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Handling Strategies and Facilities for Horticultural Crops

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Abstract

Horticultural crops are high-value crops and of higher profit than staple food crops per unit of land. It also generates income since it can be used for several purposes to achieve zero hunger and food security. The major problem with fruits and vegetables is the short postharvest shelf life. They are highly delicate and are endangered to rapid quality loss after harvest. Using best postharvest handling practices or factors like optimum temperature, right ratio, right gases in storage, right sanitizers, etc. and best physical handling procedures to take care of the standard after harvest is extremely critical. There is inadequate information on handling strategies and facilities to improve their keeping quality. To establish a good management system for the postharvest quality of these produce, food farmers' handlers and processors must follow standard strategies to ensure availability on off-seasons. This work achieved these objectives of providing information on strategies for reducing losses during postharvest handling of fruits and vegetables, factors to consider during their storage, artificial ripening of fruits and wrong use of calcium carbide and food storage structures and facilities. Until these factors are properly considered and managed, loss in quality is inevitable for farmers, handlers and food processors. Also, good knowledge of advances in technology in this area is going to be paramount in facing a future challenge in the food handling process.

Subject Areas

Agricultural Science, Food Science & Technology

Keywords

Postharvest, Pre-Harvest, Food-Safety, Control-Atmosphere, Ethylene-Production, Respiration

1. Introduction

All harvested horticultural foods are living biological organism, having a respiratory system similar to that of humans. They continue to respire after harvest and thus change their characteristics depending on produce handling and storage treatment [1]. Horticultural crops have great challenges from the standpoint of postharvest loss both in terms of quantity and quality between harvesting and final consumption [2]. Postharvest technologies constitute an interdisciplinary science and technologies (chemical engineering, Food engineering and technology, microbiology, etc.) applied to agricultural commodities after harvest for purpose of preservation, conservation, quality control/enhancement, processing, packaging, storage, distribution, marketing and utilization to meet the food and nutritional requirement of consumers in relation to their needs [3]. During postharvest storage, a number of degradations of respiratory substrates occur resulting in a number of changes which include but are not limited to changes in: taste, colour, taste, flavour and texture. Produce losses in quality and quantity can occur at any step during the postharvest chain with important economic impact [4].

According to [5], the greatest level of losses in agricultural production occurs at the post-harvest level with a worldwide estimation of 10% - 40% with the greatest quantum of losses occurring in developing nations with roots and tubers and oil-bearing crops being the most venerable.

Some factors responsible for loss of agricultural produce include but are not limited to: the selection of poor-quality planting materials, mechanical injuries, temperature, humidity, and storage atmosphere. Postharvest losses have their origin in pre-harvest stage, for example, genetic factors, infections, pest infestation, environmental factors and cultural practices during on-farm activities [5]. Food can be predisposed to damage, hazard and losses at a different point from growing through harvesting to consumption. Reduction of these losses would be of great significance for food producers and consumers alike [1].

The main objectives of applying food produce handling strategies are to take care of quality (appearance, texture, flavour and nutritive value) maintain food safety and to scale back losses between harvest and consumption [6]. Safety and perishability are the two most vital concerns in all food production. Safety is decided principally by the absence of a pathogen or toxic chemical in food. Perishability is caused by microbial degradation, enzymatic activity and/or chemical reactions, which may result in undesirable changes in sensory, physical and nutritional properties of the horticultural produce. Harvested agricultural produce varies in their perishability, counting on their consumption and required processing method, packaging and storage [7]. There is an increasing demand for products having a well-preserved nutritional value, retaining natural and fresh colour, flavour, and texture and containing fewer additives such as artificial preservatives. This requirement represents a new challenge for food processors, food handlers and food safety professionals [3]. This work has the objective of elaborating on the strategies for reducing losses during postharvest handling, principles of food produce handling, structures and facilities and resents advances for extension of shelf life of food produce

