Post-harvest Physiology and Technology of Horticultural Crops



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**CHAPTER ONE**

1. **Introduction**

**Chapter learning objectives**

At the end of this chapter students should be able to:

* Define what postharvest physiology and technology is
* Recognize basic concepts of postharvest physiology
* Differentiate the relationship between horticultural crops & postharvest physiology
* Realize the significance of post-harvest losses
* Define postharvest loss
* Estimate extent of postharvest loss of perishables
* Discuss the importance of postharvest loss
* Realize the natures and causes of post-harvest losses
* Point out/illustrate the major causes of postharvest loss
* List and discuss the means of prevention and control measures

**Content**

* 1. Basic concept of post-harvest physiology
	2. Importance of perishables
	3. Definition of post-harvest physiology and technology
	4. Postharvest nature of horticultural crops
	5. Importance of postharvest physiology
	6. Definition of post-harvest loss
	7. Extent and types of post-harvest losses
	8. Importance of postharvest losses
	9. Causes of postharvest losses

## Basic concept of post-harvest physiology

After spending months or years working in the field and harvesting the produce, everybody wants to ensure that the customers will enjoy this healthy harvest. The basic question in this intention is **how the quality and safety of the produce could be maintained during the time from harvest up to consumption**. High quality and disease free produce with a good shelf life is the result of sound production practices, proper handling during harvest and appropriate post-harvest handling and storage. Generally post-harvest handling maintains the produce through the time of harvest to the ultimate utilization, deterioration and death of the produce.

The way of utilization is not the same for all crops. For instance cut flowers are utilized as decoration whereas food crops are used for actual consumption. Different crops have also different resistance of loss in their shelf life; these are affected by the physiology of the produce. Pre-harvest factors have also an effect on post-harvest physiology. Environmental factors such as soil type, temperature, frost and rainy weather at harvest can have an adverse effect on storage life and quality of the produce.

Unsatisfactory management practices during production like watering, fertilization, control of pests and disease, and occurrence of mechanical injuries could be considered as pre-harvest factors in post-harvest physiology. Generally, understanding the post-harvest physiology and technology is very important for reduction of post-harvest losses (as these are wastage of produce, labor, material and capital).

**1.1.1. Importance of perishables**

Activity 1.1. What is importance of horticultural crops?

Activity 1.2. Why do we grow and consume fruit and vegetables?

1. **Nutritional importance**

Activity 1.3. What are phytochemicals and what are their roles in human diet?

* Fresh fruits & vegetables have been part of human diet for long time
* In the early days, animal products were more valued and only few nations capitalized on fruits and vegetables
* However, recently more attention has been rendered to the later because of more Obesity and coronary heart diseases incidences
* Estimates for the year 2006 are that 80,000,000 people in the United States have one or more forms of cardiovascular disease (CVD).
* Nearly 151,000 Americans killed by CVD in 2005 were under age 65.

Fruits and vegetables are low in fat and high in dietary fiber thus they are good substitute for animal based food staffs.

* As for ornamentals
	+ Mixed with prepared foods
	+ Principally, they are food for the mind
	+ Traditionally, they are gown in gardens, interiorscapes, hotels and offices
	+ Especial occasions
		- Weddings
		- Funerals
		- Mothers’ day
		- Valentine’s day
		- Parades and rallies
		- In some countries, they are symbol of the state

**ii. Economic importance:-** World population gets food resources from grains and cereals (52%), fruits and vegetables (41%), and animal products (7%). About 1.12 billion tons of horticultural crops (roots and tubers, vegetables and fruits) are produced all over the world every year and serve as source of income, creating job opportunity etc.

**iii. Aesthetic appeal: -** fruits and vegetables have excellent aroma, flavour and colour, that helps it to have excellent aesthetic appeal.

Activity 1.4. Define postharvest *physiology*

**Definition of post-harvest physiology and technology**

**Postharvest physiology**- It is the division of plant physiology dealing with **functional processes** in plant material after it has been harvested. It is concerned with plants or plant parts that are handled and marketed in the living state including seeds, fruits, vegetables, cut flowers and foliage nursery products, etc. It is the study that involves maintaining quality and preventing spoilage of horticultural crops. The postharvest physiology deals with the time period from harvesting or removal of the plant from its normal growing environment to the time of ultimate utilization, deterioration or death. In a situation where pre-harvest and harvesting factors have a direct influence on postharvest response, they are also considered to be vital components of the complete postharvest picture.

**Post-harvest nature of Horticultural crops**

Activity 1.5. Make a distinction between durable & perishable plant products (Discuss in group).

**Durables**

* + Low moisture (10-15%)
	+ Small unit size (<1kg)
	+ Very low respiration rate with very small heat generation
	+ Hard texture, not easily damaged
	+ Stable, natural shelf life of several years
	+ Loss mainly caused by external agents, e.g. Molds, insect & rodents

**Perishables**

* + High moisture (50-90%)
	+ Large unit size (5g-5kg or more)
	+ High to very high respiration rate, with high heat production
	+ Soft texture, easily damaged
	+ Perishable, natural shelf life few days at best several months
	+ Loss caused partly by external agents e.g. rotting, bacteria & fungi and partly by endogenous factors, respiration, senescence and sprouting
	1. **Importance of post-harvest physiology and handling of perishable products**

Activity 1.6. Why the study of postharvest physiology & technology of horticultural crops is so important?

When we harvest wheat or teff, little harm is done. While in vegetables, fruits and ornamentals the damage is painful. In human terms it is “murder” (Ramswamy, 2005). So harvesting marks the beginning of deterioration process. Understanding postharvest physiology has advantages in increasing food supply and improving the economic situation of the producers and the country. Some of the importance of knowing post-harvest physiology & technology are the following:

* Horticultural products are usually of high value (compared to grains) and need to be handled carefully in order to preserve that value.
* Horticultural products are living commodities even after they have been harvested and deteriorate in quality very quickly. Therefore, it needs to maintain their quality in terms of appearance, texture, flavor and nutritional value etc…
* A lot of money and other resources are invested in growing the crop, and to get the best price possible for the crop, it must be looked after appropriately until it reaches the consumer.
* Horticultural crops are rich source of vitamins, minerals, proteins and medicinal substances proper care helps maintain nutritional & pharmacological value.
* Quantity and quality of food supply will be maintained.
* Reducing post-harvest loss has economical advantage. Remind that post-harvest handling uses only <1% of the energy used in production.
* Respiration and other metabolic activities takes place even after harvest, hence there should be substrates for such respiration;
* Water is the major constituent, hence easily perishable or having short shelf life;
* Fresh produce are used in a state which require careful handling to maintain its food safety from harvesting to ultimate use. Hence mechanical injury and contamination with harmful, dust or any other extraneous materials should be avoided in order to have good quality and healthy produce for consumers;

**1.6 Definition of post-harvest loss**

Activity 1.7. What is Post-harvest loss?

Activity 1.8. When do we say a given perishable crop is lost?

A **post-harvest loss** is any change in the quantity or quality of a product after harvest that prevents or alters its intended use or decreases its value. Losses can be qualitative or quantitative. The extent of loss in perishables depends upon type of commodity (5-100 percent).

Activity 1.9. Where is the beginning of postharvest loss?

Losses can occur at any stage after harvest

* Culling after harvest
* Grading (field or packing house)
* Storage loss
* Transit loss
* Retail loss
* Consumer loss



**The best quality goes to the market!!! The poor quality goes to waste and some part to secondary market!!!s**

Figure 2.1.Graphic representation of the food pipeline by Bourne (1977)

**1.7. Extent of post-harvest losses**

Activity 1.7. How big is the extent of post-harvest loss?

Activity 1.8. How do you think postharvest losses vary across commodity types, with production areas and the season of production?

Generally, Post-harvest losses vary greatly across **commodity types**, **with production areas** and the **season of production**.

1. **The nature of the product/its perishability**

In nature, horticultural products are more perishable that agronomic products. This is due to the fundamental differences between perishables/horticultural crops/ and durables /agronomic crops/. Generally postharvest loss is expected to be 25% and 25–100% for durables and perishables, respectively. There is also a difference among horticultural crops in terms of postharvest period losses. Fruits and vegetables are more perishable than root and tuber crops.

Table 2.1. Reported losses in less developed countries on different horticultural commodities, production amount & estimated loss

|  |  |  |  |
| --- | --- | --- | --- |
| **No**  | **Commodities**  | **Production (000 tone)**  | **Estimate loss (%)** |
| 1 | **Root and tuber crops** |  |  |
| Carrot  | 557 | 44 |
| Potato  | 26,909 | 5 – 40 |
| Sweet potato  | 17,630 | 35 – 95 |
| Yams | 20,000 | 10 – 60 |
| Cassava  | 130,486 | 10 – 25 |
| 2 | **Vegetables**  |  |  |
| Onion  | 6,474 | 16 – 35  |
| Tomatoes  | 12,755 | 5 – 50  |
| Plantain  | 18,301 | 35 – 100  |
| Cabbage  | 3,036 | 37 |
| Cauliflower  | 916 | 48 |
| Lettuce  | - | 62 |
| 3 | **Fruits**  |  |  |
| Banana  | 36,898 | 20 – 80  |
| Papaya  | 931 | 40 – 100  |
| Avocado | 1,020 | 43 |
| Citrus  | 22,040 | 20 – 95  |
| Grape  | 12,720 | 27 |

1. **Production area**

The amount of postharvest loss is different in developed (5 - 25%) and less developed (20 – 50%) countries. The pattern of loss is also different in the two classes of the world. When compared to postharvest loss, high loss is occur on the farm during harvest in developed countries due to; mechanical damage by machine harvesters and rejection of the product (only by considering their size, shape and color on the field without looking its quality or content). On the other hand, harvest losses on the farm are low in less developed countries because of; less mechanical damage/harvest is done by hand picking/ and low quality standards. However, postharvest losses are high in these countries because of the very poor postharvest technology. Generally, the magnitude and pattern of loss varies among developed and less developed countries because of the variation in economic and technological situations. Overall, about one third of horticultural crops produced are never consumed by humans. Overall, about one third of horticultural crops produced are never consumed by humans.

The extent of loss in perishables depends upon type of commodity 5-100%. Post-harvest losses in developed countries are much less as compared to developing countries.

* In Ethiopia, some perishables have shown up to **80%** loss
* Loss of product = much more than just the cost of the commodity

### 1.8. Types of post-harvest losses

The types of postharvest loss could be:

* **Quantitative loss:-** complete physical loss or loss of weight or volume
* **Qualitative loss:-** loss of nutritional value, sensory/change in aroma, flavour, color, texture and freshness
* **Economic/marketability loss**

### Activity 1.9.What is the role of internal and external quality attributes?

**1.9 Causes of post-harvest losses**

Factors affecting post-harvest food losses of perishables vary widely from place to place and become more and more complex as systems of marketing become more complex. A farmer who is growing fruit for his family's consumption probably doesn't mind if his produce has a few blemishes and bruises. If he is producing for a market at any distance from his own locality, however, he and his workers, if he has any, must have a different attitude if he hopes to get the best money return on his work. All fruits, vegetables and root crops are living plant parts containing 65 to 95 percent water, and they continue their living processes after harvest.

Their post-harvest life depends on the rate at which they use up their stored food reserves and their rate of water loss. When food and water reserves are exhausted, the produce dies and decays. Anything that increases the rate of this process may make the produce inedible before it can be used. The principal causes of loss are discussed below.

The grower must recognize that small changes in attitudes toward the prevention of post-harvest food losses may profit him more than changes in the techniques of the marketing chain, whether containers or transport improvements, and may cost him less in the long run. He must instruct his family, field workers, and others in the methods of reducing his losses.

Activity 1.10. What are the major causes of loss after harvest?

**Bourne (1977); Salunke and Desai (1989) have classified the causes of loss as follows:**

1. **Primary Causes of Loss**

Primary causes of losses are those causes that directly affect the food. They may be classified into the following groups:

1. **Biological:** Consumption of food by rodents, birds, monkeys and other large animals causes direct disappearance of food. Sometimes the level of contamination of food by the excreta, hair and feathers of animals and birds is so high that the food is condemned for human consumption. Insects cause both weight losses through consumption of the food and quality losses because of their webbing, excreta, heating, and unpleasant odors that they can impart to food.
2. **Microbiological:** Damage to stored foods by fungi and bacteria. Micro-organisms usually directly consume small amount of the food but they damage the food to the point that it becomes unacceptable because of rotting or other defects. Toxic substances elaborated by molds (known as mycotoxins), cause some food to be condemned and hence lost. The best known of the mycotoxins is aflatoxin (a liver carcinogen), which is produced by the mold Aspergillusflavus.

Another mycotoxin which is found in some processed apple and pear products is patulin, which is formed in the apple by rotting organisms such as *Penicilliumexpansum* which infect fresh apples before they are processed.

All living material is subject to attack by parasites. Fresh produce can become infected before or after harvest by diseases widespread in the air, soil and water. Some diseases are able to penetrate the unbroken skin of produce; others require an injury in order to cause infection. Damage so produced is probably the major cause of loss of fresh produce. The influences of all three causes are strongly affected by the various stages of post-harvest operations. Furthermore, they all have great effect on the marketability of the produce and the price paid for it.

1. **Chemical:** Many of the chemical constituents naturally present in stored foods spontaneously react causing loses of color, flavor, texture and nutritional value. An example is the Maillard reaction that causes browning and discoloration in dried fruits and other product. There can also be accidental or deliberate contamination of food with harmful chemicals such as pesticides or obnoxious chemicals such as lubricating oil.
2. **Biochemical reactions:** A number of enzyme-activated reactions can occur in foods in storage giving rise to off-flavors, discoloration and softening. One example of this problem is the unpleasant flavor that develops in frozen vegetables that have not been blanched to inactivate these enzymes before freezing.
3. **Mechanical:** Bruising, cutting excessive pulling or trimming of horticultural products are causes of loss. Careless handling of fresh produce causes internal bruising, which results in abnormal physiological damage or splitting and skin breaks, thus rapidly increasing water loss and the rate of normal physiological breakdown. Skin breaks also provide sites for infection by disease organisms causing decay.
4. **Physical:** Excessive or insufficient heat or cold can spoil foods. Improper atmosphere in closely confined storage at times causes losses.
5. **Physiological:** Natural respiratory losses which occur in all living organisms account for a significant level of weight loss and moreover, the process generates heat. Changes which occur during ripening, senescence, including wilting, and termination of dormancy (e.g., sprouting) may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. A reduction in nutritional level and consumer acceptance may also arise with these changes. Production of ethylene results in premature ripening of certain crops. An increase in the rate of loss because of normal physiological changes is caused by conditions that increase the rate of natural deterioration, such as high temperature, low atmospheric humidity and physical injury. Abnormal physiological deterioration occurs when fresh produce is subjected to extremes of temperature, of atmospheric modification or of contamination. This may cause unpalatable flavours, failure to ripen or other changes in the living processes of the produce, making it unfit for use.
6. **Psychological:** Human aversion, such as "I don't fancy eating that today". In some cases food will not be eaten because of religious taboos.

**Microbiological, mechanical and physiological** factors cause most of the losses in perishable crops.

1. **Secondary Causes of Loss**

These are losses that lead to conditions that encourage a primary cause of loss. They are usually the result of inadequate or non-assistant capital expenditures, technology and quality control. Some examples are:

* Inadequate harvesting, packaging and handling skills.
* Lack of adequate containers for the transport and handling of perishables.
* Storage facilities inadequate to protect the food.
* Transportation inadequate to move the food to market before it spoils.
* Inadequate drying equipment or poor drying season.

Traditional processing and marketing systems can be responsible for high losses.

Table 1.1 Main causes of post-harvest losses in vegetables



Activity 1.11.How do we minimize these losses?

* **There is a huge loss! What can be done?**
* **Grow more food or reduce postharvest loss?**
* **How much more food?**

World population is increasing at faster rate than food production. Population growth: 50% increase in 20 years. Food production: increases by 3-5% per 5 years. However, with increasing population and limited land, this option has proved impossible. Employing modern agricultural operations was also less applicable to developing countries.

Another practical alternative is to minimize post-harvest losses to increase food availability. Grow **More Food & reduce post-harvest losses**. Although minimizing post-harvest losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5 percent of the funding of agricultural research and extension programs worldwide is devoted to activities related to maintenance of produce quality and safety during post-harvest handling. This situation must be changed if success is to be achieved in reducing post-harvest losses of horticultural perishables.

**How do we grow more food?**

* + Cultivate more land
	+ **Intensify** agricultural production
	+ Use high density planting
	+ Use modern tools
	+ Use growth promoters
	+ Use new varieties, new fertilizers
	+ Use **genetically modified** foods??
	+ We should do EVERYTHING we can

**PLUS, more importantly reduce post-harvest losses**

**Farmer must give careful attention to:**

* Market demand for the products he will grow; he must know the market and his buyers.
* Cultivation: Follow Good Agricultural Practices (GAP)
* Suitable and attractive packing or packaging.
* Transportation in refrigerated van
* Market handling; possibly storage or refrigeration.
* Perishability of the produce.
* Appropriate post-harvest processes (harvesting, cleaning, grading, cooling, storing, packaging, transporting and marketing).

 **Advantages of reducing PHL**

* Nutritional advantages
* Economic Advantages
* Feedback incentive to the growers
* Cost effective
* Environmentally friendly
* Consumer satisfaction
* How can we reduce post-harvest losses?

 **How can we reduce post-harvest losses?**

 **We can do it if we**

* 1. Understand the causes of postharvest losses
	2. Determine factors which affect them and how
	3. Effectively use conditions which control the factors and minimize the spoilage
	4. Understanding the nature of the produce
	5. Design an appropriate handling techniques that maintain the produce in best condition

**1.2. Structure and Composition of horticultural crops**

**1.2.1. Structure of the harvested product**

Activity 1.2.1. What is the significance of know the structure of harvested products in relation to their postharvest physiology?

The physiological changes that take place on harvested products and the way to handle the products depends on the material harvested. The above two are related with the structure of the product which in turn related with the function, because there is specialization in the intact plant. Based on structure, horticultural products are categorized as leaves, stems, flowers, fruits, and below ground structures (roots, bulbs and tubers).

1. **Leaves**

Harvested leaves of vegetables like spinach, cabbage, lettuce, celery, leek, and onion widely used as food. When the leaves are on intact plant, they play important role in carbon fixation (photosynthesis) and transpiration (control loss of water and heat removal).

At harvest, carbon fixation and transpiration stopped, stomata closed and the continued survival of the leaf depends on the energy and water already present in the leaf. Leaves of most species do not act as long term reserves because of rapid respiration and water loss; leaf area is large and the harvested material is exposed to sunlight and water easily evaporate which lead to rapid deterioration of the products quality.

