and handling**

Use a sharp knife and cut keeping the blade aligned with the soil.

**Broccoli.** Harvesting is done by hand while the head is still compact and before the flowers open. The central heads should be dark blue or green. If harvested too late or when the heads are over-mature, woodiness in the stem will develop.

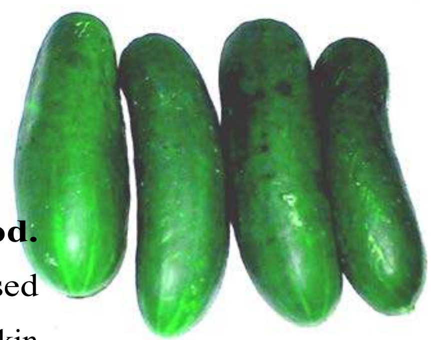
Depending upon marketing requirements, the main head is cut with 3 to 5 cm of the stem. Sometimes a second harvest of side shoots can be obtained. Quality of broccoli is based upon the degree of compactness, leafiness, trimness of heads, damage and freedom from insects and external debris. Broccoli is packed in one layer boxes with the heads upright to avoid scrubbing of the flowers.

**Cauliflowers**. When ready to harvest, the heads should be compact and clear white. Heads become discolored and develop an unpleasant flavor when exposed to sunlight. The longest leaves are normally tied loosely together over the head to "blanch" and prevent the head for being exposed to the sun. Large heads cannot be normally obtained by delaying harvest. Cauliflower is harvested by hand and cut with one or two whorls of leaves to protect the head and permit packing in two layer cardboard boxes.

## 8.2. Storage

Broccoli can be stored at 0° C, 95-98% Relative Humidity for only 1 to 2 weeks to avoid yellowing. Cauliflowers can be stored at 0° C, 95-98% Relative Humidity for no more that 3 to 4 weeks, or longer with leaves protecting the head, to avoid black spots of fungus diseases.

# 9. Cucumbers



Latin name: *Cucumis sativus*.

## 9.1. Harvesting

**Harvesting maturity and harvesting method.** For table or slicing cucumbers quality is primarily based on uniform shape, firmness, and a dark green skin color. Additional quality indices are size, freedom from growth or handling defects, decay and absence of yellowing. Cucumbers are harvested at a range of developmental stages. Depending on cultivar and temperature, the time from flowering to harvest may be 55 to 60 days. Cucumbers generally are harvested at a slightly immature stage, near full size but before seeds fully enlarge and harden. Firmness and external glossiness are also indicators of a pre-maturity condition. At the proper harvesting maturity a jellylike material has begun to form in the seed cavity. Harvesting is done by hand by cutting free of the vine with a sharp knife, rather than by tearing. Cucumbers are packed in two layer boxes, cardboard, wooden or plastic.

## 9.2. Storage

Storage of cucumbers at 10 to 12° C and 95% Relative Humidity is generally less than 14 days as visual and sensory quality deteriorate rapidly. Short term storage or transit temperature such as 7° C is often used but after 2 to 3 days chilling injuries will result. Cucumbers are highly sensitive to ethylene present in the storage room or in the transport vehicle. Do not mix bananas, melons, tomatoes and other ethylene producing products with cucumbers.

## 9.3. Post-harvest losses

- Chilling injuries;
- Bruising; and
- Yellowing.

# III. HARVEST AND POST-HARVEST HANDLING FOR SELECTED ROOT CROPS

## 1. Sweet potato

**Latin name :** *Ipomoea batatas*

Sweet potatoes are grown widely throughout the tropics as a basic or subsidiary staple food crop in subsistence economies. They are also widely used as animal feed and in some countries as an industrial raw material.

### 1.1. Harvesting

**Harvesting maturity.** Sweet potatoes are considered ready for harvest when the leaves begin to yellow. A further test of readiness to harvest is said to be that of cutting mature tubers the cut surfaces do not discolor. In some countries experienced growers harvest at a specified time after planting. This has to be based on careful observation and long experience since there is a difference in the maturity period of the various cultivars.