2. Strategies for Reducing Losses during Postharvest Handling

2.1. Appropriate Pre-Harvest Cultural Practices Improve Postharvest Quality

Pre-harvest factors such as production location, planting date, soil type, irrigation, shading and nutrient largely affect post-harvest quality of produce [3]. Kader [8] reported that soil type, mulching, fertilization, micro agro-climatic conditions of the soil and other cultural practice influences the water and nutrient content of the plant which can also affect compositional attributes such as appearance, texture, taste, and aroma of the harvested plant parts. The report also stated that climatic condition especially temperature, humidity and light intensity has strong effect on the nutritional quality of food products.

Fischer [9] reports that the capacity of photosynthesis depends on the incidence of light, whereby the shaded parts of the canopy assimilate less and need more leaves than the well-illuminated part for optimum fruit development. Heavy pruning diminishes leaf area, whole tree photosynthesis and translocation of photosynthates of fruits and root crops, increasing the root/shoot ratio and favouring vegetative growth. Field management practices such as pest control, soil fertility and water management are of great importance in achieving good quality attributes in size, colour, flavour, texture and nutritional value of vegetables [10]. Optimum plant performance depends on a balanced availability of mineral nutrients that can be limited in many soils around the world [11]. Nitrogen (N) and potassium (K) are the principal nutrient needed by plants [12] Nitrogen and calcium have profound effect on firmness, ethylene production, respiration, storage life, ripening and decay of produce especially fruit and vegetables.

Environmental factors such as light, CO_2, relative humidity, temperature and water availability are major direct or indirect constraints of plant photosynthesis there by providing energy precursors for the synthesis of bioactive compounds [11].

Abiotic conditions such as soil fertility and water availability vary from year to year and from location to location and this affects quality of the produce after harvest [13]. Increase exposure to light increases fruit size [14] total soluble solid and flesh firmness [15]. Quality of cultivar is important for good quality produce, horticultural breeding and biotechnology plays a significant role in improving and maintaining postharvest quality and safety, the growers have the choice of selecting preferred cultivars prior to planting crops [8].

2.2. Appropriate Postharvest Practices Improve Produce Quality

According to Jagdish [16], the operation of harvesting consists of the following: Identifying and judging fruit maturity, Selecting the fruit which are matured, Separating the fruit from tree, Collecting the fruits which are matured.

2.2.1. Maturity

Maturation is the stage of several developments resulting in the attainment of physiological or horticultural maturity. Physiological maturity is that stage of development when a plant or plant structure will still develop even if detached. Horticultural maturity refers to that stage of development when plant or plant structures possesses the essentials for its utilization by consumers for an exact purpose [17]. Example green beans, okra and cucumbers are not allowed to attain its physiological maturity rather horticultural maturity. Maturity stage of any crop at harvest has an important effect on the postharvest quality [17]. Postharvest processes like storage, transportation and marketing are influenced by the stage at which the commodities are harvested. Fruits are harvested when they have attained physiological maturity which is the stage of maximum dry weight while vegetables are harvested at the stage of horticultural maturity. This stage is dependent on consumer's willingness. Maturation, ripening and senescence are the critical stages that predominantly determine shelf life of fruits and vegetables. The stage of maturity gives an indication of the fruit being ready for harvest [18] Stage of maturity also depends on how far the fruit will be transported, how long it will be kept in the storage and requirement for specific market [19].

2.2.2. Illustration of Maturity Stages in Tomato Production

Depending on the mode of disposal, the tomato fruits may be harvested at various stages of maturity. The stages include:

1) Green stage: This describes the stage when fruits are fully developed but are still green and suitable for sending to distant markets.

2) Pink stage: This describes the stage of maturity when some of the portion of the fruit is red or pink and the fruit is not fully ripe. It is most fitted to local markets.

3) Ripe stage: This describes the stage when the major portion of the fruit is red and the softening begins. It may be picked up for home or table use.