1. **Stems**

Some vegetables like asparagus (sprouted stem), Brussels (auxiliary buds) and Sugar cane (true stem) have edible stems and these stems are young tissues, metabolically active and it has continued development after harvest.

1. **Flowers**

Flowers are composed of compressed shoots that are adapted for reproduction. Plant breeders have produced various vegetables with dense massed flower heads that can be eaten when the flowers are immature buds. These have long been popular in temperate countries but in recent years have become well-known in the tropics, where cultivars that can be grown in warm conditions or at higher altitudes have been developed. Flowers of Cauliflower, Broccoli, Artichoke and many ornamentals served as a food. Flowers postharvest handling is very difficult because:

they have little reserve food; contain diverse, young and meristematic parts that affect their postharvest life; and are meant to live for a short period (source of water and reserves for flowers are stems and leaves attached with flowers).

1. **Fruits**

Fruit is mature ovary with a number of associated parts. It can be categorized in to:

* Fleshy fruits: example Banana, Papaya
* Dry fruits: they release their seeds after their external cover is removed. E.g. nuts
* Vegetable fruits: they are treated as vegetables

The postharvest behavior is also different in each category.

**Fleshy fruits:** can be classified as

Activity 2.2. Differentiate between Climacteric fruits and Non-climacteric fruits

1. **Climacteric fruits**: - have the potential to ripen after harvest. Example: Banana, Tomato
2. **Non-climacteric fruits**: - must be harvested when they are completely ripe. Example: Citrus, Avocado. They are very difficult to preserve after they are harvested since they are harvested when they fully ripen.

**V. Below ground structures**

These are underground parts of plants, adapted for the storage of food materials. They are the means by which the crop survives unfavorable seasonal conditions, and they provide the food reserve enabling the plant to make rapid growth when conditions are favorable. They serve as organs of storage and propagation. Their continued existence depends on the reserve material and utilization of starch is take place to provide energy for the produce existence.

Dormancy is present in some of these products (potato, yam) and desirable in postharvest aspect because when the produce is dormant it has low metabolic activity.

Buds are present on these structures and they determine how long the product is preserved; because buds are capable to grow and deteriorate the reserve food.

Roots are also act as storage organs for several crops like Carrot, Beet, Radish, Cassava and Sweet potato. Rhizomes and tubers are underground structures/specialized stems for some crops like Potato, Yam, Taro, Enset and Ginger.

Bulbs are underground stems, which serve as storage and propagation organs. There is no anatomical distinction/abscission zone/ between the stem and the leaf base and on maturation the leaf dies and shrinks, so harvesting is removal of the dead leaves and collection of the bulbs but the leaves continue further development.

When we see the tomato, it has abscission zone between the fruit and the fruit stalk which protects further growing, but in bulbs there is no such anatomical structure and the bulb is exposed to wounding and continuous development. To summarize, the structure and response, horticultural product structures generally are perishable, but there is a great difference among different structures.

**1.2.2. Composition of fruits and vegetables**

Activity 12.2. Name the main composition of fruits and vegetables

**a. Water**

The moisture content in horticultural crops is the most abundant constituent and ranges from 65% - 95%. It is an important component of product quality that is related to turgidity, freshness, firmness, and succulence of the harvested product. It is also part of the weight of the produce and quantitative loss will happen when the water content of the produce reduced.

Most vegetables and fruits = 80 g water/100 g produce

Cucumber, lettuce, melons = 95 g water

Starch tubers, seeds, yam, cassava, corn = less water but > 50 g

The water content of the produce depends on

* + - Available water at harvest
		- Diurnal variation in Temperature and RH

Therefore, for most harvesting should be at maximum possible water content because it results in crisp texture, esp. in leafy vegetables.

 **b. Carbohydrates**

Carbohydrates are the most abundant biochemical constituents in plants, representing (50 - 80%) of the dry weight of the plant. They are also the largest constituents (2% - 40%) of harvested fruits and vegetables and functions as a form of stored energy reserves and make up much of the structural frame work of the cells.

The main types of sugars in fruits & vegetables are:

* + Sucrose, glucose, and fructose
	+ Glucose and fructose occur in all produce and are often present at similar levels
	+ Sucrose is only present in about 2/3 of produce
	+ Highest level of sugars are found in tropical and subtropical fruits, with grape being the only temperate fruit listed

|  |  |  |  |
| --- | --- | --- | --- |
| * + 1. Produces
 | * + 1. Glucose
 | * + 1. Fructose
 | * + 1. Sucrose
 |
| * + 1. Apple
 | * + 1. 3
 | * + 1. 6
 | * + 1. 2
 |
| * + 1. Banana
 | * + 1. 4
 | * + 1. 4
 | * + 1. 10
 |
| * + 1. Beet root
 | * + 1. <1
 | * + 1. <1
 | * + 1. 8
 |
| * + 1. Capsicum
 | * + 1. 2
 | * + 1. 2
 | * + 1. 0
 |
| * + 1. Grape
 | * + 1. 8
 | * + 1. 8
 | * + 1. 0
 |
| * + 1. Onion
 | * + 1. 2
 | * + 1. 2
 | * + 1. 1
 |
| * + 1. Orange
 | * + 1. 2
 | * + 1. 2
 | * + 1. 4
 |
| * + 1. Peach
 | * + 1. 1
 | * + 1. 1
 | * + 1. 5
 |
| * + 1. Pear
 | * + 1. 2
 | * + 1. 7
 | * + 1. 1
 |
| * + 1. Pine apple
 | * + 1. 1
 | * + 1. 2
 | * + 1. 5
 |
| * + 1. Tomato
 | * + 1. 1
 | * + 1. 1
 | * + 1. 0
 |

* + Sucrose, glucose, and fructose
	+ Glucose and fructose occur in all produce and are often present at similar levels
	+ Sucrose is only present in about 2/3 of produce
	+ Highest level of sugars are found in tropical and subtropical fruits, with grape being the only temperate fruit listed

|  |  |  |  |
| --- | --- | --- | --- |
| * + 1. Produces
 | * + 1. Glucose
 | * + 1. Fructose
 | * + 1. Sucrose
 |
| * + 1. Apple
 | * + 1. 3
 | * + 1. 6
 | * + 1. 2
 |
| * + 1. Banana
 | * + 1. 4
 | * + 1. 4
 | * + 1. 10
 |
| * + 1. Beet root
 | * + 1. <1
 | * + 1. <1
 | * + 1. 8
 |
| * + 1. Capsicum
 | * + 1. 2
 | * + 1. 2
 | * + 1. 0
 |
| * + 1. Grape
 | * + 1. 8
 | * + 1. 8
 | * + 1. 0
 |
| * + 1. Onion
 | * + 1. 2
 | * + 1. 2
 | * + 1. 1
 |
| * + 1. Orange
 | * + 1. 2
 | * + 1. 2
 | * + 1. 4
 |
| * + 1. Peach
 | * + 1. 1
 | * + 1. 1
 | * + 1. 5
 |
| * + 1. Pear
 | * + 1. 2
 | * + 1. 7
 | * + 1. 1
 |
| * + 1. Pine apple
 | * + 1. 1
 | * + 1. 2
 | * + 1. 5
 |
| * + 1. Tomato
 | * + 1. 1
 | * + 1. 1
 | * + 1. 0
 |

 Sugar content (g/100g fwt) of some fruits & vegetables

Beet root contains the highest sugar among vegetables (8 g/100 g) with sucrose being the only sugar present. Much of the sensory appeal for fruits is due to sugar since sweetness is the universal innate human taste preference. Produces such as cassava and yam commonly contain > 20g / 100 gr as starch.

**Starch from -** Plantain, cassava, yam, taro, Sweet potato and potato provide the bulk of energy in the diet of subsistence group

Cellulose, pectin substances and hemicelluloses are the main carbohydrate polymers that constitute fiber. Dietary fiber is not digested by humans because enzymes are not secreted that can break down polymers to monomers that can be absorbed.

* + - Starch – requires amylase
		- Cellulose- requires cellulase
		- Pectin- pectinase
* Dietary fiber, though has no nutritional value
	+ Avoids constipation
	+ Avoids a raft of diseases, mostly affiliated to western countries (Diseases of affluence)

**c. Protein**

The protein content in horticultural products varies between 1–2%, about 5% in legumes and contains molecules/enzymes involved in the metabolic regulations.

Fresh fruits and vegetables contain = 1g/100 g in fruits. 2 g /100 g in vegetables

Most abundant being in

* + Brassica vegetables = 3.5 g protein/100 g
	+ Legumes = 5 g /100 g

The protein is mostly functional as in the form of enzymes rather than storage organ. Fresh fruits and vegetables are not important sources of protein

**d. Lipids**

Lipids comprise less than 1 g/ 100g. Usually found associated with cuticle. Avocado and olive exceptionally have 20 g & 15 g lipid/100 g as oil droplets in the cells. Generally low lipid content is seen as a positive factor in combating the rise of heart diseases. Therefore, increased consumption of fruits & vegetables is extensively promoted by health authorities. Even high lipid fruits like Avocado and Olive have mono-unsaturated fats, which have been shown not to increase the incidence of heart diseases.

Fatty acids are substantial physical and chemical properties of lipids due to the long chain present in fatty acids. The most common fatty acids in plants range from carbon in size, with oleic and lemoleic being the most prevalent types. Among the lipids, waxes, cutin and subrin are the protective compounds of the outer surface of plants. In which waxes and cutin acts as the protective coating on much of above ground parts of the plants. Likewise, subrin; a lipid derived polymeric material is found on underground plant part and on healed surface of wounds.

These plant waxes, are extremely important during the postharvest storage and marketing of plant products in that, they function by limiting the water loss from the tissue and impeding the invasion of pathogens. Fatty acids are synthesized within the cytocol of the cell and in many cases within certain plastids (e.g. chloroplast, chromoplast).There are two path ways for these processes, one from **saturated fatty acids** and the other forming **unsaturated fatty** acids.

**e. Vitamins**

Vitamins represent a group of organic compounds that are required in the diet in relatively small amounts for normal metabolism and growth. Plant products provide a major source for many of the vitamins required by the humans. Exception would be B12, which appears to be synthesized only by microorganisms, and vitamin D, obtained from the exposure of skin to the ultraviolet irradiation. In plants, many of the vitamins perform the same biochemical functions as they do in animal cells. Consequently, most have a vital role in plant metabolism, in addition to being a source of vitamins for animals.

Typically, vitamins are separated in to two classes based on their solubility: the **water-soluble** vitamins including (thiamine, riboflavin, nicotinic acid, panthothenic acid, pyridoxine, biotin, folic acid, and ascorbic acid), and the **lipid-soluble vitamins** are, (vitamin A, E, and K). Normally the lipid-soluble vitamins are stored in the body in moderate amount; as a consequence, a consistent daily intake is not essential. The water soluble vitamins, however tend not to be stored and a fairly constant day-to-day supply is required.

**f. Minerals**

All vegetables and fruits contain important minerals, such as potassium, calcium, magnesium, phosphorus, iron, and zinc. Minerals are basic components **in secondary metabolic pathways** that produce valuable phytochemicals for normal human health. The contents of minerals in vegetables are variable; green vegetables have higher amounts of calcium and iron than root vegetables. Calcium is not only associated with preventing osteoporosis, but it also appears to have protective effects in some types of cancer, most recently colon cancer.

**g. Organic acids**

Organic acids are major components of fruits and some vegetables. 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).Organic acids are present in a significant concentration in a number of harvested plants, and the level of organic acids present often represents important quality parameters in many fruits. Many organic acids have multiple functions in the plants. In addition, in food produce, organic acids share a significant portion of the characteristic flavour, both taste and odour. Organic acids also have very important role in the TCA cycle. The number of organic acids present in postharvest products include: glycolic acid, lactic acid, glyceric acid, pyruvic acid, glycoxylic acid, oxalic acid, succinic acid, fumaric acid, malic acid, etc. Organic acids play important role in harvested products. Where they are found in high concentration, they represent a readily available source of stored energy that can be utilized after the product is severed. In food products organic acids may take a significant portion of the characteristic flavour; taste and odour. Aromatic compounds like esters of organic acids represent characters that impart the major portion of the characteristic aroma.

The dominant acids are:

* + Citric acid (Citrus)
	+ Malic acid (Banana)

Others are:

* + Tartaric acid (grapes)
	+ Oxalic acid (Spinach)
	+ Isocitric acid (black berries)

Organic acids contribute to the taste, particularly of fruits

The balance between sugar and acids gives rise to the desirable taste of specific produce.

* High sugar and High acid - Good taste
* Low sugar and High acid - Tart test
* High sugar and Low acid- Bland test
* Low Sugar and Low Acid- Tasteless

**h. Plant pigments**

Human lives are surrounded and in many ways dominated by plant colors which are due to the presence of pigments within the plants and their interaction with sun light striking them, which some of them will be absorbed by photosynthesis. These plant pigments are separated in to four primary classes based on their chemistry known as; Chlorophyll, Carotenoids, Flavonoids and Betains.

1. **Chlorophyll: The plant body attains the green color, which is the result of the presence of the chlorophyll pigments. Chlorophylls are the primary light accepting pigments that help plants to carryout photosynthesis through the fixation of carbon dioxide and the release of oxygen. There are four types of chlorophylls named as, a, b, c and d, in which c and d are present in limited number of plant species. Chlorophylls are hydrophobic (water insoluble) and their function is to absorb light energy and convert it to chemical energy in the chloroplast.**
2. **Caroteniods:** Are a large group of pigments associated with chlorophyll in the chloroplasts and are found also in the chromoplasts. Their colors range from red, orange and yellow to brown and are responsible for much of outer leaf pigmentation. It is grouped into the carotenes and their oxygenated derivatives, the xanthophylls. In photosynthetic tissues, carotenoids functions both in the photosynthesis process and as Protestants, preventing chlorophyll molecules from being oxidized in the presence of light and oxygen. In flower and fruits, carotenoids appear to act as attractants that aid securing pollination or dispersal.
3. **Flavonoids:** Even though green is the dominant color in plants, other colors having tremendous attraction both for man and animals. Many of the intense colors of flowers fruits and some vegetables are the result of flavonoid pigments. They represent a large class of water soluble compounds with adverse range of colors (yellow, red, oranges) and are found in the cytosol and in vacuoles.
4. **Betains:** It represents a restricted group of plant pigments. Found in the flowers, fruits, and other plant parts. Give colours of yellow, orange, red and violate. Example is the red-violate pigment of beet root. Characterized from the others by being water soluble nitrogenous pigment found in the cytosol and vacuole. Its function is unknown but they may function like the anthocynonins enhancement insect or bird pollination and seed dispersal

**Review questions**

1. Specify the distinguishing features of pre-harvest, postharvest physiology and technology.
2. Give explanation on how ornamentals plants are said to be **food for the mind**.
3. What is the need of studying about perishables after harvest?
4. Quality products are produced in the field. But, the quality of a product is maintained during its harvest and post-harvest management. What do you understand from this sentence?
5. What are the negative consequences of inappropriate post-harvest handling? Illustrate clearly in detail.
6. Why do we need to cool horticultural produce as soon as possible after harvest
7. “A fruit per day keeps a doctor away.” What do you understand from this sentence?
8. Leafy vegetables are highly and easily perishables. True /False. Why?
9. Knowing the composition of fruit and vegetables is essential to understand their postharvest physiology. How?

**CHAPTER TWO**

**2. Physiology & Biochemistry of produce in relation to post harvest**

**Chapter learning objectives**

**After studying, this chapter, the student should be able to:**

* Comprehend different physiological processes of harvested materials
* Explains the relationships between respiration, shelf life and quality
* Identify the role of transpiration and quality of horticultural crops
* List factors affecting respiration and transpiration
* Recognize the role of phyto-hormones to post harvest
* Enlighten how stresses affects post-harvest physiology of horticultural crops

2.1. **Stages of fruit and vegetable development**

Developmental period of plants begins with germination and end up on death and it can be viewed at both the whole plant as well as organ level.

**Terminologies**

**Growth: -** the time of active cell division and enlargement which leads to increase in size or volume.

**Maturity: -** the time period when the plant has completed its active growth (vegetative stages, stages of flowering and seed production) stages.

**Ripening: -** the developmental stage of fruits and vegetables which is characterized by a series of diverse physical and chemical changes and follows maturation.

**Senescence: -** refers to the time when a series of deteriorative changes occur leading to the natural death of the plant

The developmental cycle of plants is usually interrupted by harvesting. For example: asparagus and lettuce are harvested when they produce sprouted stems; fleshy fruits harvested when they are at mature/ripe stage; and seeds of grains harvested when they completed their development including senescence.

**Maturity**

A critical time for growers of fruit and vegetables is the period of decision on when to harvest a crop. Normally any type of fresh produce is ready for harvest when it has developed to the ideal condition for consumption. This condition is usually referred to as harvest maturity. Confusion may arise because of the word maturity since, in the botanical sense, this refers to the time when the plant has completed its active growth (vegetative growth) and arrived at the stage of flowering and seed production (physiological maturity) as shown in Figure 4.1. Harvest maturity thus refers to the time when the "fruit" is ready to harvest and must take into account the time required to reach market and how it will be managed en route. This time lag usually means that it is harvested earlier than its ideal maturity.

Maturity can be categorized as physiological and harvest maturity. Physiological maturity refers to the stage of development when the plant is capable of shifting from vegetative to reproductive growth stages whereas, harvest maturity refers to the stage of development that is considered an ideal condition for consumption/ harvest. However, harvest maturity doesn’t mean immediate utilization or consumption.

For example, Banana for long distance transport should be harvested when 3/4th of the ripened stage (green stage) is completed and the rest of ripening stages will be completed during storage and transportation.

Harvest maturity consists of different considerations.

1. **Stages of harvest: -** horticultural crops have wide variations in their stages of harvest maturity. For example, fruits reach at their harvest maturity when they are at mature/ripe stage, whereas, vegetables harvested at all levels of developmental cycles/stages (sprouts, stems and leaves, inflorescences, root and tubers at various developmental stages, and seeds).
2. **Duration of the period of harvest maturity:** the period of harvest maturity can be stayed in several months (example; root crops like Cassava and Enset) or in weeks (example; oranges, coffee) or even in hours (example; flowers).

Optimum maturity/the right time for harvest/ determine: optimum quality, postharvest period, and maintenance of quality after harvest. Most growers identified/decide optimum harvest maturity (when to harvest) by looking and sampling. Judgments are based on: sight (colour, size and shape), touch (texture, hardness or softness), smell (odour or aroma), taste (sweetness, sourness, bitterness), or resonance (sound when tapped).

Experience is the best guide for this kind of assessment. Newcomers to fresh produce-growing may find that learning takes time. Harvest maturity can readily be observed in some crops: bulb onions when their green tops collapse and potatoes when the green tops die off. Other crops can be more difficult: for example, avocados remain unripe off the tree after maturity.