**Harvesting method.** Harvesting is carried out either progressively or all at one time. Subsistence growers tend to harvest progressively, often from the same plants over a long period. Sweet potato crops grown on a commercial scale are usually harvested all at one time.

The preferred harvesting tools for most small-scale producers are pointed wooden sticks or metal bars, or machetes (cutlasses, bolos, pangas), especially where progressive harvesting is practiced. These tools are said to cause less damage to the roots and enable a few roots to be harvested from a plant on each occasion. When the whole crop is harvested at one time, growers tend to use pronged rakes, hoes or digging forks.

**Field assembly**. On no account should the roots be thrown, whether into field and storage containers or at any other time during their handling. Great care must be taken to avoid damage to the skin of sweet potato roots since they are very subject to post-harvest decay under tropical conditions. For this reason it is recommended that the harvested roots be gathered into baskets, boxes or crates in which they can remain throughout their post-harvest life without disturbance, through curing and storage if necessary. Harvested tubers which have damp soil adhering to them at harvest may be left in the field for an hour or so to dry, but not long enough to suffer sun scorch. The soil can then be carefully removed.

**1.2. Post-harvest**

**Selection and grading.** All decaying roots should be discarded. Slightly damaged roots can be used for immediate consumption, and those which are undersize or badly damaged may be fed to animals. Tubers which are to be stored should be fully mature and free from visible injury. Most sweet potatoes are size/graded by the retailer if necessary.

**Post-harvest treatments.** Curing of those roots which are to be stored after harvest is the only treatment necessary for sweet potatoes.

The roots should remain in the containers into which they were harvested and in which they will be stored. The containers can be placed in the storage structure and covered with straw. Ventilation should be restricted to allow a buildup of heat and moisture in the store, to give the correct conditions for storage, which are: 27 to 34$^{o}$ C, 85-90% Relative Humidity for a curing time of 15 to 20 days.

Curing is a process of healing by the formation of new skin on damaged areas of sweet potatoes, and also of the maturing and hardening of the whole skin of the roots. The length of time required for curing cannot be forecast since it has been shown to vary even under identical environmental conditions. Indications of maturity are said to be thus: when the skin can no longer be rubbed off easily from a sample root and when small buds appear on the roots.

### 1.3. Storage

Sweet potatoes are subject to very rapid deterioration after harvest at ambient tropical temperatures. There are reports in the literature of storage of sweet potatoes for four months or more. In most reported instances of successful storage for such a time the storage temperature has been in the low range of 10-18° C. Even at the higher end of this range sprouting of the roots has been a problem. At temperatures below 10° C sweet potatoes suffer chilling damage.

The storage structures used have been either custom-built ventilated stores, with or without refrigeration, or sunken or underground chambers, protected by a building above. Conditions required for successful storage are as follows:

- The roots must be fully mature and well cured before storage;
- They must be handled carefully at all times and only sound roots should be stored;
- The best temperature range for storage is 10-15° Celsius; and
- The relative humidity should be 85 to 90 percent.

If there is any indication of free water on the roots or in the store, more ventilation should be provided to remove the excess moisture. If the air gets too dry the floor of the store can be lightly sprinkled with water.

These conditions can be achieved at higher altitudes in the tropics at those times when night temperatures fall to within the required range. In a well-insulated ventilated store, the tubers can be cooled at night by full ventilation and heat rise can be slowed during the day by closing the store.

It is unlikely that sweet potatoes can be stored at ambient tropical temperatures for more than three weeks without heavy losses from decay and sprouting.

**Packaging.** The best form of packaging for long transport is either wooden crates or cardboard boxes holding not more than 25 kg. The roots should be packed firmly to prevent movement within the boxes or crates during handling and transport. Sweet potatoes should not be packed in 50 kg sacks, which are difficult to handle and, when dropped, cause heavy damage to the roots.

## 2. Yams

**Latin name:** *Dioscorea spp.*

Yams are grown principally as a subsistence crop and for internal marketing.