4) Full ripe stage: This describes the stage when the fruit develops maximum colour and turns soft. It is suited for processing purposes. After picking the fruits are graded and sorted out into cracked, bruised, injured fruits and well-matured ripe fruits.

➢ How is harvest maturity identified? Most growers decide when to harvest by looking and sampling. Judgements 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. 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: avocados remain unripe off the tree after maturity.

2.2.3. Technique of Harvesting

Selection of suitable technique for harvesting is necessary to avoid bruises and injuries which subsequently manifest as black or brown patches making them unappealing. Latex coming out of stem of mango should not be allowed to drop as it creates black spot. Injury may turn to be an entry point for microorganism causing rotting. Varied harvesting gadgets have been developed. The most generally used are the picking shears and blade which are hand held or pole mounted

The fruits and vegetables would be tough to catch, sometimes, materials which is made of impact cushion would be kept girding the tree so that impact on the fruit will be averted when they are falling from high trees [17]. Reaping/harvesting vessels like bags worn at the waistline and containers such as plastic pails would be suited for carrying reaped fruits. The vessels must have a certifiable smooth exterior with no sharp edge to avoid damage on the fruits. Large scale agriculturist will use bulk boxes which has the capacity of 200 to 500 kgs in which crops like apples, tomato etc. are placed and these will be transferred for selection, packing and grading for large scale packing house [17]. The harvesting time is also of important, fruits plucked before 10 am and transported to packing house yields better and last longer. It is desirable that fruits are picked during the cooler part of the day to reduce the hazard of heat injury and sunburn [20]. **Figure 1** shows an example of hand-held harvesting tools.

Figure 1. Pictorial presentations of hand-held harvesting tools.

2.2.4. Pre-Cooling

Pre-cooling is done for rapid cooling of harvested products to the needed storehouse temperature and to retard physiological processes. Rapid cooling of fruits after harvesting is most important operation as increased field heat gives rise to undesirable changes in some metabolism and triggers quality deterioration [21]. Precooling minimizes microbial growth and multiplication, metabolism, respiration rate and ethylene output. It is well known that a rise in temperature of the environment by 10˚C doubles the rate of chemical and biochemical reactions (Q_{10} Value) conversely a reduction in temperature by 10˚C will reduce the rate of these reactions by one half. It also reduces ripening rate, water loss and decay there by maintaining the quality and extending shelf life of harvested fruits [22]. Pre-cooling can be done using processes like forced cooling, hydro-cooling, vacuum cooling and ice cooling. The rate of cooling depends on the techniques chosen, thermal properties of the fruits, heaping pattern and contact between cooling medium and the fruits [23].

2.2.5. Field Curing

Curing roots and tuber crops like as potatoes, sweet potatoes, cassava and yams is an important practice these crops are to be stored for some time. Curing is achieved by holding the fruits at high temperature and high relative humidity for several days after harvesting with the aim to heal the scratches and form a new self-protective layer of cells. It is common practice to cure onion and garlic bulbs, directly following harvest [23]. Best practice for curing varies among crops as follows: potato at 15˚C - 20˚C, 90% - 95% R. H., for 5 - 10 days; sweet potato at 30˚C - 32˚C, 85% - 90% R.H., for 4 - 7 days; yam at 32˚C - 40˚C., 90% - 100% R.H., for 1 - 4 days; cassava at 30˚C - 40˚C, 90% - 95% R.H., for 2 - 5 days" [24]. The dried layer of skin will protect the produce from further water loss during storage and reduce mould and bacteria attacks. **Table 1** shows conditions suggested for the curing of roots and tubers, while **Figure 2** show sketches of traditional yam and onion curing methods.

2.2.6. Waxing

The use of wax or comparable coating enhances appearance and limit water losses from products such as citrus. It requires special equipment and has little

Table 1. Conditions suggested for the curing of roots and tubers.