Different actors have different maturity criteria. For example, for the producer optimum maturity means when the produce fetch maximum price and he/she may harvest produce even when they do not reach at the right harvest maturity. For the transporter, the optimum maturity is the condition when produce can reach at the desired utilization site with minimum damage. For the store people, optimum maturity means the stage of the product that can take minimum place and the product can stay for maximum possible period without appreciable loss. For the consumer, optimum maturity means the stage at which the product has maximum nutritional and visual quality.

 **Maturity indices**

Importance of Maturity Indices

* Sensory and Nutritional Quality
* Use Fresh market or Processed
* Adequate shelf - life
* Facilitate marketing standards
* Productivity

**PHYSIOLOGICAL MATURITY:** The stage of development when a plant part will continue development even if detached; mature fruits

* Reached at the end of development
* May not coincide with ripening maturity

**HORTICULTURAL MATURITY:** The stage of development when a plant part possesses the necessary characteristics for use by consumers

* Reached well before end of development
* May or may not be followed by physiological process

e.g. cucumber

**Maturity Indices for different crops**

**Onions/Garlic**

* + Size
	+ Drying and collapse of the “neck”
	+ Drying of leaf scales

**Potatoes**

* + Death of the plant
	+ Size of tubers
	+ Starch content; specific gravity
	+ Periderm development

**Asparagus**

* + Size
	+ Apex closed

 **Broccoli/Cauliflower**

* + Size
	+ Florets closed

**Carrot**

* + Size

 **Lettuce, head**

* + Size
	+ Firmness, solidity
	+ Flavor-sweetness, bitterness

 **Lettuce, Romaine**

* + Size
	+ Number of leaves

**Beans**

* + Size
	+ Seed development

**Summer Squash & Cucumber**

* + Size
	+ External color

**Peppers**

* + Size
	+ Color
	+ Firmness
	+ Seed development

 **Tomato**

* + External and Internal color
	+ Development of locules (jelly)
	+ Firmness
	+ Size
	+ Development of cuticle

**Mango maturity indices:**

* Fullness of shoulders
* Internal and external color
* Lenticels and hairs on pit
* Starch content; specific gravity

**Apples**

Days from full bloom

* Time/temp (heat units) from anthesis
* Days from harvest to onset of ethylene production
* Ground color
* Soluble solids content (SSC)
* Flesh firmness and SSC
* Starch disappearance pattern
* Internal ethylene concentration
* Changes in firmness or starch content

**What is a good maturity index?**

* Simple, easy to carry out
* Objective vs subjective indicators
* Related to quality
* Related to storage life
* Represents a progressive change with maturity
* Permits prediction of maturity from year to year
* Inexpensive

**Predicting Maturity**

* Days from planting to harvest
* Progressive changes in size, composition
* Difficult to do; need new tools and methods
	+ Nondestructive firmness measurement: fruits
	+ Chlorophyll fluorescence, broccoli: green tissues
	+ NIR spectroscopy: sugar concentration in melon
	+ Imaging constituents: internal defects

**2.2. Respiration**

Activity 3.1. What is respiration? Why do plants respire?

Respiration (i.e. biological oxidation) is the oxidative breakdown of complex substrate molecules normally present in plant cells such as starch, sugars, and organic acids to simpler molecules such as CO2 and H2O. Concomitant (associated) with this catabolic reaction is the production of energy and intermediate molecules that are required to sustain the myriad (countless) of anabolic reactions essential for the maintenance of cellular organization and membrane integrity of living cells.

Maintaining an adequate supply of adenosine triphosphate (ATP) is the primary purpose of respiration. The overall process of aerobic respiration involves the regeneration of ATP from ADP (adenosine diphosphate) and Pi (inorganic phosphate) with the release of CO2 and H2O. If hexose sugar is used as the substrate, the overall equation can be written as follows:

C6H12O6 +6 O2 +38 ADP +38 Pi 6 CO2 +6 H2O +38 ATP+686 kcal

**2.2.1. Significance of respiration in postharvest biology**

Activity 3.2. Correlation between respiration, postharvest life and quality

In general, there is an **inverse relationship** between respiration rates and the postharvest life of fresh horticultural crops. The higher the respiration rate, the more perishable (shorter postharvest life) the commodity. Respiration plays a major role in the postharvest life of fresh fruits and vegetables for the reasons given below.

1. **Loss of Substrate**

Use of **various substrates** in respiration can result in **loss of food reserves** in the tissue and loss of taste **quality** (especially sweetness) and **food value** to the consumer. For certain commodities that are stored for extended periods of time, such as onions for dehydration, the loss of dry weight due to respiration can be significant. When hexose sugar is the substrate, 180 g of sugars are lost for each 264 g of CO2 produced by the commodity.

1. **Oxygen Requirements**

An adequate O2 concentration must be available to maintain aerobic respiration. This should be considered in selecting the various postharvest handling procedures, such as waxing and other surface coatings, film wrapping, and packaging. On the other hand, reduction of O2 concentration to less than 10% provides a tool for controlling respiration rate and slowing down senescence.

1. **Carbon Dioxide Production**

Accumulation of CO2 produced by the commodity in its ambient atmosphere can be beneficial or harmful, depending upon each commodity’s tolerance to elevated CO2 levels. For some vegetables, increasing the CO2 concentration around them in a controlled or modified atmosphere can be used to delay senescence and retard fungal growth.

1. **Release of Heat Energy**

The heat produced by respiration (vital heat), which is about 673 kcal for each mole of sugar (180 g) utilized, can be a major factor in establishing the refrigeration requirements during transport and storage. Vital heat must be considered in selecting proper methods for cooling, package design, method of stacking packages, and refrigerated storage facilities (i.e., refrigeration capacity, air circulation, and ventilation).

**2.2.2. Factors affecting respiration rate**

Activity 2.2.2. Which factors do you think can affect respiration rate?

Respiration has a direct bearing on quality. Deterioration of quality increases rapidly with respiration rate. However, respiration rate is not an absolute index of quality deterioration rate because commodities with same respiration rate have different storage life.

**Internal factors influence respiration**

* **Type of organ or commodity**:

 Leaves > fruits> roots.

* **Product size:**

 Bigger size< respiration rate.

* **Stages of development:**

 Young leaves >respiration.

* In fruits will depend on their classification as climacteric or non-climacteric.

**External factors influence respiration**

* **Mechanical damage** and product’s sanitary condition.
* **Temperature**
* **Atmosphere composition**
	+ Oxygen
	+ CO2
	+ Ethylene
* **Physical barriers**
	+ Waxes, plastic films, etc.

Respiration rate is measured by either measuring the amount of O2 consumed or CO2 produced over a given time and it is indicative of the general rate of metabolism. The **higher the rate of respiration** of a harvested product, the **faster the deterioration** and **shorter the shelf life**. Respiration has a direct bearing on quality. Deterioration of quality increases rapidly with respiration rate.

**A. Internal Factors**

i. **Type of organ or commodity**

Fruit and vegetables vary greatly in their respiration rates. Root, tuber, and bulb vegetables have low respiration rates. Fruit-type vegetables that are picked mature, such as tomato and melons, respire at a lower rate than those picked immature, such as green beans, sweet corn and okra. In general, leafy & tender vegetables (spinach, peas, corn, broccoli) have very high rates of respiration (Leaves > fruits> roots). Fruits with well-developed skin (Apple, orange, melons, etc) have lower rate than those with soft skinned (strawberry & raspberry). The respiratory rate is generally high in the developing stage which generally decrease as the tissues matures (Stages of development: young leaves >respiration).

Table 3.1. Classification of sample horticultural commodities according to respiration rates

|  |  |
| --- | --- |
| **Class**  | **Commodity**  |
| Very low | Dried fruits, nuts  |
| Low | Apple, garlic, grapes, onions, potatoes (mature), sweet potatoes. |
| Moderate  | Cabbages, carrots, figs (fresh), lettuce, nectarines, peaches, pears, peppers, plums, potatoes (immature), tomatoes |
| High  | Artichokes, Brussels sprouts, cut flowers, green onions, snap beans |
| Extremely high  | Asparagus, broccoli, mushrooms, peas, sweet corn |

Plant parts with vegetative floral meristematic tissues, such as asparagus, broccoli and green onions, have very high respiration rates. In general, the degree of perishability of fresh vegetables is directly proportional to their respiration rates. Differences among plant parts in the **surface area–to-volume** ratio and in the nature of their **surface coatings** (e.g., cuticle thickness, stomata, lenticels) influence their gas diffusion characteristics and consequently their respiration rates. Such differences are also responsible for genotypic variation in respiratory activity within a given commodity, as shown for lettuce. Pre-harvest factors, such as climatic conditions and cultural practices, can also affect the morphological and compositional characteristics of a given genotype, which, in turn, influences its respiration rate.

**There are two types of fruits**

* + **Climacteric fruits**: Manifest appearance of CO2 or ethylene peak coinciding with ripening or senesce (on or off the tree)
	+ **Non-Climacteric fruits**: are fruits that don’t show respiratory or ethylene pea

Table 2.2. Climacteric fruits and vegetable versus Non-climacteric fruits

|  |  |
| --- | --- |
| **Climacteric fruits**  | **Non-climacteric fruits**  |
| Apple, apricot, banana, fig, guava, mango, Avocado, nectarine, papaya, peach, pear, plum Plantain | Blackberry, cherry, date, grape, lemon, sweet orange, olive, lime, pineapple, strawberry |
| **Climacteric vegetables**  | **Non-climacteric vegetables**  |
| Muskmelon, tomato | Cucumber, eggplant, okra, pea, pepper, chili, summer squash, watermelon, gourd |

 **External factors**

**Temperature**

Temperature is the **most important environmental factor** in the postharvest life of fresh vegetables, fruits and ornamentals because of its dramatic effect on rates of biological reactions, including respiration. Respiration involves many enzymes whose activity is influenced by temperature. Limiting one enzyme affects the rest. The rise in temperature of the harvested produce increases the rate of respiration that leads the product to have undesirable characters. This is because, for every increase in temperature by 100C, the respiration rate will be double fold (Van’t Hoff rule). Respiration rate begins to increase from just above freezing and ceases at thermal death point. The rate increase is fairly linear until it approaches thermal death point where it becomes sigmoidal. Within certain temperature limits, respiration rate approximately doubles for every 10°C rise in temperature. This is called the Q10 value. It is also an indicator of the temperature sensitivity of respiration rate based on **Vant Hoff’s Law**

Q10 = Rate of respiration at (T° + 10)

 Rate of respiration at T°

However, for biological processes the relationship varies. Q10 values are usually high between 0-100C and fall to between 2-3 over 100C. Above 200C there often can be abnormal physiological phenomena which cause it to go very high or very low.

**Availability of oxygen**

The level of oxygen in the harvested perishable products determines the desirable or undesirable nature of that particular plant product. Respiration can take place with or without O2. But anaerobic respiration is undesirable because of off-flavor production. Oxygen levels higher than air (21%) don’t necessarily increase respiration rate while levels below 20% decrease the respiration rate. Air contains about 20 % of the oxygen essential to normal plant respiration, during which starch and sugars are converted to carbon dioxide and water vapor. When the air supply is restricted and the amount of available oxygen in the environment falls to about 2 % or less, fermentation instead of respiration occurs. Fermentation breaks down sugars to alcohol and carbon dioxide, and the alcohol produced causes unpleasant flavors in produce and promotes premature ageing Therefore, the extinction point of oxygen level when kept at minimum concentration is important to maintain aerobic respiration in a storage chamber of the produce. However the lower limits of O2 tolerance must be known to enable slowing down of respiration while avoiding anaerobic metabolism.

The minimum oxygen level necessary to maintain aerobic respiration in a storage chamber is called Extinction point (EP).Storage chambers should have proper ventilation to maintain O2 level above the EP. Waxing alters the skin porosity and rate of diffusion of CO2 and O2. The respiratory quotient (RQ) balance is maintained until O2 reaching the EP level, but once below the EP, it results in a significant increase in the RQ.

**Presence of carbon dioxide**

Carbon dioxide, which is the product of respiration, the presence of excess CO2 favors suppression of respiration. Generally, CO2 concentration up to 5% has beneficial effects in reducing respiration. While at higher concentrations it also has fungicidal effect. However, the product must be tolerant to high CO2 level. E.g. Strawberry.

Usually high RQ values with normal substrates may indicate onset of anaerobic respiration, while usually low RQ values may suggest incomplete oxidation to CO2. The composition of a commodity frequently determines which substrates are utilized in respiration and consequently the respiratory quotient (RQ). The RQ is defined as the ratio of CO2 produced to O2 consumed (measured in moles or volumes). Depending on the substrate being oxidized, RQ values for fresh vegetables range from **0.7 to 1.3** for aerobic respiration. When carbohydrates are being aerobically respired, the RQ is near 1, while it is <1 for lipids and >1 for organic acids. Very **high RQ** values usually indicate **anaerobic respiration** in those tissues that produce ethanol. In such tissues, a rapid change in the RQ can be used as indication of the shift from aerobic to anaerobic respiration.

RQ = CO2 produced / O2 consumed

**Ethylene production**

Ethylene is commercially used as ripening agent. It is produced in trace amounts as a result of respiration. Ethylene in the case of climacteric does not change the peak of respiration, instead it brings a shift in time of peak development, whereas for non- climacterics which have no respiratory peaks but a uniform respiration rate, the application of ethylene helps for the formation of respiratory peaks or Rate of respiration is dramatically increased. Ethylene stimulates a rise in respiration in both climacteric and non-climacteric fruits. In climacteric fruits, it shorten the time to the respiratory peak i.e. hastens ripening.

**Stress**

Injury (Chilling injury, freezing injury, physical and mechanical damage) –results in hastening respiration rates. Physical stress stimulates the respiration rate of fresh vegetables and fruits. For example, impact bruising of mature-green tomatoes increases their rates of respiration and ethylene production during subsequent ripening at 20°C. The extent of this increase in respiration rate is usually proportional to the severity of bruising; however, extensive injury can actually depress respiration. Any mechanical injury such as cutting, abrading, slicing, and shredding of vegetables during harvesting, handling, or processing into fresh-cut or minimally processed, value-added products increases their respiration rates. The magnitudes of CO2 production and O2 consumption increase with the degree of wounding. For example, the respiration rate of grated or shredded carrots is higher than that of sliced carrots, whose respiration rate is higher than that of whole-peeled carrot sections. During physical damage isolated enzyme & substrates contact is created. This contact triggers various biochemical reactions (Browning and softening of tissue)

**Growth regulators**

Several PGR used pre and post-harvest application has influence on product quality and respiration rates

* 1. Delayed or accelerated ripening (Alar)
	2. Higher yield & greater diseases resistance - GA
	3. Improved color-Alar
	4. Prevention of abscission-NAA
	5. Sprout inhibitor (MH)

**Control measures to minimize respiratory losses**

Activity 2.1. How do you think we can minimize respiratory losses to prolong shelf life and maintain quality of produces?

1. **Temperature control**
* Harvest at cool times
* Cool down & transfer produce to cold store as fast as possible
* Maintain lowest permissible temperature
* Maintain the cold storage properly (good air circulation & refrigeration)
* Product protection from sun heat (full sunlight) after harvesting.
* Pre-cooling treatments to remove field heat.
* Refrigeration.
* Maintaining the cold chain.

**N.B.**A key factor affecting product deterioration rate. Temperature is the most effective tool for extending the shelf life of fresh horticultural commodities. Has a significant effect on spores germination and pathogenic growth.

1. **Maturity**
* Harvest vegetables at appropriate stage for intended use
* Harvest fruits at mature but at sufficiently pre-climacteric stage
1. **Reduce availability of oxygen**
* Use controlled atmosphere storage
1. **Add CO2 to the environment**
* Use CA (controlled atmospheric) storage
* Use excess CO2 where permissible
1. **Ethylene (C2H4)**
* Avoid Ethylene producing chemicals on produce intended for long storage
* Scrub ethylene from storage rooms
1. **Others (stress, injuries)**
* Handle the produce carefully!!

**Transpiration**

Generally, fruits, vegetables and ornamentals contain 65 to 95% moisture. After harvest they continue to lose this moisture through natural pores or directly through thin skin. This **loss of moisture** is called **transpiration**. But they cannot replace this moisture due to detachment from plant roots. The rate of losing moisture depends upon the moisture contents in their surrounding environment. Lesser the moisture in their surroundings, greater will be the force to pull moisture out of the produce. Transpiration is **also a destructive process** by which the produce loses its **freshness** and eventually leads to deterioration. Transpiration is the second most important factor with respect to quality loss during storage and transportation. It also contributes to cooling of the produce.

**Significance of transpiration during plant growth**

* + Cooling effect,
	+ Mineral salt and water absorption &
	+ Mineral salt distribution

**Transpiration represents economic loss**

* + 3-4% moisture loss can make the produce unsalable
	+ Actual moisture loss that commodities can withstand varies from: 3% for leafy vegetables, 5% for common vegetables to about 10 % of onions.
	+ In addition, transpiration can result serious quality loss ( Appearance, Texture and Flavor)
* Wilting, shriveling, shrinkage, drying, dehydration, desiccation, etc are results of transpiratory activity.

Transpiration occurs through specialized tissues. Gas & water from fruits and vegetables exchange occurs through specialized surface structures like **Stomata**, **guard cells, lenticels**, wax, cuticle, cuticular membrane, corky tissue, suberin, etc. Leaves may contain as many as 50,000 stomates per cm2 while orange peel may contain about 1500 stomates per cm2.

**Factors that affect transpiration**

1. **Environmental Factors**

Environmental factors—such as humidity, temperature, pressure, and air movement determine the magnitude of the transpirational driving force

1. **Humidity**

Air spaces are present inside all plants so that water and gases can pass in and out of all their parts. The air in these spaces contains water vapor, a combination of water from the transpiration stream and that produced by respiration. Water vapour inside the plant develops pressure causing it to pass out through the pores of the plant surface. The rate at which water is lost from the parts of plant depends on the difference between the pressure of water vapour inside the plant and the pressure of water vapour in the air. To keep water loss from fresh produce as low as possible, it must be kept in a moist atmosphere.

1. **Temperature**

Evaporation involves the escape of water molecules from the surface and depends on their free energy. Assuming other factors are held equal, raising the product temperature increases the free energy of the water molecules and, accordingly, their potential for evaporation.

1. **Air movement**

Air movement assists in better heat transfer to effectively transfer the heat of respiration and any sensible or field heat associated with the produce. On the other hand, promotes the mass transfer in terms of removing moisture transpired by the produce from its neighbor. This results in further transpiration. If moisture that comes out the produce is held in the immediate neighborhood, this would help to reduce the ***wvpd*** and hence its transpiration rate as would happen, in packaged produce

The faster the surrounding air moves over fresh produce, the quicker water is lost. Air movement through produce is essential to remove the heat of respiration, but the rate of movement must be kept as low as possible. Well-designed packaging materials and suitable stacking patterns for crates and boxes can contribute to controlled air flow through produce.