### 2.1. Harvesting

**Harvesting maturity.** Yams are ready for harvest when the above-ground parts of the plants have died off. The Greater and White Yams can be left in the ground for a time after maturity. Yellow Yams, which have a very short dormant period, should be lifted as soon as mature.

**Harvesting method.** Yams is normally harvested by carefully scraping the soil away from the tubers in order to avoid damaging them. Wooden digging sticks or spades are less likely to cause damage to the tubers than are metal forks or hoes.

### 2.2. Post-harvest

**Selection and grading.** Heavily damaged or decaying yams should be discarded. Those which are slightly damaged may be consumed immediately or subjected to a curing process before storage. Size-grading is not always practiced. It is mainly done when there is an advantage to be gained in the packaging for marketing.

**Post-harvest treatments.** Where yams are cut or deeply injured, a new skin can be formed on the damaged surfaces by curing the tubers at high temperature and humidity.

Curing has been shown to be effective in Yellow and White Yams, but its effectiveness in other types is not known. Injuries caused by skin abrasion or bruising tend to dry out rather than form replacement skin.

A method recommended in West Africa for curing yams which are to be stored is given below. This provides the necessary conditions for raising the temperature and moisture content of the air to suitable levels by restricting ventilation.

The conditions found to be effective in promoting the curing of Greater and White Yams are: 32 to 40° C, 90-95% Relative Humidity.

Curing, which will be done in 1 to 7 days, should be carried out immediately after harvest at the location where the yams are to be stored.

Yams stacked in this method to cure skin damage should be covered with grass to keep the canvas or jute cover from touching the yams. The curing pile should not be exposed to direct sunlight and the cover should be removed after four days.

In humid areas of West Africa yams may be stored in 'barns" whose side poles have taken root and are growing leaves to provide shade. Inside walls of yam barn are vertical frames to which yams are tied.

**Packaging.** Yams being sent to local markets may be carried in bulk by vehicle, in ordinary baskets or in plastic or wooden field crates. When they are carried in bulk, the floor and sides of the vehicle should be padded with sacks loosely packed with straw, or with grass mats or plastic foam covered with polythene sheet. Whether the yams are carried in bulk, in crates or in baskets, the vehicle must not be overloaded and should be driven with care. For internal urban markets the tubers are best packed in wooden or plastic field crates or ventilated cardboard boxes. These containers should not be over-packed and must be handled and transported carefully.

### 2.3. Storage

Greater and White Yams in good condition can be stored for several months under appropriate conditions. Yellow yams have poor storage potential due to their very short dormancy period. Although yams may keep in storage for several months, they shrink over such a period owing to water loss and to natural living processes which use up stored dry matter (starch). There may also be additional losses because of decay caused by moulds. There are many different storage practices in various countries. Owing to the generally non-commercial nature of yam production and limited resources of growers, most storage uses low-cost methods. Yams are generally stored during the hot dry part of the year when the provision of ventilation and other conditions which help to reduce their temperature are key factors. Yams kept in the ground and harvested progressively when needed are subject to attack by insects and other pests. They are also exposed to attack by moulds. Yams kept undug may also tie up limited land resources. The tubers can be piled in small numbers in shaded situations or in well ventilated huts built of local materials, in which case they are best stored on racks or shelves. In West Africa, yam "barns" are a common method of storage. They are vertical frames to which individual yams are tied. The uprights supporting the frames are bush poles up to two or more meters in height. The use of poles which will take root and provide a protective canopy of leaves to shade the yams is of benefit. Such growing poles are also less likely to decay or be attacked by termites. The stored frames of yams may be protected by a fence to keep out rats.

### 3. Dasheen

Latin name: *Colocasia esculenta var esculenta.*

#### 3.1. Harvesting

**Harvesting maturity.** Maturity is based on corm size, harvested 8-12 months after planting, depending mainly on desired corm size and on market conditions.