Crop	Temperature (˚C)	Relative humidity (%)	Curing time (days)
Irish potato	13 - 17	above 85	7 - 15
Sweet potato	27 - 33	above 90	5 - 7
Yam	32 - 40	above 90	1 - 4
Taro (dasheen)	30 - 35	above 95	4 - 7
Cassava	30 - 35	above 80	4 - 7

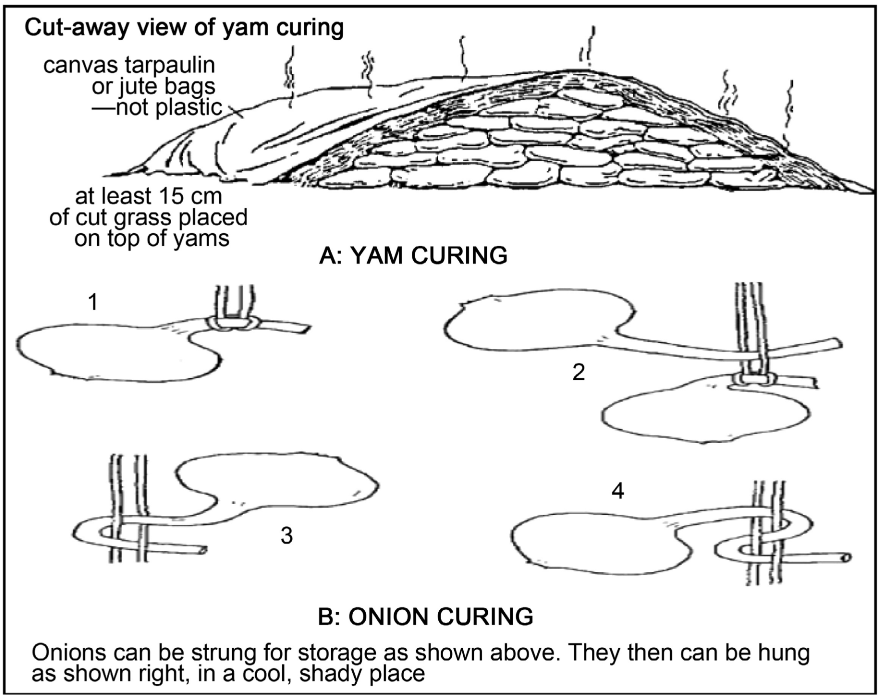


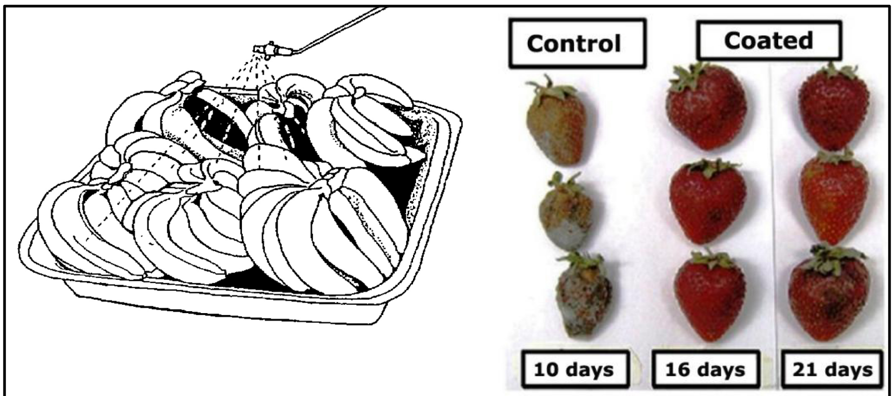
Figure 2. Sketches of traditional yam and onion curing methods [24].

relevance to small-scale handling. Waxing is generally receded by fungicide treatment.