1. **Respiration**

Respiration produces heat and moisture. The heat if not removed efficiently, can rise the produce temperature and hence its transpiration.

1. **Physical/Mechanical damage**

Wounds, cuts etc caused mechanical or physical damages increase the transpiration rate because. they expose the cellular components directly to the environment without the normal protection that was previously offered by the protective tissue.

1. **Maturation and Ripening**

Wardlaw and Leonard (1936, 1939, and 1940) carried out the earliest research on the relationship of ripening and transpiration in bananas and other tropical fruits. Ripening ‘‘Gros Michel’’ bananas kept at 29°C and 85% RH transpired at a constant rate during the pre-climacteric period, but this rate rose at the beginning of the climacteric period. After the climacteric, a steady state was attained, but at a rate twice as high as before the climacteric. Mangoes and papayas also underwent a similar sequence of changes in transpiration rates. In contrast, the rate of water loss from apples (Smock and Neubert, 1950) and from several avocado cultivars did not change with ripening (Aharoni*et al*., 1968). Furthermore, plums were found to lose more water when unripe than when ripe (Sastry*et al*., 1978). However, Wolstenholme (1992) showed that the rate of water loss in cold-stored avocado depends on its maturity at harvest and is lower in very mature, tree-stored fruit than in less mature, early-harvested fruit.

1. **The influence of the type of produce and surface area on water loss**

The rate at which water is lost varies with the type of produce. Leafy green vegetables, especially spinach, lose water quickly because they have a thin waxy skin with many pores. Others, such as potatoes, which have a thick corky skin with few pores, have a much lower rate of water loss. The significant factor in water loss is the ratio of the surface area of the type of parts of plant to its volume. The greater the surface area in relation to the volume, the more rapid will be the loss of water.

**Methods of controlling transpirational losses**

1. **Maintain as high RH in the chamber as possible.**
	* For this, several techniques (humidification, jacketed storage) are employed
2. **Maintain a low temperature difference between the produce and the cooling coils**
	* This will reduce the chances of the cold air being cooled below its dew point.
	* This is achieved by maintaining large cooling surfaces, better refrigeration capacity, moderate high air speeds, proper stacking of produce, and prompt pre-cooling of produce prior to storage

**3. Protect from mechanical and physical injuries**

**4. Regulate moisture loss by controlling the permeability of the produce tissue.**

* + Primarily this is achieved by waxing (apples, citrus, cucumber, bell pepper, banana, etc.)
	+ A good wax should have low toxicity, rapid drying characteristics, strong adherence characteristics, high gloss and low cost.

**5. Prepackage in polymeric films**

* + This is very effective way of controlling moisture loss by **maintaining high RH** levels within the package.
	+ **Perforations** must be provided to allow gas escape otherwise CO2 gases will build-up inside.
	+ **Permeability** of film to oxygen is important to keep the required **minimum oxygen** levels inside the package.
	+ The produce is allowed to transpire to accumulate the moisture to the maximum level which will automatically suppress the subsequently transpiration.
		1. **Fruit ripening**

Fleshy fruits undergo a natural stage of development known as ripening. This occurs when the fruit has ceased growing and is said to be mature. Ripeness is followed by ageing (often called senescence) and breakdown of the fruit. The fruit referred to here includes those used as vegetables or salads, such as, sweet pepper, tomato, banana, avocado etc. Ripening process is marked by a series of non-reversible changes in the fruit and they transformed non-edible fruits into edible one. A number of changes are accompanied during ripening. These are: physiochemical changes, respiration and hormonal changes.

**Physiochemical changes during ripening**

Ripening involves a complex of changes which are either synthetic or degradation changes. Some of the changes that occurred during ripening are: seed maturation, softening, change in respiration rate, change in pigmentation and composition, and change in the level of hormone.

1. **Softening/textural change: -**is resulted in because of hydrolysis of cellulose, hemicelluloses, and pectin substances by cellulase and pectinase enzymes which are either synthesised or activated during the process. It is one of the significant changes during ripening and it affects the edibility of the fruit and the length of time the fruit may be handled. Softening may be essential (in the development of quality) or detrimental (in fruits which are consumed in unripe state like cucumber, squash). Softening is the beginning of senescence and if it is beyond the limit, it leads to loss of quality.

**ii. Change in composition**: a series of compositional changes have been take place during ripening

1. **Conversion of starch into sugar**

The conversion of starch into sugar develops sweetness of the fruit and increase quality, because the glucose served as a precursor for the synthesis of flavour and aroma elements. In some fruits, total conversion of starch into sugar is take place. For example in Banana; the starch and sugar content of the fruit at mature green stage is about 20 – 30% and 1%, respectively, and during ripening about 1% and 14 – 15% respectively. Generally, the highest amount of sugar present in the fruits after it has been harvested is attained in different ways among climacteric and non-climacteric fruits. In climacteric fruits, sugar content increased after harvest due to hydrolysis of starch present in the fruit, whereas, non-climacteric fruits harvested when they are fully and the increased sugar content in the ripened fruit is attained through transport from the mother plant.

1. **Change in the level of organic acids**

Generally, the level of organic acids during ripening is decreased except in banana and pineapple, in which there is an increased in organic acid level during ripening. The reduction of organic acids during ripening is due to utilization of acids as a respiratory substrate and served as C-skeleton for the synthesis of new molecules. The sugar acid ratio is the most important indicator of maturity.

1. **Change in nitrogenous compounds**

Metabolic activities are high during ripening and both synthesis (the level of free amino acid is low) and degradation (conversion of protein into smaller units called amino acids, hence the level of free amino acids is high) of nitrogenous compounds take place. The synthesis reaction involves for the synthesis of enzymes.

1. **Change in pigmentation**

Colour is used as an index for the degree of ripeness (example, tomato, and banana) and as a criterion in determining ripening by consumers. Colour change occur during ripening due to two processes

* **Unmasking of already existing colours: -** during ripening, chlorophyll is degraded by the enzyme chlorophylase, as a result carotenoids (responsible for orange and red colour) and anthocynins (responsible for pink, red, purple or blue colours) become unmasked and reflect new colour of the product.
* **Synthesis of new pigments**: some fruits like Avocado and Apple retain their colour during ripening through synthesis of new pigments, while climacteric fruits are the ability to develop their colour after harvest (Tomato, Banana), but non-climacteric fruits can’t develop colour after harvest.

**Factors affecting colour changes**

* **Light:-** it accelerates the degradation of chlorophyll and also enhances the synthesis of carotenoids in tomato harvested prior to ripening
* **Temperature: -**lycopene **synthesis** in tomato is inhibited at > 30OC and citrus fruits rarely develop their orange colour in tropics when the temperature is less that about 13OC. If the temperature is < 13 OC the fruit remains green.
* **Oxygen concentration: -** with the increase in oxygen concentration carotenoid synthesis is increased.

**Respiration patterns in ripening fruits**

Rate of respiration is regulated by the metabolic activity of the produce. Usually, young plants have high rate of respiration & cell division and enlargement is high and require enormous amount of carbon & energy unlike old plant that have very low respiration rate.

For developed fruits and organs there is also the same trend; initiation and fruit development require more carbon and energy and have high rate of respiration, whereas at maturity and ripening, rate of respiration decreased.

The relationship between carbon dioxide evolution and fruit ripening has been investigated widely for some of the deciduous fruits. With the apple and pear, in particular, it has been shown that changes in certain manifestations of maturity are accompanied by a greatly accelerated rate of respiration. Similar observations were made for the banana.

This rapid increase in carbon dioxide production is referred to as the "climacteric" rise in respiration. Not all fruits appear to exhibit this respiratory trend, however. In the lemon and orange, which have relatively low respiring power, no climacteric has thus far been observed. There are two characteristic types of fruit ripening that show different patterns of respiration:

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

**Climacteric fruit ripening**-refers to fruits that can be harvested when mature but before ripening has begun. These fruits may be ripened naturally or artificially. The start of ripening is accompanied by a rapid rise in respiration rate, called the respiratory climacteric (see figure 3.2, left side). After the climacteric, the respiration slows down as the fruit ripens and develops good eating quality. Examples are: apple, avocado, guava, fig, mango, passion fruit, banana, melon, papaya, tomato, peach pear, water melon.

During the ripening process, some fruits evolve large amounts of ethylene, sometimes referred to as an autocatalytic increase in ethylene production, which occurs in conjunction with an increase in respiration referred to as the respiratory climacteric. Fruits are generally classified into climacteric or non-climacteric types on the basis of the pattern of ethylene production and responsiveness to externally added ethylene.

The climacteric fruits characteristically show a marked enhancement in ethylene production and respiration, as noticeable by the evolution of carbon dioxide.

In climacteric fruits, their metabolic activity/respiration increase during ripening and this is mainly accompanied by the increase in ethylene production (figure 3.2, right side). Enzymatic activation may provide an explanation for the rapid acceleration in respiration rate during- the climacteric and the fall in carbon dioxide evolution in the post-climacteric stage may be the result of substrate shortage. By contrast, the non-climacteric fruits emit a considerably reduced level of ethylene.

After the initiation of ripening or harvest, several biochemical changes occur in fruits and vegetables. As some of these changes such as the development of color, flavor, and sweet taste are desirable for fruits, any sort of quality changes are ideally not desired in vegetables. Thus, strategies for the preservation of shelf life and quality in fruits and vegetables could be entirely different. It is important to know the biochemical differences between fruits and vegetables and several biochemical pathways that operate in these tissues to develop ideal conditions of storage for the preservation of shelf life and quality.

Climacteric pattern is practically important in postharvest of fruits and vegetables by allowing greater degree of flexibility in handling of products:

* Harvesting is done while the fruits are ripe/unripe
* Ripening can be induced and allow greater degree of synchronization

**2.3. Hormonal changes in relation to ripening**

1. **Ethylene (CH2=CH2)**

Ethylene regulates many developmental processes including flowering, ripening, senescence, abscission, dormancy and stress. The earlier discoverers called ethylene “the ripening hormone”. In the case of fruits, an increase in the biosynthesis of the gaseous hormone ethylene serves as the physiological signal for the initiation of the ripening process. In general, all plant tissues produce a low, basal, level of ethylene. All living parts of plants including the cells of fruits produce ethylene throughout their growth and development. There is alteration in ethylene synthesis with the onset of ripening. Climacteric fruits exhibit a surge of ethylene synthesis near the onset of ripening, whereas non-climacteric fruits doesn’t show any change in the concentration of ethylene accompanying to ripening.

In climacteric fruits such as apple, pear, banana, tomato, and avocado, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, micro liter per liter), whereas in nonclimacteric fruits such as orange, lemon, strawberry, and pineapple, ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening.

There are also differences between climacteric and non-climacteric fruits in response to ethylene application. 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 *μ*L/(kg h), with slightly higher levels as in cassava (1.7 *μ*L/(kg h)), breadfruit (1.2 *μ*L/(kg h)), and cucumber (0.6 *μ*L/(kg h)) when measured at 20–25◦C.

Table 5.1.Difference between climacterics & non-climacterics in response to ethylene

|  |  |  |  |
| --- | --- | --- | --- |
| No  | Character  | Climacterics  | Non-climacterics  |
| 1 | Internal ethylene concentration | Highly variable | Low and constant through different developmental stages |
| 2 | Autocatalytic (ethylene induced) ethylene production  | Present  | Absent  |
| 3 | Response to exogenous application of ethylene | Stimulate respiration once | Stimulate respiration throughout the postharvest period |
| 4 | Magnitude of respiratory rise | Independent of ethylene concentration | Dependent on ethylene concentration |
| 5 | Respiratory rise mediated by ethylene | Irreversible  | Reversible and dependent on continued response |

Generally, 0.1 to 1 *μ*L/L is sufficient for respiratory rise.

There are differences in the sensitivity of fruits to ethylene application. For example Avocado and Banana need 1*μ*L/L and 10 *μ*L/L of ethylene to induce ripening. There are also variations in internal ethylene concentration which is genetically controlled. The resistance of the tissue to ethylene is also varied between different fruits. The sensitivity of the tissue to ethylene is also different for various developmental stages and is highest near the onset of ripening.

How ethylene induces ripening is not exactly known till now. However, ethylene is believed to be the signal turning in climacteric fruits. In many fruits (Banana, Avocado) the rise in ethylene concentration precedes respiratory rise, whereas in some fruits (Mango, Apple) the rise in ethylene concentration occurs simultaneously with the respiratory rise.

In commercial fruit production and marketing, artificial ripening is used to control the rate of ripening, thus enabling transport and distribution to be carefully planned. Ethylene is a gaseous hormone and if ripe and unripe fruits stored together, the ethylene produced from ripen fruits may cause unplanned ripening of unripe fruits. Climacteric fruits may be harvested in green mature stage for long distance market, but if the vehicle is either uploaded with ripen fruits or where uploaded other fruits and is not properly cleaned unwanted ripening may occur and lead to over maturity while is not on the proper destination. Smoking near the fruit orchid as well as near the store also can make fruits to become ripe uniformly.

 **2. Other hormones**

In some fruits like Avocado, harvested fruits ripened more readily than those remained on the tree. There are some hormones that control the ripening process when fruits are on the tree and ripening process is initiated when they detached from the tree. In Apples for example, when fruits harvested, the rate of ethylene synthesis increases, hence there is something that hinder ethylene synthesis while the fruit is attached to the plant. Auxin is known to be the most ethylene synthesis inhibitor hormone.

**Senescence**

Senescence is an integral part of the normal development of organisms and it is not happened as a result of a disease or abnormal conditions. It can be defined as a serious of endogenously controlled deteriorative changes leading to the natural death of cells, organs, plants, etc. In postharvest point of view, it is very important stage because if we can’t maintain the product metabolic rate at minimum level it might lead to the death of the produce which leads to loss of the produce. So, delaying or minimizing the death of the product is the critical objective of postharvest handling. A great loss of quality will happen during senescence even before the product completely dead. There are changes occur during senescence. At the cellular level, the following major alterations occur during senescence.

1. **Degradation of chlorophyll** which lead to colour change
2. **Degradation of protein and decrease in protein synthesis**.

During senescence, enzymes involved in anaerobic process are withdrawn from the cell.

1. **Alterations in membrane structure/Loss of membrane integrity**

Senescence is accompanied by softening, as senescence advances beyond softening stage:

* Membrane rigidity decreases as a result of loss of water
* Membrane leakiness increases which lead to removal of materials from the cell
* Altering enzymes activity

Senescence is an active process that requires energy and carbon for the changes to take place, and highly dependent on oxygen concentration (low oxygen concentration delays senescence. It is also dependent on gene activation, and enzymes which are involved in senescence are synthesised or controlled their amounts by those gene activations. Substances that inhibit RNA or protein synthesis delay senescence. The disappearing of the cell takes place in ordering fashion or orderly dismantling of cells i.e., those proteins/cells which are less important for the survival of the cell dismantled first and which are important for survival of cells like nuclear membrane, mitochondria are dismantled at the very end.

**Causes of senescence**

1. **Genetic causes**

Living things are programmed that die at certain period. Programme death can be illustrated for e.g.

* Monocarpic plants die away after they produce flowers/fruits once (e.g. Banana, pine apple).
* Perennial plants continue to live long period
* Organs- fruit ripening is one form of programmed death.
* Petals are programmed to live for a few days
* Leaves have also a certain duration of existence i.e all leaves can’t live up to the whole plant life

The plant removes organs that finish their life cycle (example; fruits, petals) or remove organs in the case of adaptation that require more energy (assimilates). Therefore, senescence in this case is advantage of the plant because it avoids the demand of more energy, but in postharvest aspect, it is disadvantageous at it leads to loss of the produce.

1. **Loss of homeostasis: -**keeping a balance for the time.

Homeostasis is an active process that needs investment to get energy for the process to be undergone. Homeostasis lost during senescence because input (stored food) and output (energy and carbon resulted from respiration) are not balanced.

Maintenance is a result of degradation and synthesis changes and these doesn’t become equal, there is loss of homeostasis. Once fruits, leaves, etc are harvested the inputs (e.g. Light) are affected and the input – output balance disturbed which result in loss of homeostasis.

**Regulation of homeostasis**

**i. endogenous regulation**

* Application of ethylene accelerates ripening in fruits, senescence of flowers, leaf abscission. Therefore, substances which inhibit the synthesis and/or action of ethylene delay senescence.
* In ethylene-insensitive plants like daylily, abscisic acid (ABA) is thought to be the primary hormonal regulator of flower senescence, and exogenous application of ABA accelerates visual senescence symptoms and regulates transcription of senescence-related genes. ABA promotes senescence, resulted in loss of chlorophyll, increased protein degradation and reduces synthesis, and alters membrane degradation.
* Application of potassium and calcium can delay/inhibit senescence

**ii. Environmental factors**

* Stress (biotic and abiotic) can induce senescence and influence its rate
* Temperature, both high and low
* Atmospheric gas composition
* Water- both deficit and excess

**Review questions**

1. Are harvested horticultural crops are still living organs? How?
2. Is respiration desirable or detrimental for harvested product? If yes, how and if not why?
3. List and discuss the factors that affect respiration.
4. What is the relationship between respiration and temperature?
5. Can we stop respiration after harvest?
6. Compare and contrast climacteric and non-climacteric fruits?
7. Discuss the advantages and disadvantages of ethylene?
8. What factors tend to increase water loss?
9. Describe the role of phyto-hormones for postharvest physiology of horticultural crops.
10. How do we control stress and injury?

**CHAPTER THREE**

**MAJOR CAUSES OF POSTHARVEST LOSSES**

**Session objectives:** at the end of this chapter, students are expected to be able to

* + **Identify pre-harvest factors that affect postharvest loss**
	+ **Explain water loss and its effects**
	+ **Differentiate mechanical damages**
	+ **Identify compositional change**
	+ **Describe physiological disorder**
	+ **Know infections by microorganisms**
* There are several factors affecting postharvest losses which can be groped as internal and external factors.

**Internal factors:**

* Transpiration: Weight losses
* Internal quality (e.g. texture)
* External appearance (e.g. wilting)
* Ethylene production
* Respiration:  Climacteric VS. Non-climacteric
* Biochemical changes of fresh produce
* Growth & development of fresh produce

**External factors:**

* Temperature
* Moisture
* Atmosphere
* Light & Gravity
* Disease and Insects
* Ethylene
* Edaphic factors

The keeping and the preparation of fresh produce after harvest affects its nutritional value in several ways, for example:

* **Dry-matter** content is reduced with time as the continuation of living processes within the produce uses up stored food reserves.
* **Vitamin C** content decreases with time after harvest, and little may remain after two or three days. Cooking partially destroys vitamins C and B1. Raw fruit and vegetables are particularly valuable provided they are grown and handled hygienically. Water used in cooking vegetables or fruit contains the dissolved minerals and trace elements of the food and should not be thrown out but used in soups or in preparing other foods.