Maturity is also indicated by wilting and drying of the older outer leaves. Length of growth period and senescence of leaves are therefore indicators that the root is fully mature. A few roots should be lifted to ensure that the dasheen is well- formed, evenly shaped, round to oval and brown in color.

**Harvesting method and field handling.**

Harvesting is carried out using a fork or a cutlass, and the corm gently removed from the ground. The corms and the roots should be left attached to the corm, the surrounding soil gently broken away from the dasheen, preliminary selection executed (under-sized, damaged, soft, insect damages or infested corms should be removed) and packed into 20-25 kg wooden or plastic field crates. Sacks should be avoided to reduce breakage of the corms, bruising and other damages to the corms. Packing should be executed within the 12 hours of harvest. On arrival at the packing facilities, the dasheen if not cleaned in the field, is cleaned to remove excess soil, preferably by hand and repacked in smaller containers. If handled correctly, dasheen can be stored up to 2-3 weeks. Dipping in water should be avoided in order not to reduce shelf-life. Dasheen for export market could be dipped in a chemical solution (such as Redomil) to control fungal infections. 15 g of chemical should be mixed with 30 liters of water and corms dipped for 5 to 10 seconds. Solution should be changed when water becomes dirty. Drainage is required to remove excess liquid. Corms are packed in "banana "type boxes before becoming fully dry.

**3.2. Storage**

Dasheen should be stored at 10-12$^{o}$ C and 80-90% Relative Humidity. If handled correctly corms should remain in good conditions for up to 4 weeks.

**3.3. Post-harvest losses**

- Mechanical damages;
- Micro-organism infections; and
- Chilling injuries.

## 4. Cassava

Latin name: *Manihot esculenta C.*

Cassava is an irreplaceable food security crop in a large part of the developing world. Although in the Americas cassava is slowly evolving from a traditional staple to a market oriented inexpensive row material for the manufacture of human (casabe, farinha, gar, fufu and kuanga are only a few products) livestock and industrial products. This manufactured cassava products have a more elastic market than the fresh cassava, which starts spoiling within 48-72 hours after harvest, unless the root receive a special treatment to extend shelf-life to 3-4weeks.

### 4.1. Harvesting

**Harvesting maturity.** There is no mature stage for cassava. Plants are ready for harvest as soon as storage roots large enough to meet the requirements of the consumer. Typically harvesting can begin eight months after planting. In the tropics plants can remain un-harvested for more than one growing season, allowing the storage root to enlarge further. However as the root age, the central portion becomes woody and inedible.

**Harvesting method and field handling**. Most cassava is harvested by hand, lifting the lower part of the stem from the base of the plant. The upper part of the stems with the leaves are removed before harvest. Removing the leaves 2 weeks before harvesting lengthens the shelf-life to 2 weeks. Levers, forks or ropes can also be used to assist harvesting. Cassava is very susceptible to damage at harvest.

Harvested roots should be packed in wooden or plastic field crates in a shaded place and sent to the nearest market as soon as possible.

### 4.2. Post-harvest handling and storage

The shelf life of cassava is only a few days unless the roots receive a special treatment. Dipping the roots into a permitted chemical (fungicide), followed by immersion in paraffin or wax and storing them in plastic bags. The treatment reduces the incidence of vascular streaking and extends shelf-life to 3 to 4 weeks. Dipping will permit the supply of fresh roots to overseas markets.

## ANNEX. RECOMMENDED STORAGE TEMPERATURES

Recommended temperature and relevant humidity and storage life for fruits, vegetables and root crops.