It can be achieved by coating citrus and apples, carnauba and shellac, or apricots with sucrose fatty acid esters. During the process of waxing the internal gases and the moisture content of the fruits change, waxing can be achieved using spray or by dipping method. After drying, the coating changes the internal environment to form a thin film around the surface of the produce [25]. The resulting coating reduces the amount and size of lentils by limiting the amount of water that leaves the product as a result of transpiration. This leads to moisture concentration within the fruit environment and modulates the gas exchange on the surface of the fruit resulting in higher level of CO_2 and Low O_2 level [26]. The low oxygen levels produced by the wax affect physiological processes such as respiration and enzyme-mediated processes such as the ethylene biosynthesis pathway. Low O_2 status has been reported to limit the activity of 1-aminocyclopropene-1carboxylic acid (ACC) oxidase [27] the enzyme that catalyzes the conversion of ACC to ethylene. Lower level of enzyme activities during breaking down of chlorophyll and cell wall degradation have also been reported to occur with low O_2 conditions [28]. **Figure 3(a)** shows the process of spraying coatings using hand operated knapsack pump, and **Figure 3(b)** presents the resultant effect of coatings on fruit for 10 (control), 16 and 21 days.

2.2.7. Packing

Locations for packing operations may simply provide short-term or temporary shelter in fields next to harvest areas to shield farm produce and workers from



(a) Spraying of produce using hand-operated knapsack Pump. These bananas will dry on perforated tray.

(b) fruits treated with coatings have prolonged shelf-life

Figure 3. (a) Spraying of coatings using hand operated knapsack pump; (b) Resultant effect of coatings on fruit for 10, 16 and 21 days [24].

the harsh weather while in fields. This is a very important step for fruits that are harvested in hot and sunny conditions. Even a few hours of exposure to harsh weather significantly accelerates aging, or wet crops in the wet season greatly increase the chances of microbial infection.

2.2.8. Sanitizing and Cleaning

The removal of dirt and stones can be done manually or through a sieve. Some fruits can be washed, brushed, or wiped with a soft cloth. Cleaning is required to clean fruits that have latex stains due to crop injuries, such as in mango, papaya, and breadfruit. Fruits and vegetables can get contaminated during harvest operation and thus requires good sanitation system particularly during all pre and postharvest operations to eliminate sources of infection and reduce levels of fruit contamination [29]. Good hygienic practices are important throughout fruits handling practices not only to control postharvest deterioration but also for prevention of food born illness that may manifest in individuals [30]. Disinfectants like sodium hypochlorite, thiabendazole, chlorine dioxide [31], ozone [32], electrolyzed water [33], hydrogen peroxide [34] organic acids [35], peroxyacetic [36], trisodium phosphate [31], and radiation [37] *et al.* The pH of wash solution is ascertained to be more effective within the range of 6.5 to 7.5 [33].

2.2.9. Sorting and Grading

This is one of the most important processes after harvesting. it is done primarily to achieve quality packing and removal of diseased and unwholesome fruits from the lot [38]. Sorting is defined as the process of removing damaged, diseased, rotten fruits from healthy and clean ones which are unacceptable for market and storehouse [39]. Grading is the process of separating fruits and vegetables in two categories based on their shape, size, colour, and internal characteristics. This process helps food handlers to achieve storage in favorable containers based on size and shape [30]. Colour grading helps to remove over-ripe fruits which will produce ripening hormone ethylene thereby quicken the ripening of the fruits of whole mass [30]. **Figure 4** shows the diagram of sorting and grading instruments.

2.2.10. Packaging

Packaging entails enclosing produce to protect them from external contamination (physical, chemical and biological) and mechanical injuries [40]. Fruits are fragile products and therefore need packaging to protect them from mechanical damage [41]. Cardboard boxes, plastic trays, cartons are suitable for packing fresh fruits and are very common in developing countries [42]. Packaging material should be environmentally friendly, have sufficient strength in compression, be stable during the entire distribution chain, be compatible to mechanical filling system, be cost effective, easily printable and have consumer appeal [43]. **Figure 5** shows the diagram of Plastic trays as packing instruments for fruits and vegetables.