Thus, farmers must give careful attention to:

* Market demand for the products he will grow; he must know the market and his buyers
* Cultivation
* Harvesting and field handling
* Packing or packaging
* Transport
* Market handling; possibly storage or refrigeration
* Sales to consumers, wholesalers or agents
* Perishability of the produce.

The overall quality and condition of fresh produce cannot be improved after harvest. The final potential market value of produce depends on the grower's decisions on what and when to plant and on the subsequent cultivating and harvesting practices. Market factors affecting farmers' decisions on the growing of specific crops are:

* **Potential purchasers**: neighbors, retailers, jobbers or middlemen, wholesalers
* **Quality requirements** of the buyer: size, shape, maturity, appearance, perishability of the produce; pricing limitations of the buyer.
	1. **Pre-harvest factors on postharvest quality**

Pre-harvest production practices may seriously affect post-harvest returns in quality and quantity and result in the rejection or downgrading of produce at the time of sale. The postharvest quality of fruits and vegetables are largely determined by pre-harvest factors **such as**

* 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/crop rotation
* Pest and diseases
* Stage of harvest
* Time of harvest
* Methods of harvesting

3.1.1**. Temperature**

Atmospheric temperature has been found to influence fruit shape, size, colour and other quality parameters. Temperature variation during the early stage of fruit development caused variation in shape of orange fruit. Temperature caused undesirable thick peel and puffiness in citrus. Pineapple fruits grown in winter months or in cool growing areas had reduced eating qualities due to lower sugar/acid ratio.

* + 1. ***Plant growth regulators (PGR)***

The application of plant growth regulators in the fruit development stage has important effects on the quality parameters of fruits. Different types of growth regulators are applied to the plants to improve the fruit qualities, which include gibberellins, cytokinin and auxins. The application of gibberellins during fruit development increased fruit weight. They also increase shelf life and reduce fruit splitting in persimmon and citrus, respectively.

In Bangladesh, PGRs are used in horticultural crops to increase the size of the edible portion of fruits and vegetables and to obtain early bearing. In the case of mango, growers apply PGRs from the stage of flowering to entire harvesting season. In case of banana, majority of growers apply plant growth regulators to banana crops from the stage of flowering to the entire harvesting season at a rate of 5-15 mL/10-16 L of water.

* + 1. ***Harvest maturity***

The stage of maturity at harvest affects fruit quality. Generally, the fruits harvested at the advanced stage of maturity have increased fruit size and eating qualities (taste and aroma) but decreased shelf life. Harvest maturity influences physiological and storage disorders of mango. Mango fruits harvested 7 days before optimum maturity showed better storage performance but failed to arrest skin discoloration, and caused uneven ripening.

* + 1. ***Water supply (Irrigation)***

Growing plants need a continuous water supply for both photosynthesis (the process by which plants convert light to chemical energy and produce carbohydrates from carbon dioxide and water) and transpiration (the giving off by a plant of vapour containing waste products). Bad effects can be caused by: too much rain or irrigation, which can lead to brittle and easily damaged leafy vegetables and to increased tendency to decay; lack of rain or irrigation, which can lead to low juice content and thick skin in citrus fruit; dry conditions followed by rain or irrigation, which can give rise to growth cracks or secondary growth in potatoes or to growth cracks in tomatoes.

* + 1. ***Soil fertility, use of fertilizers***

Lack of plant foods in the soil can seriously affect the quality of fresh produce at harvest. On the other hand, too much fertilizer can harm the development and post-harvest condition of produce. Some of the effects are:

* **Lack of nitrogen** can lead to stunted growth or to the yellow-red discoloration of leaves in green vegetables, e.g. cabbage; lack of potash can bring about poor fruit development and abnormal ripening;
* **Excessive N element** is very detrimental in terms of postharvest quality attributes.
* **Calcium-moisture** imbalance can cause blossom-end rot in tomatoes and bitter pit in apples;
* **Boron deficiency** can lead to lumpiness in papaya; hollow stem in cabbage and cauliflower; the cracking of outer skin in beets.
* **Higher Ca concentration** result in increased firmness; reduced disease incidence, chilling injury, physiological disorders (skin splitting) and ripening; and improved storability.
* **Potash** has been found to improve fruit qualities. In bananas, high K increased total soluble solids and vitamin C and reduced acidity. In pineapple, the influence of K is detrimental.

These are a few of the commoner soil-nutrition problems that can be readily identified at harvest. The problem of fertilizer balance in soils and its effect on crops is complex and depends also on other conditions such as temperature, moisture, acidity of the soil and reactions among different fertilizer chemicals. Severe soil-nutrition problems need reference to specialist advice, if available.

* + 1. ***Cultivation practices***

Good crop husbandry is important in achieving good yields and quality of fresh produce. Certain aspects are particularly important, such as: weed control-weeds are commonly alternate or alternative hosts for crop diseases and pests, and those growing in fallow land near crops are as important as those growing among the crop. Weeds also compete with crops for nutrients and soil moisture; crop hygiene-decaying plant residues, dead wood, and decaying or mummified fruit are all reservoirs of infection causing post-harvest decay. Their collection and removal are crucial factors in the reduction of post-harvest losses.

* + 1. ***Agricultural chemicals***

These are of two types: Pesticides and herbicides are used as sprays or soil applications to control weeds, disease and insect pests. They are dangerous because they can damage produce by producing spray bums if used incorrectly, and they can leave poisonous residues on produce after harvest. In most countries there are laws to control the use of pesticides, which should be used only in recommended concentrations. Strict observance of the recommended delay between the last spraying and the harvesting is required in order to keep poisonous spray residues from reaching the consumer.

A critical time for growers of fruit and vegetables is the period of decision on when to harvest a crop. Normally any type of fresh produce is ready for harvest when it has developed to the ideal condition for consumption. This condition is usually referred to as harvest maturity. Confusion may arise because of the word maturity since, in the botanical sense, this refers to the time when the plant has completed its active growth and arrived at the stage of flowering and seed production. Harvest maturity thus refers to the time when the "fruit" is ready to harvest and must take into account the time required to reach market and how it will be managed en route. This time lag usually means that it is harvested earlier than its ideal maturity.

Most growers decide when to harvest by looking and sampling. Judgments are based on:

* Sight-colour, size and shape
* Touch-texture, hardness or softness
* Smell-odour or aroma
* Taste-sweetness, sourness, bitterness
* Resonance-sound when tapped.

Experience is the best guide for this kind of assessment.

* 1. **Physiological Disorder/Deterioration**

An increase in the rate of loss because of normal physiological changes is caused by conditions that increase the rate of natural deterioration, such as high temperature, low atmospheric humidity and physical injury. Abnormal physiological deterioration occurs when fresh produce is subjected to extremes of temperature, of atmospheric modification or of contamination. This may cause unpalatable flavours, failure to ripen or other changes in the living processes of the produce, making it unfit for use.

* 1. **Mechanical Damages**

***Handling during harvest***

Harvesting involves a number of other activities undertaken in the field. This includes those of commercial interest. Examples of operations to facilitate preparation for the market include pre-sorting, removal of foliage and other non-edible parts. In some cases, the product is completely prepared for the market in the field. However, the normal practice is' to empty the harvest containers into larger ones for transportation to the packinghouse. Here, they are dry or water dumped onto grading lines. While these activities are being undertaken, bruising which has a cumulative effect can affect the final quality of product.

Different types of lesions exist. Wounds {cuts and punctures) occur as a result of loss of tissue integrity. This type of damage is frequent during harvest and mainly produced by the harvesting tools used for the removal of plants. Other causes include the nails of pickers or peduncles from other fruits. Rotting fungi and bacteria penetrate produce in this way. This type of damage can be easily detected and is usually removed during grading and packing. Bruises are more common than wounds. They are less noticeable and symptoms show up several days later when the product is in the· hands of the consumer. There are three main causes of bruises:

1. ***Impact:***Injury caused either by dropping the fruit (or packed fruits) onto a hard surface or the impact of fruit rubbing against other fruit. These types of bruises are common during harvest and packing.
2. ***Compression:***Deformation under pressure. This often occurs during storage and bulk transportation and is caused by the weight of the mass of fruits on bottom layers. It also happens when the packed mass exceeds the volume of the container or by the collapse of weak boxes or packages unable to withstand the weight of those piled up high.
3. ***Abrasion:***Superficial damage produced by any type of friction (other fruits, packaging materials, packing belts, etc.) against thin-skinned fruit such as pears. In onions and garlic, abrasion results in the loss of protective scales.

Bruise symptoms depend on the affected tissue, maturity, type and severity of the bruise. They are cumulative and in addition to their traumatic effect, trigger a series of responses to stress, including the onset of healing mechanisms. This physiological reaction is as follows: a temporary increase in respiration which is associated with degradation; a transient production of ethylene, which accelerates maturation and contributes to softening. In some cases, mechanical disruption of membranes puts enzymes in contact with substrates which lead to the synthesis of secondary compounds that may affect texture, taste, appearance, aroma or nutritive value. Firmness on the site of impact decreases rapidly because of damage and cell death as well as the loss of tissue integrity.

The more mature the product, the more severe the damage. Its effect is exacerbated by higher temperatures and longer storage periods. Ethylene removal or neutralization under controlled or modified atmosphere conditions reduces the speed of healing. However, atmospheric composition also reduces the rate of stress response mechanisms.

***Harvest recommendations***

If the time of day can be selected, it is recommended to harvest during the cool morning hours. This is because products are more turgid. Furthermore, less energy is required for refrigeration. Harvesting maturity is a function of the distance to the destination market: those within close proximity allow ripening on the plant. Harvested product needs to be kept in the shade until the time of transportation, avoid product bruising. Harvesting scissors or knives should have rounded ends to prevent punctures and be sharp enough to prevent tearing off. Harvest containers should be cushioned, smooth and free of sharp edges. Do not overfill field containers and move them carefully. Minimize drop heights when transferring produce to other containers.

* 1. **Compositional changes**

Internal composition of fruits and vegetables keeps changing during growth and development and after harvest. Changes could be desirable or not, depending on the product and how and when it is going to be processed. Soluble solids content and acidity are two important parameters for fruits, frequently related to stage of maturity, flavor, and consumer preferences, and used as quality parameters for product selection for processing. Little changes occur in nonclimacteric fruits after harvest (pineapple, citrus fruits), while climacteric fruits suffer important changes as they continue to ripen.

Aroma compounds losses or the production of off-flavors and off-odors directly affect fruit and vegetable flavor. They can be associated to maturity stage, unfavorable storage conditions, or enzymatic activity of peroxidases and lypoxygenases in chile peppers, broccoli, asparagus, carrots, and green beans. Antioxidant and other nutritional attributes can be lost during handling and processing. Kader and Barret (2004) pointed out the high sensibility of ascorbic acid to high temperatures, light, low humidity environments, physical damages, and chilling injuries.

* 1. **Water Loss/Transpiration**

Most fresh produce contains from 65 to 95 percent water when harvested. Within growing plants there is a constant flow of water. Liquid water is absorbed from the soil by the roots, then passed up through the stems and finally is lost from the aerial parts, especially leaves, as water vapour. The passage of water through the plants is called the transpiration stream. It maintains the high water content of the plant, and the pressure inside the plant helps to support it. A lack of water will cause plants to wilt and perhaps to die. The surfaces of all plant parts are covered by a waxy or corky layer of skin or bark limiting water loss. Natural water loss from the plant occurs only through tiny pores, which are most numerous on the leaves. The pores on the plant surfaces can open or close with changing atmospheric conditions to give a controlled rate of loss of water and to keep the growing parts in a firm condition.

Fresh produce continues to lose water after harvest, but unlike the growing plant it can no longer replace lost water from the soil and so must use up its water content remaining at harvest. This loss of water from fresh produce after harvest is a serious problem, causing shrinkage and loss of weight. When the harvested produce loses 5 or 10 percent of its fresh weight, it begins, to wilt and soon becomes unusable. To extend the usable life of produce, its rate of water loss must be as low as possible.

* Loss of water, as vapor, from the product’s area exposed to the air, throughout the cuticle, lenticels, stomas, etc. is a main cause of deterioration because it results in:
* Direct loss of salable weight
* Loss in appearance (wilting and shriveling)
* Loss of textural quality (softening, crispness)
* Small fruit have large surface-to-volume ratios, and especially suffer from water loss!

**The *effect of moisture content of the air on water loss***

Air spaces are present inside all plants so that water and gases can pass in and out to all their parts. The air in these spaces contains water vapour, a combination of water from the transpiration stream and that produced by respiration. Water vapour inside the plant develops pressure causing it to pass out through the pores of the plant surface. The rate at which water is lost from plant parts depends on the difference between the water vapour pressure inside the plant and the pressure of water vapour in the air. To keep water loss from fresh produce as low as possible, it must be kept in a moist atmosphere.

***The effect of air movement on water loss***

The faster the surrounding air moves over fresh produce the quicker water is lost. Air movement through produce is essential to remove the heat of respiration, but the rate of movement must be kept as low as possible. Well-designed packaging materials and suitable stacking patterns for crates and boxes can contribute to controlled air flow through produce.

***The Influence of the type of produce on water loss***

The rate at which water is lost varies with the type of produce. Leafy green vegetables, especially spinach, lose water quickly because they have a thin waxy skin with many pores. Others, such as potatoes, which have a thick corky skin with few pores, have a much lower rate of water loss. The significant factor in water loss is the ratio of the surface area of the type of plant part to its volume. The greater the surface area in relation to the volume the more rapid will be the loss of water.

**Ways to reduce water loss after harvest:**

1. Low temperatures
2. High RH
3. Prevent surface injuries
4. Application of waxes or other coatings
5. Wrapping with plastic films
	1. **Microbial Spoilage / Macro/microorganisms’ damage**

Fruits and vegetables are good sources of nutrients and water for humans, but also for microorganisms, which can grow easily under ambient conditions. Microorganisms can get into the fruits at different stages of their field production, at the earlier stages of development, or during postharvest handling and processing operations. Some microbes can rapidly deteriorate fruit and vegetables’ appearance and other quality attributes, but do not represent a risk for consumers (phytopathogens), while others can be harmful for consumer health (food safety related microorganisms). They can be separated into two different groups:

* Microorganisms cause loss but not toxic: Include molds, yeast, bacteria and viruses which affect product quality, but do not represent a risk for consumer health.
* Harmful microorganisms: They can cause illness and even death to consumers, but in general they affect neither the product appearance nor other quality attributes of the fruit or vegetable. Since no deterioration symptoms are observed in the product, care must be taken to avoid product contamination. Sanitation programs in the fields and processing area and good hygienic practices of the operators are needed to avoid product contamination.

Diseases caused by fungi and bacteria commonly result in losses of fresh produce. Virus diseases, which can cause severe losses in growing crops, are not a serious post-harvest problem. Insect pests that are mainly responsible for wastage in cereals and grain legumes are rarely a cause of post-harvest loss in fresh produce. Where they do appear, they are often locally serious, e.g. the potato tuber moth.

Losses from post-harvest disease in fresh produce fall into two main categories.

1. Loss in quantity, the more serious, occurs where deep penetration of decay makes the infected produce unusable. This is often the result of infection of the produce in the field before harvest.
2. Loss in quality occurs when the disease affects only the surface of produce. It may cause skin blemishes that can lower the value of a commercial crop. In crops grown for local consumption, the result is less serious since the affected skin can often be removed and the undamaged interior can be used.

***Diseases****:* Fungal and bacterial diseases are spread for the most part by microscopic spores, which are widely distributed in the air and soil and on dead and decaying plant material. Produce can become infected: through **injuries** caused by careless handling, by insect or other animal damage, or through **growth cracks**; through **natural pores** in the above- and below-ground parts of plants, which allow the movement of air, carbon dioxide and water vapour into and out of the plant; by direct penetration of the intact skin of the plant. The time of infection varies with the crop and with different diseases. It can occur in the field before harvest or at any time afterwards. Field infections before harvest may not become visible until after harvest. For example, decay of root crops caused by soil moulds will develop during storage. Similarly, tropical fruits infected at any time during their development may show decay only during ripening.

Infection after harvest can occur at any time between the field and the final consumer. It is for the most part the result of invasion of harvesting or handling injuries by moulds or bacteria. Post-harvest diseases may be spread in the field before harvest by the use of infected seed or other planting material Many diseases can survive by using weed plants or other crops as alternate or alternative hosts. They are also spread by means of infected soil carried on farm implements, vehicles, boots, etc. and from crop residues or rejected produce left decaying in the field. Post-harvest diseases can also be spread by: field boxes contaminated by soil or decaying produce or both; contaminated water used to wash produce before packing; decaying rejected produce left lying around packing houses; contaminating healthy produce in packages.

***Pest:***Although relatively few post-harvest losses of fresh produce are caused by attacks of insects or other animals, localised attacks by these pests may be serious. Insect damage is usually caused by insect larvae burrowing through produce, e.g. fruit fly, sweet potato weevil, potato tuber moth. Infestation usually occurs before harvest. Post-harvest spread is a problem where produce is held in store or is exposed to lengthy periods of transport. Rats, mice and other animal pests again are sometimes a problem when produce is stored on the farm.

**CHAPTER FOUR**

**POSTHARVEST HANDLING TO MAINTAIN QUALITY**

Session objectives: at the end of this chapter students are expected to be able to

* **Describe harvesting and field handling methods**
* **Explain in-field temperature management**
* **Manage relative humidity for harvested commodities**
* **Distinguish common packinghouse managements**
* **Identify packaging materials**
	1. **Harvesting and field handling methods**

Postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. Instantly after the 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.

The most important goals of post-harvest handling are **keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage.** Sanitation is also an important factor, to reduce the possibility of pathogens that could be carried by fresh produce, for example, as residue from contaminated washing water. After the field, 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 and the like. In mechanized harvesting, processing may also begin as part of the actual harvest process, with initial cleaning and sorting performed by the harvesting machinery.

Initial post-harvest storage conditions are critical to maintaining quality. Each crop has an optimum range for storage temperature and humidity. Also, certain crops cannot be effectively stored together, as unwanted chemical interactions can result. Various methods of high-speed cooling, and sophisticated refrigerated and atmosphere controlled environments, are employed to prolong freshness, particularly in large-scale operations. Regardless of the scale of harvest, from domestic garden to industrialized farm, the basic principles of post-harvest handling for most crops are the same: handle with care to avoid damage (cutting, crushing, bruising), cool immediately and maintain in cool conditions, and cull (remove damaged items).