| PRODUCT | TEMPERATURE | | RELATIVE HUMIDITY (PERCENT) | APPROXIMATE STORAGE LIFE |
|---|---|---|---|---|
| | C | F | | |
| Apples | 1-4 | 30-40 | 90-95 | 1-12 months |
| Apricots | -0.5-0 | 31-32 | 90-95 | -1-3 weeks |
| Asian Pear | 1 | 34 | 90-95 | 5-6 months |
| Avocados, Fuerte, Hass | 7 | 45 | 85-90 | 2 weeks |
| Avocados, Lula, Booth-1 | 4 | 40 | 90-95 | 4-8 weeks |
| Avocados, Fuchs, Pollock | 13 | 55 | 85-90 | 2 weeks |
| Bananas, green | 13-14 | 56-58 | 90-95 | 14 weeks |
| Barbados Cherry | 0 | 32 | 85-90 | 7-8 weeks |
| Bean sprouts | 0 | 32 | 95-100 | 7-9 days |
| Beans dry | 4-10 | 40-50 | 40-50 | 6-10 months |
| Beans, green or snap | 4-7 | 40-45 | 95 | 7-10 days |
| Beans, Lima, in pods | 5-6 | 41-43 | 95 | 5 days |
| Beans, bunched | 0 | 32 | 98-100 | 10-14 days |
| Beets, topped | 0 | 32 | 98-100 | 4-6 months |
| Bitter melon | 12-13 | 53-55 | 85-90 | 2-3 weeks |
| Black sapote | 13-15 | 55-60 | 85-90 | 2-3 weeks |
| Blood Orange | 4-7 | 40-44 | 90-95 | 3-8 weeks |
| Boniato | 13-15 | 55-60 | 85-90 | 4-5 weeks |
| Broccoli | 13-15 | 55-60 | 85-90 | 2-6 weeks |
| Cabbage, early | 0 | 32 | 95-100 | 10-14 days |
| Cabbage, late | 0 | 32 | 98-100 | 3-6 weeks |
| Calabaza | 10-13 | 50-55 | 50-70 | 2-3 months |
| Cantaloupes (¾-slip) | 2-5 | 36-41 | 95 | 15 days |
| Cantaloupes (full slip) | 0-2 | 32-36 | 95 | 5-14days |
| Carambola | 9-10 | 48-50 | 58-90 | 3-4weeks |
| Carrots, bunched | 0 | 32 | 95-100 | 2 weeks |
| Carrots, mature | 0 | 32 | 98-100 | 7-9 months |
| Carrots, immature | 0 | 32 | 98-100 | 4-6 weeks |
| Cashew apple | 0-2 | 32-36 | 85-90 | 5 weeks |
| Cauliflower | 0 | 32 | 95-98 | 34 weeks |
| Celery | 0 | 32 | 98-100 | 2-3 months |
| Chayote squash | 7 | 45 | 85-90 | 4-6 weeks |
| Cherimoya | 13 | 55 | 90-95 | 2-4 weeks |
| Cherries, sour | 0 | 32 | 90-95 | 3-7 days |
| Cherries, sweet | -1 to 0.5 | 30-31 | 90-95 | 2-3 weeks |
| Coconuts | 0-1.5 | 32-35 | 80-85 | 1-2 months |
| Corn, sweet | 0 | 32 | 95-98 | 5-8 days |
| Cucumbers | 10-13 | 50-55 | 95 | 10-14 days |
| Custard apples | 5-7 | 41-45 | 85-90 | 46 weeks |
| Eggplants | 12 | 54 | 90-95 | 1 week |
| Endive and escarole | 0 | 32 | 95-100 | 2-3 weeks |
| Garlic | 0 | 32 | 65-70 | 6-7 months |
| Ginger root | 13 | 55 | 65 | 6 months |
| Granadilla | 10 | 50 | 85-90 | 3-4 weeks |
| Grapefruit, Calif. & Ariz | 14-15 | 58-60 | 80-90 | 6-8 weeks |
| Grapefruit, Fla.& Texas | 10-15 | 50-60 | 80-90 | 68 weeks |
| Greens, leafy | 0 | 32 | 95-100 | 10-14 days |
| Guavas | 5-10 | 41-50 | 90 | 2-3 weeks |
| Haricot Vert | 4-7 | 40-45 | 95 | 7-10 days |
| Jackfruit | 13 | 55 | 85-90 | 2-6 weeks |
| Jicama | 13-18 | 55-65 | 65-70 | 1-2 months |
| Kiwifruit | 0 | 32 | 90-95 | 3-5 months |
| Leeks | 0 | 32 | 95-100 | 2-3 months |
| Lettuce | 0 | 32 | 98-100 | 2-3 weeks |