2.2.11. Storage

"Storage" as now applied to fresh produce is almost automatically assumed to mean the holding of fresh fruit and vegetables under controlled conditions. There are variations in the storage potential of different cultivars of the same crop. The storage potential of these, particularly tropical fruits in tropical countries, are very limited under ambient conditions. They quickly deteriorate

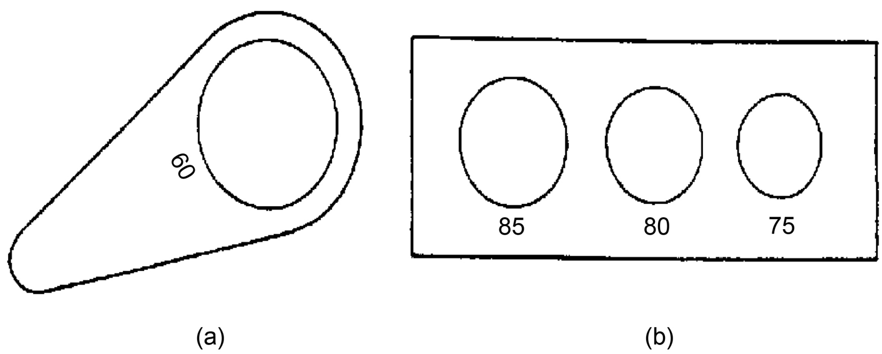


Figure 4. Sorting and grading instruments [30].

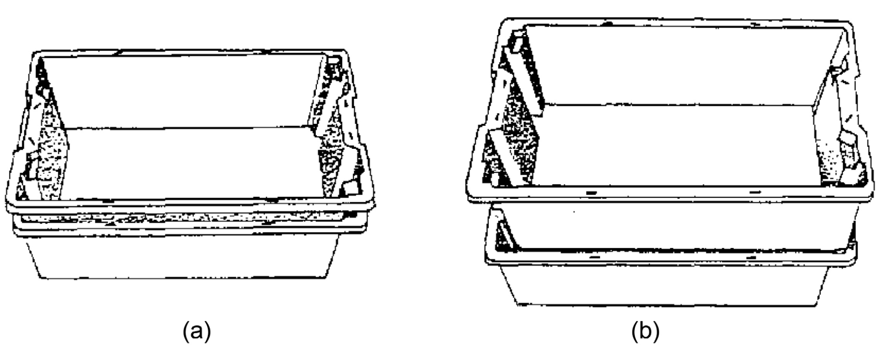


Figure 5. Plastic trays as packing instruments for fruits and vegetables [28].

because of their fast respiration rates, which cause rapid heat build-up and depletion of their high moisture content. Pulses have a long storage life, provided they are kept dry, and do not present a storage problem as is the case of fresh produce. Some of the factors that affect storage of fruits and vegetables are discussed in details below.

3. Factors to Consider during Storage of Fruits and Vegetables

3.1. Climacteric and Non-Climacteric Fruits Considerations

Climacteric fruits are defined to be those fruits that continue to ripen after harvest. During this process, the fruits release ethylene with rapid respiration rate. The fruit is still firm and green at harvest, but fully matured. They are ripened at the point of consumption because fully ripe fruits are too soft to withstand the stress of long-distance transportation. Small amounts of ethylene are used to accelerate the aging process under temperature and humidity-controlled conditions. Examples of climacteric fruits are apples, bananas, mangoes, kiwis, and figs, etc.

Non-climacteric fruits do not ripen further once they are plucked out of the parent tree. They produce little or no ethylene and do not respond to ethylene treatment there is no characteristic increase in rate of respiration or production of CO_2. Non-climacteric fruits include orange, grapes, watermelon, cherry, cashew, raspberry, etc.