Once harvested, vegetable and fruit are subject to an active process of decay. Numerous biochemical processes (postharvest physiology) are continuously changing the original composition of the crop until it becomes no longer marketable. The period before drastic change has occurred is defined as the time of "post-harvest freshness" .since freshness is an important factor in product quality, its evaluation should rest upon objective methods, but until recently only sensory tests or mechanical and colorimetric, (optical) criteria have been used. A recent study attempted to discover a biochemical marker and fingerprint methods to serve as a freshness index.

* + 1. **Maturity Index for Fruits and Vegetables**

Maturity indices include

* Visual indices (size, shape and color)
* Physical indices (firmness and specific gravity)
* Chemical measurement: Soluble Solids Content (SSC) or total soluble solids (TSS) and Titratable acidity (TA)
* Calculated indices: calendar date and heat units

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. Postharvest 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. Ripening follows or overlaps maturation, rendering the produce edible, as indicated by taste. Senescence is the last stage, characterized by natural degradation of the fruit or vegetable, as in loss of texture, flavor, etc. Some typical maturity indexes are described in following sections.

1. **Skin Colour**

This factor is commonly applied to fruits, since skin colour changes as fruit ripens or matures. Some fruits exhibit no perceptible colour change during maturation, depending on the type of fruit or vegetable. Assessment of harvest maturity by skin colour depends on the judgment of the harvester, but colour charts are available for cultivars, such as apples, tomatoes, peaches, chili peppers, etc.,

1. **Optical Methods**

Light transmission properties can be used to measure the degree of maturity of fruits. These methods are based on the chlorophyll content of the fruit, which is reduced during maturation. The fruit is exposed to a bright light, which is then switched off so that the fruit is in total darkness. Next, a sensor measures the amount of light emitted from the fruit, which is proportional to its chlorophyll content and thus its maturity.

1. **Shape**

The shape of fruit can change during maturation and can be' used as a characteristic to determine harvest maturity. For instance, a banana becomes more rounded in cross sections and less angular as it develops on the plant. Mangoes also change shape during maturation. As the mango matures on the tree the relationship between the shoulders of the fruit and the point at which the stalk is attached may change. The shoulders of immature mangoes slope away from the fruit stalk; however, on more mature mangoes the shoulders become level with the point of attachment, and with even more maturity the shoulders may be raised above this point.

1. **Size**

Changes in the size of a crop while growing are frequently used to determine the time of harvest. For example, partially mature cobs of *Zea mays saccharata* are marketed as sweet com, while even less mature and thus smaller cobs are marketed as baby com. For bananas, the width of individual fingers can be used to determine harvest maturity. Usually a finger is placed midway along the bunch and its maximum width is measured with calipers; this is referred to as the caliper grade.

1. **Aroma**

Most fruits synthesize volatile chemicals as they ripen. Such chemicals give fruit its characteristic odour and can be used to determine whether it is ripe or not. These doors may only be detectable by humans when a fruit is completely ripe, and therefore has limited use in commercial situations.

1. **Leaf Changes**

Leaf quality often determines when fruits and vegetables should be harvested. In root crops, the condition of the leaves can likewise indicate the condition of the crop below ground. For example, if potatoes are to be stored, then the optimum harvest time is soon after the leaves and stems have died. If harvested earlier, the skins will be less resistant to harvesting and handling damage and more prone to storage diseases. Abscission As part of the natural development of a fruit an abscission layer is formed in the pedicel. For example, in cantaloupe melons, harvesting before the abscission layer is fully developed results in inferior flavored fruit, compared to those left on the vine for the full period.

1. **Firmness**

A fruit may change in texture during maturation, especially during ripening when it may become rapidly softer. Excessive loss of moisture may also affect the texture of crops. These textural changes are detected by touch, and the harvester may simply be able to gently squeeze the fruit and judge whether the crop can be harvested. Today sophisticated devices have been developed to measure texture in fruits and vegetables, for example, texture analyzers and pressure testers; they are currently available for fruits and vegetables in various forms. A force is applied to the surface of the fruit, allowing the probe of the penetrometer or texturometer to penetrate the fruit flesh, which then gives a reading on firmness. Hand held pressure testers could give variable results because the basis on which they are used to measure firmness is affected by the angle at which the force is applied. Two commonly used pressure testers to measure the firmness of fruits and vegetables are the Magness-Taylor and UC Fruit Firmness testers.

A more elaborate test, but not necessarily more effective, uses instruments like the Intron Universal Testing Machine. It is necessary to specify the instrument and all settings used when reporting test pressure values or attempting to set standards. Juice Content The juice content of many fruits increases as the fruit matures on the tree. To measure the juice content of a fruit, a representative sample of fruit is taken and then the juice extracted in a standard and specified manner. The juice volume is related to the original mass of juice, which is proportional to its maturity.

1. **Oil content and Dry Matter Percentage**

Oil content can be used to determine the maturity of fruits, such as avocados. According to the Agricultural Code in California, avocados at the time of harvest and at any time thereafter shall not contain in weight less than 8% oil per avocado, excluding skin and seed. Thus, the oil content of an avocado is related to moisture content. The oil content is determined by weighing 5-10 g of avocado pulp and then extracting the oil with a solvent in a distillation column (figure 1). This method has been successful for cultivars naturally high in oil content. A round flask is used for the solvent. Heat is supplied with an electric plate and water recirculated to maintain a constant temperature during the extraction process. Extraction is performed using solvents such as petroleum ether, benzene, diethyl ether, etc., a process that takes between 4-6 h. After the extraction, the oil is recovered from the flask through evaporation of the water at 1OsoC in an oven until constant weight is achieved.

1. **Sugars**

In climacteric fruits, carbohydrates accumulate during maturation in the form of starch. As the fruit ripens, starch is broken down into sugar. In non-climacteric fruits, sugar tends to accumulate during maturation. A quick method to measure the amount of sugar present in fruits is with a brix hydrometer or a refractometer. A drop of fruit juice is placed in the sample holder of the refractometer and a reading taken; this is equivalent to the total amount of soluble solids or sugar content. This factor is used in many parts of the world to specify maturity. The soluble solids content of fruit is also determined by shining light on the fruit or vegetable and measuring the amount transmitted. This is a laboratory technique however and might not be suitable for village level production. Starch Content Measurement of starch content is a reliable technique used to determine maturity in pear cultivars. The method involves cutting the fruit in two and dipping the cut pieces into a solution containing 4% potassium iodide and 1% iodine. The cut surfaces stain to a blue-black colour in places where starch is present. Starch converts into sugar as harvest time approaches. Harvest begins when the samples show that 65-70% of the cut surfaces have turned blue-black.

1. **Acidity**

In many fruits, the acidity changes during maturation and ripening, and in the case of citrus and other fruits, acidity reduces progressively as the fruit matures on the tree. Taking samples of such fruits, and extracting the juice and titrating it against a standard alkaline solution, gives a measure that can be related to optimum times of harvest. Normally, acidity is not taken as a measurement of fruit maturity by itself but in relation to soluble solids, giving what is termed the brix: acid ratio. Sanchez et al. studied the effect of inducing maturity in banana *(Musa sp* (LJ, *AAB)* "Silk" fruits with 2-chloroethyl phosphoric acid ("ethephon"), in some trials in Venezuela. Pour treatments (0, 1000, 3000, and 5000 ppm) were applied. The results obtained revealed that the "ethephon" treatments increased the acidity and total soluble solids. The sucrose formation accelerated while the pH was not affected significantly. On the other hand, the relationship of the Brix/acidity ratio was increased according to the "ethcphon" dose, as presented in **Table 4.**

1. **Specific Gravity**

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

* + 1. **Harvesting methods**

**Harvesting** is the process of gathering mature crops from the fields. **Reaping** is the cutting of grain or pulse for harvest, typically using a scythe, sickle, or reaper. The harvest marks the end of the growing season, or the growing cycle for a particular crop, and this is the focus of seasonal celebrations of many religions. On smaller farms with minimal mechanization, harvesting is the most labor-intensive activity of the growing season. On large, mechanized farms, harvesting utilizes the most expensive and sophisticated farm machinery, like the combine harvester. Harvesting in general usage includes an immediate post-harvest handling, all of the actions taken immediately after removing the crop-cooling, sorting, cleaning, packing-up to the point of further on farm processing, or shipping to the wholesale or consumer market.

Harvest timing is a critical decision that balances the likely weather conditions with the degree of crop maturity. Weather conditions such as frost, rain (resulting in a "wet harvest"), and unseasonably warm or cold periods can affect yield and quality. An **earlier harvest date** may avoid damaging conditions, but result in poorer yield and quality.

**Delaying harvest** may result in a better harvest, but decreases the shelf life. Timing of the harvest often amounts to a significant gamble. Harvesting is the gathering of plant parts that are of commercial interest. These include:

***Fruits****-e.g.* tomatoes, peppers, apples,

***Root crops****-e.g.* beets, carrots etc;

***Leafy vegetables***- spinach and Swiss chard;

***Bulbs****-onions* or garlic;

***Tubers***- potatoes;

***Stems***- asparagus;

***Petioles****-celery* and

***Inflorescences***- broccoli, cauliflower etc.

Harvesting can be performed by **hand/manually** or **mechanically**. However, for some crops e.g. onions, potatoes, carrots *e.t.c.,* 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.

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. **A decision to purchase equipment requires** careful evaluation of:

* The initial investment required,
* Maintenance costs and the long period in which equipment may have to stand idle.
* The entire operation needs to be designed specifically for mechanized harvesting-distances between rows, field leveling, pesticide spraying, cultural practices to varieties which can be adapted to rough handling.
* Market preparation (grading, cleaning, packing, etc.) and the trade should also be able to handle large volumes of produce.

**Hand harvesting** is particularly suitable for crops with an extended harvest period. The rate of harvesting can be increased by hiring more workers if, for example, due to climate, there is accelerated ripening and a need to harvest the crop quickly. 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. This is important for tender crops. However, adequate training, including supervision of the harvest crew, is required. Contractual arrangements with harvest labour also influences the final quality of product harvested. When wages are paid per week, fortnight or month, harvesting is undertaken carefully. However, when payment is per box, meters of row or number of harvested plants, harvesting can be careless. Establishing teams and division of labour also influences quality. Long working days and/or few breaks as well as extremely adverse conditions (excessive heat or cold) can result in unnecessary rough handling of produce. Harvest labour needs to be adequately trained to give them the necessary skills to select produce at the correct stage of ripeness or degree of maturity as well as sorting techniques to minimize damage.

**Harvest Ripeness and Readiness for Harvest**

In many cases harvest ripeness and readiness for harvest are used synonymously. However, it is more technically accurate to use "ripeness" for fruits such as tomato, peach, pepper, etc. Here, the consumption stage continues after certain changes in colour, texture and flavor. On the other hand, in species where these changes do not occur such as asparagus, lettuce, and beets, the term "readiness for harvest" is preferable.

Maturity is the harvest index most widely used in fruits. However, **physiologicalmaturity**needs to be distinguished from **commercial maturity***.* The former is reached when development is over. It may or may not be followed by the ripening process to achieve the commercial maturity required by the market. Every fruit shows one or more apparent signs when it reaches physiological maturity. For example, in tomato, the gelatinous mass fills the internal locules and seeds cannot be cut when fruits are sectioned with a sharp knife. In peppers, seeds become hard and the internal surface of the fruit starts colouring.

**Over maturity** or **over ripening** is the stage that follows commercial maturity and is when the fruit softens and loses part of its characteristic taste and flavor. However, it is the ideal condition for preparing jams or sauces. **Commercial maturity** may or may not coincide with physiological maturity. For cucumbers, zucchinis, snap beans, peas, vegetables, and many others, commercial maturity is reached well before the end of development.

At this point, it is necessary to differentiate between two types of fruits: climacteric and non-climacteric. Climacteric include for example tomatoes, peaches etc. They are capable of generating ethylene, the hormone required for ripening even when detached from the mother plant. Non-climacteric includes for example peppers, citrus etc. Commercial maturity is only obtained on the plant.

Climacteric fruits are autonomous from the ripening point of view and changes in taste, aroma, colour and texture are associated with a transitory respiratory peak and closely related to autocatalytic ethylene production. Climacteric fruits such as tomato reach full red colour even when harvested green. On the other hand, in non- climacteric fruits such as bell peppers, slight changes in colour take place after harvest. Full red colour is only obtained while fruit is attached to the plant. As a general rule, the more mature the product, the shorter its post-harvest life. For distant markets, this means climacteric fruits need to be harvested as early as possible, but always after reaching their physiological maturity.

Changes in colour are the .most apparent external symptoms of ripening. They are the result of chlorophyll degradation (disappearance of green colour) and the synthesis of specific pigments. In some fruits such as lemons, chlorophyll degradation allows yellow pigments that are already present to show. However, these are masked by the green colour. Other fruits such as peaches, nectarines and some varieties of apples have more of one type of colour; the ground one is associated with ripeness and the cover in many cases is specific to the variety. Maturity can be estimated by colour charts based on the percentage of desired colour or by objective measurements with colourimeters.

Many crops show apparent external symptoms when ready for harvest. These include for example **tops** **falling** over in onions, development of **abscission** layers in the pedicel of some melons, shell fragility in some nuts. Degree of filling is an index used in bananas and mangoes while sweet corn is harvested when kernels are plump and no longer "milky". Colour, degree of development or both are the main criteria used for harvest in most fruits and vegetables. It is, however, common to combine these with other objective indices. These include for example, firmness (apple, pear, stone fruits), tenderness (peas), starch content (apple, pear)r soluble solid content (melons, kiwifruit), oil content (avocado), juiciness (citrus), sugar content/acidity ratio (citrus), aroma (some melons), etc. For processing crops, it is important to keep a. constant flow of raw material in the harvesting schedule. It is therefore normal practice to calculate the number of days from -flowering and/or the accumulation of heat units.

* + 1. **Harvesting Containers**

Harvesting containers must be easy to handle for workers picking fruits and vegetables in the field. Many crops are harvested into bags. Harvesting bags with shoulder or waist slings can be used for fruits with firm skins, like citrus fruits and avocados. 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. Other types of field harvest containers include baskets, buckets, carts, and plastic crates. For high risk products, woven baskets and sacks are not recommended because of the risk of contamination.

**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. 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. The contents of the bag are emptied through the bottom into a field container without tipping the bag. Plastic buckets are suitable containers for harvesting fruits that are easily crushed, such as tomatoes. These containers should be smooth without any sharp edges that could damage the produce. Commercial growers use bulk bins 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.

**Packing in the field and transport to packinghouse**

Berries picked for the fresh market are often mechanically harvested and usually packed into shipping containers. Careful harvesting, handling, and transporting of fruits and vegetables to packinghouses are necessary to preserve product quality.

1. ***Polyethylene bags***

Clear polyethylene bags are used to pack banana bunches in the field, which are then transported to the packinghouse by means of mechanical cableways running through the banana plantation. This technique of packaging and transporting bananas reduces damage to the fruit caused by improper handling.

1. ***Plastic field boxes***

These types of boxes are usually made of polyvinyl chloride, polypropylene, or polyethylene. They are durable and can last many years. Many are designed in such a way that they can nest inside each other when empty to facilitate transport, and can stack one on top of the other without crushing the fruit when full.

1. ***Wooden field boxes***

These boxes are made of thin pieces of wood bound together with wire. They come in two sizes: the bushel box with a volume of 2200 in3 (36052 cm3) and the half-bushel box. They are advantageous because they can be packed flat and are inexpensive, and thus could be non-returnable. **Figure 2.** Typical wooden crate holding fresh tomatoes

1. ***Bulk bins***

Bulk bins of 200-500 kg capacity are used for harvesting fresh fruits and vegetables. These bins are much more economical than the field boxes, both in terms of fruit carried per unit volume and durability, as well as in providing better protection to the product during transport to the packinghouse. They are made of wood and plastic materials. Dimensions for these bins in the United States are 48 x 40 in, and 120 x 100 cm in metric 30 Post-harvest Technology of Horticultural Crops system countries. Approximate depth of bulk bins depends on the type of fruit or vegetable being **transported (Table 5)**

* + 1. **Packing house operations**

It is important to minimize mechanical damage by avoiding drops, rough handling and bruising during the different steps of pack house operations. Secondly the pack house operations should be carried out in shaded area. Shade can be created using locally available materials like, shade cloth, woven mats, plastic tarps or a canvas sheet hung from temporary poles. Shade alone can reduce air temperatures surrounding the produce by 8–17 °C. The packing house operations include the following steps:

1. ***Dumping****:* The first step of handling is known as dumping. It should be done gently either using water or dry dumping. Wet dumping can be done by immersing the produce in water. It reduces mechanical injury, bruising, abrasions on the fruits, since water is gentler on produce. The dry dumping is done by soft brushes fitted on the sloped ramp or moving conveyor belts. It will help in removing dust and dirt on the fruits.
2. ***Pre-sorting****:* It is done to remove injured, decayed, misshapen fruits. It will save energy and money because culls will not be handled, cooled, packed or transported. Removing decaying fruits are especially important, because these will limit the spread of infection to other healthy fruits during handling.
3. ***Washing*** *and* ***cleaning****:* Washing with chlorine solution (100–150 ppm) can also be used to control inoculums build up during pack house operations. For best results, the pH of wash solution should be between 6.5 and 7.5
4. ***Sizing/grading****:* Grading can be done manually or by automatic grading lines. Size grading can be done subjectively (visually) with the use of standard size gauges. Round produce units can be easily graded by using sizing rings

**Operations prior to packaging**

Fruits and vegetables are subjected to preliminary treatments designed to improve appearance and maintain quality. These preparatory treatments include cleaning, disinfection, waxing, and adding of colour.

1. ***Cleaning***

Most produce receives various chemical treatments such as spraying of insecticides and pesticides in the field. Most of these chemicals are poisonous to humans, even in small concentrations. Therefore, all traces of chemicals must be removed from produce before packing. The fruit or vegetable passes over rotary brushes where it is rotated and transported to the washing machine and exposed to the cleaning process from all sides. From the washing machine, the fruit passes onto a set of rotary sponge rollers (similar to the rotary brushes). The rotary sponges remove most of the water on the fruit as it is rotated and transported through the sponger.

1. ***Disinfection***

After washing fruits and vegetables, disinfectant agents are added to the soaking tank to avoid propagation of diseases among consecutive batches of produce. In a soaking tank, a typical solution for citrus fruit includes a mixture of various chemicals at specific concentration, pH, and temperature, as well as detergents and water softeners. Sodiumortho-phenyl-phenate (SOPP) is an effective citrus disinfectant, but requires precise control of conditions in the tank. Concentrations must be kept between 0.05 and 0.15%, with pH at 11.8 and temperature in the range of 43-48°C. Recommended soaking time is 3-5 minutes. Deviation from these recommendations may have disastrous effects on the produce, since the solution will be ineffective if the temperature or concentration is too low. Low concentrations of chlorine solution are also used as disinfectant for many vegetables. The advantage of this solution is that it does not leave a chemical residue on the product.