| PRODUCT | TEMPERATURE | | RELATIVE HUMIDITY (PERCENT) | APPROXIMATE STORAGE LIFE |
|---|---|---|---|---|
| | C | F | | |
| Lime | 9-10 | 48-50 | 85-90 | 6-8 weeks |
| Malanga | 7 | 45 | 70-80 | 3 months |
| Mamey | 13-15 | 55-60 | 90-95 | 2-3 weeks |
| Mangoes | 13 | 55 | 85-90 | 2-4 weeks |
| Melons: | | | | |
| Casaba | 10 | 50 | 90-95 | 3 weeks |
| Crenshaw | 7 | 45 | 90-95 | 2 weeks |
| Honeydew | 7 | 45 | 90-95 | 3 weeks |
| Persian | 7 | 45 | 90-95 | 2 weeks |
| Okra | 7-10 | 45-50 | 90-95 | 7-10 weeks |
| Onion, green | 0 | 32 | 95-100 | 34 weeks |
| Onion, dry | 0 | 32 | 65-70 | 1-8 months |
| Onion set | 0 | 32 | 65-70 | 6-8 months |
| Oranges, Calif. & Ariz | 3-9 | 38-48 | 85-90 | 3-8 weeks |
| Oranges, Fla. & Texas | 0-1 | 32-34 | 85-90 | 8-12 weeks |
| Papayas | 7-13 | 45-55 | 85-90 | 1-3 weeks |
| Passion fruit | 7-10 | 45-90 | 85-90 | 3-5 weeks |
| Pears | -1.5 to 0.5 | 29-31 | 90-95 | 1-2 weeks |
| Peas, green | 0 | 32 | 95-98 | 6-8 weeks |
| Peppers, Chill (dry) | 0-10 | 32-50 | 60-70 | 6 months |
| Peppers, Sweet | 7-13 | 45-55 | 90-95 | 2-3 weeks |
| Pineapples | 7-13 | 45-55 | 85-90 | 24 weeks |
| Plantain | 13-14 | 55-58 | 90-95 | 1-5 weeks |
| Pummelo | 7-9 | 45-48 | 85-90 | 12 weeks |
| Pumpkins | 10-13 | 50-55 | 50-70 | 2-3 months |
| Sapodilla | 16-20 | 60-68 | 85-90 | 2-3 weeks |
| Snow peas | 0-1 | 32-34 | 90-95 | 1-2 weeks |
| Soursop | 13 | 55 | 82-90 | 1-2 weeks |
| Spinach | 0 | 32 | 95-100 | 10-14 days |
| Squashes, Summer | 5-10 | 41-50 | 95 | 1-2 weeks |
| Squashes, winter | 10 | 50 | 50-70 | 2-3 months |
| Sugar apples | 7 | 45 | 85-90 | 4 weeks |
| Sweet Potatoes | 13-15 | 55-60 | 85-90 | 4-7 months |
| Tamarinds | 7 | 45 | 90-95 | 3-4 weeks |
| Tangerines, mandarins, & related citrus fruits | 4 | 40 | 90-95 | 24 weeks |
| Taro root | 7-10 | 45-50 | 85-90 | 4-5 months |
| Tomatoes, mature- green | 18-22 | 65-72 | 90-95 | 1-3 weeks |
| Tomatoes, firm-ripe | 13-15 | 55-60 | 90-95 | 4-7 days |
| Watermelons | 10-15 | 50-60 | 90 | 2-3 weeks |
| White Sapote | 19-21 | 67-70 | 85-90 | 2-3 weeks |
| Yams | 16 | 61 | 70-80 | 6-7 months |

Adapted from: McGeorge, B.M. 1989. Tropical Products Transport Handbook. USDA Office of Transportation, Agriculture Handbook 668.

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