3.1.1. Effects of Ethylene Treatment on Climacteric and Non-Climacteric Fruits

Both climacteric and non-climacteric fruits respond to ethylene, but in very distinct ways that can be used as diagnostic tools [44]. Applying higher concentrations of ethylene to the climacteric fruit maintains the maximum respiratory rate, peak time accelerates with maximum respiratory rate (and ripening) even after treatment is stopped. In non-climacteric fruits, the respiration rate increases proportionally with increasing ethylene concentration, but the peak time does not change and respiration decreases when ethylene is removed. Non-climacteric fruits such as cherries and strawberries ripen quickly, while citrus fruits can ripen slowly. Climacteric fruits like avocados and pears ripen quickly [45]. Fruit types that have both ripening patterns include melon and plums [46]. It has long been thought that the ripening of climacteric fruits is regulated by ethylene while that of non-climacteric fruits is regulated by abscisic acid (ABA) [47]. However, it is clear that ethylene and ABA, as well as other hormones (e.g. Auxins), are involved in ripening of both types of fruits [48]. Climacteric and non-climacteric types also share many aspects of ethylene perception and signaling and interestingly, the Ethylene Receptor (*ETR*) gene is more abundant in climacteric fruit than non-climacteric fruits, and ETR accumulates earlier in the latter [49].

3.1.2. The Role of Calcium and Nitrogen in Postharvest Shelf-Life

Calcium has proven to be associated with post-harvest life and ripening process of fruits in many experiments in literature. It decreases the decay caused by various spoilage organisms and plays an important role in fruit firmness, delays senescence and reduces ethylene production. Deficiency of Ca causes many disorders in fruits; bitter pit and water core are the major ones. Application of calcium in pre- and post-harvest stage has effectively been used to reduce the incidence of physiological disorders of fruits and improve their post-harvest storability [50]. Calcium is involved in preserving the textural quality of fruits since calcium ions form links or bond between free carboxyl groups of the pectin chains, giving rise to a more strengthened cell wall [51]. Manganaris *et al.* [52] recommended 62.5 mM calcium chloride immersion process as a potential postharvest handling method for whole peaches, since improved tissue firmness reduced the proneness to physiological disorders and decreased the risk of salt-related injuries. Calcium can be used in form of calcium propionate, calcium chloride, calcium chelates and calcium lactate. Calcium lactate showed a more lasting effect of firmness preservation than calcium chloride during the storage in fresh-cut cantaloupe [53].

Nitrogen is among principal nutrients needed by plants, deficiency leads to small fruits size with poor flavor but excessive nitrogen supply can cause negative impact on the fruits quality by reducing flesh firmness and sweetness, diminishing red color appearance and increasing susceptibility to postharvest diseases [54], High fruit N has been associated with increased susceptibility to fungal decay in apple [55]. Relatively high N levels in pear flower buds may be valuable in promoting fruit set [56], but high N available for vegetative growth may promote physiological disorders and increase susceptibility to fire blight [57].

3.2. Respiration

Respiration is the process of breaking down a cell's complex substances into simpler energy-providing molecules and some specific molecules used in various cellular reactions. Thus, respiration is a good indicator of cellular metabolic activity, and breathing patterns are characteristic of stages in the fetal life cycle, such as development, ripening, and aging/senescence [58]. **Figure 6** describes

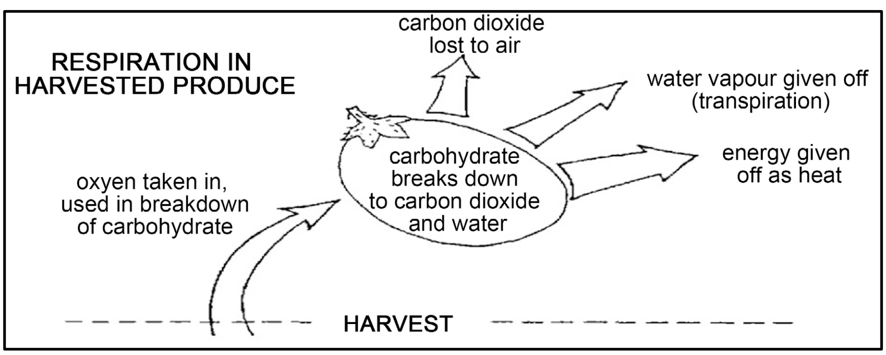


Figure 6. The process of respiration in harvested fruits [28].