1. ***Artificial waxing***

Artificial wax is applied to produce to replace the natural wax lost during washing of fruits or vegetables. This adds a bright sheen to the product. The function of artificial waxing of produce is summarized below:

* Provides a protective coating over entire surface.
* Seals small cracks and dents in the rind or skin.
* Seals off stem scars or base of petiole.
* Reduces moisture loss.
* Permits natural respiration.
* Extends shelf life.
* Enhances sales appeal.
1. ***Brand name application***

Some distributors use ink or stickers to stamp a brand name or logo on each individual fruit. Ink is not permissible in some countries (e.g., Japan), but stickers are acceptable. Automatic machines for dispensing and applying pressure sensitive paper stickers are readily available. The advantage of stickers is that they can be easily peeled off.

**Packaging**

Modern packaging must comply with the following requirements:

1. The package must have sufficient mechanical strength to protect the contents during handling, transport, and stacking.
2. The packaging material must be free of chemical substances that could transfer to the produce and become toxic to man.
3. The package must meet handling and marketing requirements in terms of weight, size, and shape.
4. The package should allow rapid cooling of the contents. Furthermore, the permeability of plastic films to respiratory gases could also be important.
5. Mechanical strength of the package should be largely unaffected by moisture content (when wet) or high humidity conditions.
6. The security of the package or ease of opening and closing might be important in some marketing situations.
7. The package must either exclude light or be transparent.
8. The package should be appropriate for retail presentations.
9. The package should be designed for ease of disposal, re-use, or recycling.
10. Cost of the package in relation to value and the extent of contents protection required should be as low as possible.

***Classification of packaging***

Packages can be classified as follows:

Flexible sacks; made of plastic jute, such as bags (small sacks) and nets (made of open mesh)

* **Wooden crates**
* **Cartons (fibreboard boxes)**
* **Plastic crates**
* **Pallet boxes and shipping containers**
* **Baskets made of woven strips of leaves, bamboo, plastic, etc.**

***Uses for above packages***

Nets are only suitable for hard produce such as coconuts and root crops (potatoes, onions, yams). Wooden crates are typically wire bound crates used for citrus fruits and potatoes, or wooden field crates used for softer produce like tomatoes. Wooden crates are resistant to weather and more efficient for large fruits, such as watermelons and other melons, and generally have good ventilation. Disadvantages are that rough surfaces and splinters can cause damage to the produce, they can retain undesirable odours when painted, and raw wood can easily become contaminated with moulds. Fibreboard boxes are used for tomato, cucumber, and ginger transport. They are easy to handle, light weight, come in different sizes, and come in a variety of colours that can make produce more attractive to consumers. They have some disadvantages, such as the effect of high humidity, which can weaken the box; neither are they waterproof, so wet products would need to be dried before packaging. These boxes are often of lower strength compared to wooden or plastic crates, although multiple thickness trays are very widely used. They can come flat packed with ventilation holes and grab handles, making a cheap attractive alternative that is very popular. Care should be taken that holes on the surface (top and sides) of the box allow adequate ventilation for the produce and prevent heat generation, which can cause rapid product deterioration.

Plastic crates are expensive but last longer than wooden or carton crates. They are easy to clean due to their smooth surface and are hard in strength, giving protection to products. Plastic crates can be used many times, reducing the cost of transport. They are available in different sizes and colours and are resistant to adverse weather conditions. However, plastic crates can damage some soft produce due to their hard surfaces, thus liners are recommended when using such crates. Pallet boxes are very efficient for transporting produce from the field to the packinghouse or for handling produce in the packinghouse. Pallet boxes have a standard floor size (1200 x 1000 mm) and depending on the commodity have standard heights.

Advantages of the pallet box are that it reduces the labour and cost of loading, filling, and unloading; reduces space for storage; and increases speed of mechanical harvest. The major disadvantage is that the return volume of most pallet boxes is the same as the full load. Higher investment is also required for the forklift truck, trailer, and handling systems to empty the boxes. They are not affordable to small producers because of high, initial capital investment.

* 1. **Cooling Methods and Temperatures**

Several methods of cooling are applied to produce after harvesting to extend shelf life and maintain a fresh-like quality. Some of the low temperature treatments are unsuitable for simple rural or village treatment but are included for consideration as follows:

1. ***Precooling***

Fruit is precooled when its temperature is reduced from 3 to 6°C (5 to 10°F) and is cool enough for safe transport. Precooling may be done with cold air, cold water (hydrocooling), direct contact with ice, or by evaporation of water from the product under a partial vacuum (vacuum cooling). A combination of cooled air and water in the form of a mist called ***hyraircooling*** is an innovation in cooling of vegetables.

1. ***Air precooling***

Precooling of fruits with cold air is the most common practice. It can be done in refrigerator cars, storage rooms, tunnels, or forced air-coolers (air is forced to pass through the container via baffles and pressure differences).

1. ***Icing***

Ice is commonly added to boxes of produce by placing a layer of crushed ice directly on the top of the crop. Ice slurry can be applied in the following proportion: 60% finely crushed ice, 40% water, and 0.1 % sodium chloride to lower the melting point. The water to ice ratio may vary from 1:1 to 1:4.

1. ***Room cooling***

This method involves placing the crop in cold storage. The type of room used may vary, but generally consists of a refrigeration unit in which cold air is passed through a fan. The circulation may be such that air is blown across the top of the room and falls through the crop by convection. The main advantage is cost because no specific facility is required.

1. ***Forced air-cooling***

The principle behind this type of precooling is to place the crop into a room where cold air is directed through the crop after flowing over various refrigerated metal coils or pipes. Forced air-cooling systems blow air at a high velocity leading to desiccation of the crop. To minimise this effect, various methods of humidifying the cooling air have been designed such as blowing the air through cold water sprays.

1. ***Hydro cooling***

The transmission of heat from a solid to a liquid is faster than the transmission of heat from a solid to a gas. Therefore, cooling of crops with cooled water can occur quickly and results in zero loss of weight. To achieve high performance, the crop is submerged in cold water, which is constantly circulated through a heat exchanger. When crops are transported around the packhorse in water, the transport can incorporate a hydro cooler. This system has the advantage wherein the speed of the conveyer can be adjusted to the time required to cool the produce. Hydro cooling has a further advantage over other precooling methods in that it can help clean the produce. Chlorinated water can be used to avoid spoilage of the crop. Hydro cooling is commonly used for vegetables, such as asparagus, celery, sweet com, radishes, and carrots, but it is seldom used for fruits.

1. ***Vacuum cooling***

Cooling in this case is achieved with the latent heat of vaporization rather than conduction. At normal air pressure (760 mmHg) water will boil at 100°C. As air pressure is reduced so is the boiling point of water, and at 4.6 mmHg water boils at O°C. For every 5 or 6°C reduction in temperature, under these. conditions, the crop loses about 1 % of its weight. This weight loss may be minimized by spraying the produce with water either before enclosing it in the vacuum chamber or towards the end of the vacuum cooling operation (hydro vacuum cooling). The speed and effectiveness of cooling is related to the ratio between the mass of the crop and its surface area. This method is particularly suitable for leaf crops such as lettuce. Crops like tomatoes having a relatively thick wax cuticle are not suitable for vacuum cooling.

***Recommended minimum temperature to increase storage time***

There is no ideal storage for all fruits and vegetables, because their response to reduced temperatures varies widely. The importance of factors such as mould growth and chilling injuries must be taken into account, as well as the required length of storage. Storage temperature for fruits and vegetables can range from -1 to 13°C, depending on their perishability. Extremely perishable fruits such as apricots, berries, cherries, figs, watermelons can be stored at -1 to 4°C for 1-5 weeks; less perishable fruits such as mandarin, nectarine, ripe or green pineapple can be stored at 5-9°C for 2-5 weeks; bananas at l0oC for 1-2 weeks and green bananas at 13°C for 1-2 weeks. Highly perishable vegetables can be stored up to 4 weeks such as asparagus, beans, broccoli, and Brussels sprouts at -I-4°C for 1-4 weeks; cauliflower at 5-9°C for 2-4 weeks. Green tomato is less perishable and can be stored at 10oC for 3-6 weeks and non-perishable vegetables such as carrots, onions, potatoes and parsnips can be stored at 5-9°C for 12-28 weeks. Similarly, sweet potatoes can be stored at l0oC for 16-24 weeks. The storage life of produce is highly variable and related to the respiration rate; there is an inverse relation between respiration rate and storage life in that produce with low respiration generally keeps longer.

For example, the respiration rate of a very perishable fruit like ripe banana is 200 mL CO2.kg-1h-1 at 15°C, compared to a non-perishable fruit such as apple, which has a respiration rate of 25 mL CO2.kg-1 h-1 at 15°C.

***High temperatures***

Exposure of fruits and vegetables to high temperatures during post-harvest reduces their storage or marketable life. This is because as living material, their metabolic rate is normally higher with higher temperatures. High temperature treatments are beneficial in curing root crops, drying bulb crops, and controlling diseases and pests in some fruits. Many fruits are exposed to high temperatures in combination with ethylene (or another suitable gas) to initiate or improve ripening or skin colour.

* 1. **Relative Humidity**

Fruits and vegetables are largely composed of water. An important factor in maintaining post harvest quality is to ensure that there is adequate relative humidity inside the storage area. Water loss or dehydration means a loss in fresh weight. This in turn affects the appearance, texture, and in some cases the flavor. Water loss also affects crispiness and firmness. Consumers tend to demand and associate these qualities with freshness, perceiving them as just harvested.

The percentage of relative humidity is the most widely used parameter to express the amount of water in the air. It is defined as the relationship between the pressure of water in the air and the temperature at saturation point. As with other gases, water vapour moves from higher to lower pressure areas. In plant tissues, water is mainly present as cellular liquids, but in equilibrium with the intercellular spaces where it exists as a vapor saturated atmosphere (100% relative humidity). Exposure to identical air conditions of relative humidity and temperature will prevent water loss from tissues.

Capacity of air to hold water increases with temperature. The reverse is also true. This means that refrigeration increases the relative humidity of air. However, in some cases humidifiers are needed to increase the moisture content so as to reach the ideal conditions for storage. Onion, garlic, pumpkin etc provide some exceptions. They are best stored at relative humidity in the range of 60-70%. Most fruits and vegetables are required to be kept at a relative humidity of 90-95%, while some others at values close to saturation.

***Short term storage* - *Refrigerated transport***

Refrigeration in cold stores is not always used to maximize the postharvest life. On the contrary, it is probably used more often during the short time required for the sequence of activities in the cold chain ending at the consumption point. Refrigerated transport is probably the best example of this. However, there are many other opportunities for the use of temporary cold storage e.g. during preparation and sale of product for the market. For example, holding product until processing, packaging, or transport is carried out. Other examples include the use of refrigerated facilities at wholesale or retail. Cold storage is also used in home to prolong the shelf-life of products.

It is hard to define what constitutes "short term and long-term storage". This is because 7 days is a long time for raspberries while for potato, onion, garlic and other products that require longer periods of storage this is considered to be relatively short. It is preferable not to store different crops together. However, this is common practice and is unavoidable in many cases, particularly at distribution or retail. This does not pose a problem provided products are not exposed to suboptimal conditions for too long and build up of ethylene is avoided. A strategy widely practiced is to set cold chambers at an average of around 5 °C and 90-95% level of relative humidity. If possible, mixed loads should have different regimes depending on the specific combination of fruits and vegetables in store. This is assuming that ambient ethylene concentration does not exceed 1 ppm.

The University of California recommends three combinations of temperature and relative humidity:

1) 0-2 °C and 90-98% RH for leafy vegetables, crucifers, temperate fruits and berries;

2) 7-10 °C and 85-95% RH for citrus, subtropical fruits and fruit vegetables;

3) 13-18 °C and 85-95% RH for tropical fruits, melons, pumpkins and root vegetables.

**CHAPTER FIVE**

**STORAGE**

**Session objectives**

* **Compatibility of fruits and vegetables for storage**
* **Pre storage treatments**
* **Traditional and modern storage structures**

The marketable life of most fresh vegetables can be extended by prompt storage in an environment that maintains product quality. The desired environment can be obtained in facilities where temperature, air circulation, relative humidity, and sometimes atmosphere composition can be controlled. Storage rooms can be grouped accordingly as those requiring refrigeration and those that do not. Storage rooms and methods not requiring refrigeration include: *in situ,* sand, coir, pits, clamps, windbreaks, cellars, barns, evaporative cooling, and night ventilation:

***In situ****.* This method of storing fruits and vegetables involves delaying the harvest until the crop is required. It can be used in some cases with root crops, such as cassava, but means that the land on which the crop was grown will remain occupied and a new crop cannot be planted. In colder climates, the crop may be exposed to freezing and chilling injury.

***Sand or coir:*** This storage technique is used in countries like India to store potatoes for longer periods of time, which involves covering the commodity underground with sand. Pits or trenches are dug at the edges of the field where the crop has been grown. Usually pits are placed at the highest point in the field, especially in regions of high rainfall. The pit or trench is lined with straw or other organic material and filled with the crop being stored, then covered with a layer of organic material followed by a layer of soil. Holes are created with straw at the top to allow for air ventilation, as lack of ventilation may cause problems with rotting of the crop.

***Clamps****.* This has been a traditional method for storing potatoes in some parts of the world, such as Great Britain. A common design uses an area of land at the side of the field. The width of the clamp is about 1 to 2.5 m. The dimensions are marked out and the potatoes piled on the ground in an elongated conical heap. Sometimes straw is laid on the soil before the potatoes. The central height of the heap depends on its angle of repose, which is about one third the width of the clump. At the top, straw is bent over the ridge so that rain will tend to run off the structure. Straw thickness should be from 15-25 cm when compressed. After two weeks, the clamp is covered with soil to a depth of 15-20 ern, but this may vary depending on the climate.

Windbreaks are constructed by driving wooden stakes into the ground in two parallel rows about 1 m apart. A wooden platform is built between the stakes about 30 cm from the ground, often made from wooden boxes. Chicken wire is affixed between the stakes and across both ends of the windbreak. This method is used in Britain to store onions.

***Cellars****.* These underground or partly underground rooms are often beneath a house. This location has good insulation, providing cooling in warm ambient conditions and protection from excessively low temperatures in cold climates. Cellars have traditionally been used at domestic scale in Britain to store apples, cabbages, onions, and potatoes during winter.

***Barns****.* A bam is a farm building for sheltering, processing, and storing agricultural products, animals, and implements. Although there is no precise scale or measure for the type or size of the building, the term bam is usually reserved for the largest or most important structure on any particular farm. Smaller or minor agricultural buildings are often labelled sheds or outbuildings and are normally used to house smaller implements or activities.

***Evaporative cooling.***When water evaporates from the liquid phase into the vapour phase energy is required. This principle can be used to cool stores by first passing the air introduced into the storage room through a pad of water. The degree of cooling depends on the original humidity of the air and the efficiency of the evaporating surface. If the ambient air has low humidity and is humidified to around 100% RH, then a large reduction in temperature will be achieved. This can provide cool moist conditions during storage.

***Night ventilation****.* In hot climates, the variation between day and night temperatures can be used to keep stores cool. The storage room should be well insulated when the crop is placed inside. A fan is built into the store room, which is switched on when the outside temperature at night becomes lower than the temperature within. The fan switches off when the temperatures equalise. The fan is controlled by a differential thermostat, which constantly compares the outside air temperature with the internal storage temperature. This method is used to store bulk onions.

Controlled atmospheres are made of gastight chambers with insulated walls, ceiling, and floor. They are increasingly common for fruit storage at larger scale. Depending on the species and variety, various blends of 02' CO2, and N2 are required. Low content 02 atmospheres (0.8 to 1.5%), called ULO (Ultra -Low Oxygen) atmospheres, are used for fruits with long storage lives (e.g., apples).

**Pest Control and Decay**

Crops may be immersed in hot water before storage or marketing to control disease. A common disease of fruits known as anthracnose, caused by the infection of fungus *Colletotrychum spp.* can be successfully controlled in this way. Combining appropriate doses of fungicides with hot water is often effective in controlling disease in fruits after harvesting. Fruit and vegetable decay is also caused by storage conditions. Too low temperatures can cause injury during refrigeration of fruits and vegetables. High temperatures can cause softening of tissues and promote bacterial diseases. The damage that microorganisms inflict on fresh fruits and vegetables is mainly in the physical loss of edible matter, which may be partial or total.

Most fruit and vegetable production in temperate areas is seasonal. In contrast, cultivation and harvest periods are much longer in tropical and subtropical areas.

Demand is year round and it is normal practice to use storage in order to ensure continuity of supply. Moreover, storage is a strategy for achieving higher returns.

Produce can be held temporarily to overcome gluts thus limiting price falls or to address shortage periods when prices are high.

Storage time depends on the intrinsic characteristics and perishability of the product.

Shelf life ranges from short - e.g. raspberries and other berries - to those which naturally adapt to longer storage periods - e.g. onions, potato, garlic, pumpkins, etc. Storage conditions also depend on specific product characteristics. For example, some commodities tolerate temperatures close to 0 °C such as leafy vegetables. Others, such as most tropical fruits (Table 1), cannot tolerate exposure to temperatures below 10°C.

To optimize storage conditions, not more than one crop should be stored ill. The same room, unless this is for a short period of time. Sharing the same storage area can result in: differences in temperature and relative humidity conditions; chilling and ethylene sensitivity; odor contamination and other problems affecting shelf life and quality.

REQUIREMENTS FOR A STORAGE FACILITY

Generally, storage facilities are linked or integrated to packinghouses or other areas where there is a concentration of product. However, often storage can also be undertaken on-farm, either naturally or in specifically designed facilities. Even under conditions of mechanical refrigeration, location and design have an impact on system operations and efficiency. First, climate is an important factor for the location of the storage facility. For example, altitude reduces temperature by 10°C for every 1 000 meters of elevation. It also increases overall efficiency of the refrigeration equipment by facilitating heat exchange with ambient temperature, thereby reducing energy costs. Shading particularly of loading and unloading areas reduces thermal differences between field and storage temperatures. Building design is an important factor to be taken into consideration. For example, a square shaped floor perimeter is thermally more efficient than a rectangular one. The roof is the most important part of the structure. This is because it has to protect produce from rain and radiant heat. Its slope should allow easy fall off of rainwater; its dimensions should exceed the perimeter of the building to protect walls from the sun and provide a dry area around the building in rainy weather. Floors should be of concrete, isolated from soil humidity, and elevated to avoid penetration of water. Doors need to be wide. Enough for mechanized handling.

Storage facilities should be thoroughly cleaned before filling. This includes brushing and washing of walls and floors to eliminate dirt and organic debris that could harbor insects and diseases. Before product is placed in the storage room, inspection and presorting should be undertaken. This is in order to remove all potential sources of contamination for the remaining load. Product should be stacked in such a way that there is free circulation of air. During storage, it should also be possible to carry out quality control inspections. If the storage facility becomes full during a long harvest period, it needs to be organized around the principles of the system *"first* in first *out".*

STORAGE SYSTEMS

As a rule, there are many ways of storing a product. The length of storage time can be longer in specifically designed structures. With refrigeration and controlled atmospheres, storage periods can be even longer. The technology utilized depends on whether the benefits (higher prices) outweigh the costs.

Natural or Field Storage

This is the most rudimentary system and is still in use for many crops. For example, roots (carrots, sweet potato, and cassava) and tubers (potato). Crops should be left in the soil until preparation for the market. This is similar to how citrus and some other fruits are left on the tree. Although storing products under natural conditions is widely practiced, it leaves them exposed to pests and diseases as well as to adverse weather conditions.

This can have a detrimental effect on quality.

Another method widely used is field storage in heaps. This method ensures that produce is free from soil humidity and is protected from the weather with a tarpaulin,straw, or plastic materials. It is a low cost alternative for bulky crops that require large buildings. For example, potato, onions, pumpkins, sweet potato etc. Field storage in bins is a more recent variation where a pair of them (one on top of the other, the one above protected from the weather) is left in the field. It has the additional advantage of making it possible to undertake mechanical handling later.

Natural Ventilation

Amongst the wide range of storage systems, this is the most simple. It takes advantage of the natural airflow around the product to remove heat and humidity generated by respiration. Buildings providing some form of protection from the external environment and with gaps for ventilation can be used. Produce can be placed in bulk, bags, boxes, bins, pallets etc. Although simple, some key concepts need to be taken into account for the efficient operation of this system.

1. Differences in internal temperature and relative humidity conditions compared to conditions externally, need to be minimal. What this means is that this system can only be used with crops that store well under natural conditions such as potato, onions, sweet potato, garlic, pumpkins, etc.

1. For adequate ventilation, openings need to be wide. This means they need to be fitted

With screens to keep animals, rodents, and pests out.

3. As with any other type of fluid, air follows the path of least resistance. This means

that if product is stored in a compact mass, air will circulate to remove heat and gases which have accumulated as a result of respiration. Efficient ventilation requires adequate space. However, this reduces storage capacity.

4. Hot and humid air rises within the storage facility. If no ventilation gaps exist, this leads to the buildup of hot and humid areas which in turn affects the quality of stored goods. This presents the ideal conditions for the development of disease.

Within certain limits, it is possible to take advantage of natural changes in temperature and relative humidity. This can be achieved by selectively opening and closing the storage ventilation. At noon, ambient temperature and relative humidity are higher and lower, respectively. However, at night the opposite happens. To reduce temperature of stored products, buildings should be left open when external air temperatures are lower.

Internal relative humidity can also be managed in a similar way.

External conditions constantly change, even during the same day. However, in comparison to air, stored mass is slower to gain and release heat. In order to handle this efficiently, internal and external electronic sensors for temperature and relative humidity are required. In addition to this, although crops suitable for this type of storage have low respiratory rates, some ventilation may be required. This is in addition to the automated opening and closing schedules.

Forced Air Ventilation

Heat and gas exchange can be improved provided air is forced to pass through the stored product. This system allows for more efficient utilization of space for bulk storage. Air conducts run under a perforated floor and air is forced through the product. Again, as air follows the least resistance path, loading patterns as well as fan capacity and conduct dimensions should be carefully calculated. This is to ensure that there is uniform distribution of air throughout the product.

Removable perforated ducts can be used for storage space when there are no products in storage.

Fan selection is the most critical factor and specialized personnel should design the system based on volume and number of air changes per unit of time required. The latter is a function of respiratory rates of products to be stored. Static pressure or resistance to the airflow by conducts and stored mass should be considered. Ideally, sensors reacting to the internal/external ambient relationship should control the system. If closed, internal air circulation only occurs. On the other hand, if opened internal atmosphere is replaced by ventilation. A partial opening produces a mix of internal and external air to reach the desired combination of temperature and relative humidity.

Refrigeration

Controlling temperature is one of the main tools for extending postharvest life: low temperatures slow product metabolism and the activity of microorganisms responsible for quality deterioration. As a result, reserves are maintained with a lower respiration rate, ripening is retarded and vapor pressure between products and ambient is minimized, reducing water loss. These factors contribute towards maintaining freshness by reducing the rate at which quality deteriorates and the nutritional value of the product is preserved.

A refrigerated room is a relatively airtight and thermally insulated building. The refrigeration equipment should have' an external escape outlet to release externally the heat generated by the product. Refrigeration capacity of the equipment should be adequate to extract the heat generated by crops with a high respiration rate.

It is also important to precisely control temperature and relative humidity conditions inside the refrigerated storage environment.

Refrigerated space depends on the maximum storage volume. Other factors to be considered include walkways and aisles to handle the product mechanically and the additional space to ensure uniform distribution of cold air. It is not uncommon to find that produce occupies only 75-80% of total surface area. Chamber height depends on product and stacking- pattern: three meters for hand stacking but more than six may be required if forklifts are utilized.

Refrigerated rooms can be made with concrete, metal; wood, or other materials. All external surfaces should be thermally insulated, including the floor and ceilings. Type and thickness of insulation material depends on building characteristics, produce to be stored and the difference in temperature required between external and internal conditions. Polyurethane, expanded polystyrene, cork and other such materials can be used as insulation materials. A vapor barrier should be placed on the warm side of the insulation material.

Mechanical refrigeration has two main components: the evaporator, inside the storage area and the condenser which is outside connected by tubing filled with refrigerant. Normally, both elements are finned coils made of high thermal conductivity materials and integrated to a fan. This facilitates heat exchange. An evaporator is placed in the upper part of one of the walls forcing cold air to flow parallel to the ceiling.

Returning air is forced past the evaporator transferring to the coil the heat extracted from the product. A refrigerant absorbs this heat as it changes to gas, cooling the air, which is forced again into the room as cold air. The refrigerant is transported as gas to the condenser where under the pressure provided by a compressor, it is transformed again into the liquid form. The internal heat is then released outside. With this repeated cycle, the system behaves like a pump - heat is extracted from the stored product and then released outside. Another key aspect of the mechanical refrigeration system is the expansion valve, which regulates the evaporation and flow of refrigerant. Ammonia and

Freon gas are the most widely used refrigerants. However, they are now being replaced by more environmentally friendly products.

In addition to design and consideration of building materials, to gain maximum benefit from refrigeration the following conditions need to be met: refrigeration capacity\ needs to be adequate - this is in order to extract respiration heat from the product as well as conductive heat (through floors, walls, and ceiling); convective heat gains (door openings), and the heat produced by equipment (forklifts, lights, pumps, etc.).

Every crop has an optimal combination of temperature and relative humidity for storage. In many cases, there are differences even within varieties. As previously mentioned, it is recommended not to store more than one crop in the same room, unless this is for a very short period (less than a week) or during transportation. Very incompatible crops should not be in the same room for more than 1 or 2 days.

*Precooling*

Refrigeration equipment is designed to keep product chilled. However, they are not capable of reducing field heat rapidly. Field temperature is close to the ambient one and is much higher if produce is not protected from the sun. When produce is exposed to colder ambient conditions, it loses field temperature only slowly. It may take up to 24 or 48 hours in order to reach the new ambient temperature. The rate at which temperature falls depends on a number of factors. These include: differences in temperature, individual volume of product, total mass required for precooling and capacity of the refrigeration equipment. Metabolic activity (respiration, ethylene production, biochemical, and enzymatic reactions) also decreases with temperature - when storage temperature is reached rapidly, this results in reduced losses in energy, stored reserves, and quality.

Precooling is the rapid reduction of field temperature prior to processing, storage, or refrigerated transport. Generally it is a separate operation requiring special facilities, but complementary to cold storage. As deterioration is proportional to the time produce is exposed to high temperatures, precooling is beneficial even when produce returns later to ambient conditions. It is critical in maintaining quality in fruits and vegetables and forms part of the "cold chain" to maximize postharvest life.

Product temperature loss is not linear. This is because it is rapid at the beginning but slows down as it approaches the medium refrigerating temperature. Operation costs increase for each degree reduced. In commercial operations, produce is precooled to

**Postharvest treatments**

Fresh fruits are living tissues subject to continuous change after harvest. Some changes are desirable from consumer point of view but most are not. Postharvest changes in fresh fruit cannot be stopped, but these can be slowed down within certain limits to enhance the shelf life of fruits. The post-harvest treatments play an important role in extending the storage and marketable life of horticultural perishables. The most important postharvest treatments include:

**(i) *Washing with chlorine solution:*** Chlorine treatment (100–150 ppm available chlorine) can be used in wash water to help control inoculums build up during packing operations. Maintain pH of wash water between 6.5 and 7.5 for best results.

**(ii) *Ethylene inhibitors/Growth regulator/fungicide treatments:*** 1-MCP

(1-methyl cyclopropene), AVG (Amenoethoxyvinyl gycine), silver nitrate, silver thiosulfate, cycloheximide, benzothiadiazole etc. are some of the chemicals which inhibit ethylene production and/or action during ripening and storage of fruits. The growth regulators or fungicidal application such as GA 3 can be effectively used to extend/enhance the shelf life of fruits.

**(iii) *Calcium application:*** The post-harvest application of CaCl 2 or Ca (NO 3 ) 2 play an important role in enhancing the storage and marketable life of fruits by maintaining their firmness and quality. Calcium application delays aging or ripening, reduces postharvest decay, controls the development of many physiological disorders and increases the calcium content, thus improving their nutritional value. The post-harvest application of CaCl 2 (2–4 %) or Ca

(NO 3) 2 for 5–10 min dip extend the storage life of pear up to 2 months, plum up to 4 weeks and apple up to 6 months at 0–2 ºC with excellent color and quality. Calcium infiltration reduces chilling injury and increase disease resistance in stored fruit.

**(iv) *Thermal treatments:*** Thermal treatments included (a) hot water treatment:

Fruits may be dipped in hot water before marketing or storage to control various post-harvest diseases and improving peel color of the fruit (Table 3 ).

(b) Vapor heat treatment (VHT): This treatment proved very effective in controlling infection of fruit flies in fruits after harvest. The boxes are stacked in a room, which are heated and humidified by injection of steam. The temperature and exposure time are adjusted to kill all stages of insects (egg, larva, pupa and adult), but fruit should not be damaged. A recommended treatment for citrus, mangoes, papaya and pineapple is 43 ºC in saturated air for 8 h and then holding the temperature for further 6 h. VHT is mandatory for export of mangoes.

**(v) *Fumigation:*** The fumigation of SO 2 is successfully used for controlling post- harvest diseases of grapes. This is achieved by placing the boxes of fruit in a gas tight room and introducing the gas from a cylinder to the appropriate concentration. However, special sodium metabisulphite pads are also available which can be packed into individual boxes of a fruit to give a slow release of SO 2. The primary function of treatment is to control the *Botrytis Cinerea.* The SO 2 fumigation is also used to prevent discoloration of skin of litchis.

**(vi)  *Irradiation:*** Ionizing radiation can be applied to fresh fruits and vegetables to control micro-organisms and inhibit or prevent cell reproduction and some chemical changes. It can be applied by exposing the crop to radiations from radioisotopes (normally in the form of gamma-rays measured in Grays (Gy), where 1 Gy = 100 rads.

**(vii) *Waxing:*** Waxing of fruits or vegetables is a common post-harvest practice.

Food grade waxes are used to replace some of the natural waxes removed during harvesting and sorting operations and can help reduce water loss during handling and marketing. It also helps in sealing tiny injuries and scratches on surface of fruits and vegetables. It improves cosmetic appearance and prolongs the storage life of fruits and vegetables. The wax coating must be allowed to dry thoroughly before packing (Dhatt and Mahajan 2007).

It could be concluded that, 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. Postharvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product. The most important goals of postharvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage.

**Table** Hot water treatments for different fruits



Adapted from Kitinoja and Gorny (1998)

**Controlled Atmospheres**

With atmosphere modification, the low metabolic rate achieved with refrigeration is extended even further. As a result, the storage period is prolonged without further losses in quality. Composition of normal atmosphere at sea level is around 78,1 % nitrogen, 21 % oxygen y 0,03% carbon dioxide. A "controlled" or "modified" atmosphere is obtained when its composition varies from the norm. In controlled atmosphere, gas composition is exactly maintained. It is often used for extremely long periods of storage in purpose built facilities. Modified atmospheres, on the other hand, are obtained when produce is packed in semi permeable films and are used for short periods. The atmospheric composition inside the package changes until it is in equilibrium with the ambient one. Equilibrium atmosphere depends on product, film characteristics, and storage temperature.

The modification of storage atmosphere delays the biochemical and physiological changes associated with senescence. This mainly involves the respiratory rate, ethylene production, softening and compositional changes. Other effects include the reduction in sensitivity to ethylene, and in some cases chilling and the severity of pathogen attack. The atmospheric composition can also be used to control insects. The risk of using abnormal atmospheres is that they may cause fermentation, tissue asphyxia, and the development of off-odors or off-flavors.

From the construction point of view, controlled atmosphere facilities are similar to refrigeration facilities. However, they should be airtight to allow creation of an atmosphere different from normal. The Oxygen consumption and its replacement by carbon dioxide by 'respiration, create the atmosphere. When the appropriate combination has been reached, a limited intake of oxygen is required to satisfy the reduced rate of respiration. Accumulation of carbon dioxide is removed by means of different methods. Because internal atmosphere behaves differently, a pressure compensating system is required to attain equilibrium with the external or ambient atmosphere. As controlled atmosphere rooms are kept locked until the end of the storage period, inspection windows are required to control refrigeration equipment. Product should also be placed at the top of one of the walls. Atmospheric composition is crop specific. However, as a general rule the most common combinations are 2-5% oxygen and 3-10% carbon dioxide.

Many crops benefit from atmosphere modification. However, usage is limited. It is difficult to define products ideal for storing under controlled atmosphere. However, one of the most important factors is that investment and operating costs should be recovered. Other factors include: First, products should be seasonal and have a stable demand during a long marketing period.-Second, product should have some unique qualities and not be easily substituted by similar products. In other words, it is beneficial to use controlled atmosphere technology when there are no competitor products on the market.

This may go some way towards explaining why its usage is limited to specific crops, particularly apples and pears.

**Chapter Six**

**Postharvest disease of Horticultural produces**

**6.1. Development of Postharvest Diseases**

 The diseases which develop on harvested parts of the plants like seeds, fruits and also on vegetables are the post-harvested diseases. The harvested products may get infected on the way to storage or to market or even before their final consumption. The plant parts may get infected in the field, but expression of symptoms may take place later, at any stage before final consumption.

The plant products may get infected by microorganisms and cause rotting or decaying — partially or totally. The quantity of plant products becomes reduced due to the above infection. The seeds or grains may get damaged by accu­mulation of toxic substance, the mycotoxin pro­duced by the infected microorganism.

The main causes for postharvest losses during storage are:

1. Physiological deterioration (softening, wilting)
2. Pathological deterioration (decay and rots)

Postharvest decay causes significant commercial losses due to wastage.

Further economic losses occurs if the market requires re-packaging of the contaminated commodity.

In consumer packages, if one fruit in the package is you need to throw away the entire bag.

**The major postharvest diseases are caused by several types of fungi:**

* ***Alternaria***
* ***Botrytis***
* ***Colletotrichum***
* ***Diplodia***

The majority of pathogens rely on damaged tissues to obtain entry into fresh produce (wounds or sites of physiological injury).

For example, the ***Penicillium*** *species* which cause blue and green mould infections of citrus and other fruit crops are classic wound pathogens, incapable of invading an undamaged fruit.

There are specific genetic interactions between the host and the pathogen, which govern if the commodity will be resistant or susceptible.

For example, *Penicillium digitatum* attacks only citrus, whereas *Penicillium expansum* can attack apples and pears but not citrus.

**6.1.1. The pathogens**

Infectious diseases are caused by pathogens, which include bacteria, fungi, protozoa, worms, viruses, and even infectious proteins called prions. Pathogens of all classes must have mechanisms for entering their host and for evading immediate destruction by the host immune system

**6.1.2. The infection process**

Fruits and vegetables may be infected in the field while they are still attached to the plant or after harvest.

Pre-harvest infection–occurs especially on floral parts and during fruit development.

These infections are arrested (‘latent’ infections) until the commodity ripens and senesces. Examples are *Colletotrichum, Botrytis and various stem-endrots.*

Postharvest infection–occurs after harvest by penetration through the skin or by invasion through surface wounds. Examples are *Penicillium and Rhizophus****.***

**6.1.3. Resistance to Infection**

Plant disease resistance protects plants from pathogens in two ways: by pre-formed structures and chemicals, and by infection-induced responses of the immune system. ... Plants consistently resist certain pathogens but succumb to others; resistance is usually specific to certain pathogen species or pathogen strains.

**6.1.4. Sources of postharvest Diseases**

* At the field or orchard
* Greenhouses
* Harvesting tools
* Buckets, carts, boxes, etc.
* Packinghouse facilities
* Storage facilities
* **Markets**

**6.2. Factors influencing postharvest disease of horticultural crops**

**6.2.1. Pre- harvest factors**

Pre-harvest factors may also be further classified depending on causes.

(1) Biological factors

(2) Physiological factors

(3) Environmental factors

(4) Mechanical damage

(5) Extraneous matter and

(6) Genetic variation and aberrations

**6.2.2. Postharvest factors**

* Immature/premature/over mature harvest
* Faulty postharvest practices
* Poor sorting and grading practices
* Poor temperature and relative
* Improper packaging and washing
* Delay and improper transport to market
* Causes of exogenous factors(rot, insects)
* Lack of knowledge on p/harvest practices

**6.3. Management of postharvest Disease of fruits and vegetables**

The diseases can be controlled or reduced following the preventive procedures are:

1. The fruits and vegetables should be harves­ted and handled carefully to avoid any injury which may facilitate the pathogen to cause infection.

2. The infected region on the vegetables should be cut off to avoid further infection during transportation and storage.

3. Storage container, warehouses etc., should be properly cleaned with CuSO4, formal­dehyde etc. to avoid contamination.

4. The crop should be stored or transported at a temperature low enough to slow down the development of disease.

5. Proper ventilation in storage reduces the spread of further development of disease.

6. The crops should be free from Insects and other pests, thus creation of new wounds and disease can be avoided.

7. Hot water and hot air treatment help to reduce further spread of the disease.

8. Chemical control. Post-harvest diseases may be controlled by the application of thiabenda­zole, dichloran, dosa-ash, etc. These chemi­cals help to prevent infection and suppress the development of pathogen on the host sur­face.

Some other chemicals, such as vapours of acetaldehyde, biphenyl/nitrogen chloride forming chemicals etc., are used as supple­mentary measures to control the post-harvest diseases during storage and transportation.