the process of respiration in harvested fruits. During respiration of harvested crops in the store house, oxygen in the environment assists in the breakdown process of carbohydrate in the fruit into carbon dioxide and water. Carbon dioxide is lost as air; water vapour is given off through the process of transpiration while energy is given off as heat. The faster the rate of respiration is, the faster the deterioration of fruits is. Ability to elongate this process will lead to increased shelf life of the produce.

4. Artificial Fruit Ripening and Wrong Use of Calcium Carbide

Ripening is the composite of the processes that occur from the latter stage of growth and development through the early stage of senescence and that results in characteristic aesthetic or food quality as evidence of changes in composition, colour, texture or other sensory attributes.

Ripening agents are agents that accelerate ripening. They include the following.

4.1. Ethylene

Ethylene is a gaseous hormone produced by many plants. There are many synthetic ethylene analogues. They allow many fruits to be harvested before they are fully ripe, which is beneficial because ripe fruits do not tolerate stress during shipment. Bananas, for example, are harvested green and artificially ripened by exposure to ethylene after shipment. The only safe and acceptable way is to use ethylene. Ethylene is a natural de-greening and ripening hormone and must be produced at controlled temperature and relative humidity. Not only that it is not harmful to the health of the consumer, it is also a disinfectant that turns the peel from green to completely yellow.

4.2. Calcium Carbide

In some countries, it is prohibited for artificial ripening of fruits. When calcium carbide comes into contact with moisture, acetylene gas is produced, which has the same effect as ethylene, a natural ripening agent.

Even though, acetylene accelerates the ripening process. It is believed to affect nervous system by reducing oxygen supply to the brain. Calcium carbide contains trace of arsenic and phosphorus. Both chemicals are poisonous and exposure may lead to severe health hazard and so the use of this chemical is illegitimate in most countries. The use of Catalytic generators to produce ethylene gas is simple and safe. The ethylene sensors can also be used to precisely control the amount of gas. Covered fruit ripening bowls or bags are also commercially available. This container helps ripening by increasing the amount of ethylene and carbon dioxide around the fruit [59].

4.3. Ethephon (2-Chloroethylphosphonic Acid)

This is also an ethylene releasing compound, categorized as noncarcinogenic to humans by IARC (International Agency for Research on Cancer). It penetrates into the fruit and decomposes to ethylene [60] and has been discovered to speedup ripening process of several fruits including bananas, apples, tomatoes, mango, peaches, citrus fruits, and guava. Pendharkar [61] worked on treatment of bananas with variable concentrations of ethephon. Here it was reported that different concentrations of ethephon significantly impacted chemical changes during ripening and 1000 ppm was reported best concentration of ethephon for early ripening.

4.4. Appropriate Technique for Delaying Ripening

This is achieved using Postharvest treatment with gibberellin, Preharvest treatment with auxin at 25 ppm, Postharvest treatment with ethylene oxide, Treatment with ethylene absorbent like $KMnO_4$ (potassium permanganate). Potassium permanganate an accepted remover of ethylene used commercially. It oxidizes ethylene to ethylene glycol and it is oftentimes incorporated into different carrier material like silica gel and activated alumina. Waxing, low oxygen, high CO_2 and ripening inhibitors can be combined to extend ripening. Banana can be packed in film bag containing $KMnO_4$ to absorb ethylene.

5. Storage Structures and Facilities

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

5.1. Traditional Storage Technologies

Some of the low-cost storage structures have been discussed below.

5.1.1. In Situ/On-Site/Field Storage

This system delays harvesting by "leaving it on the ground". The crop is left on the ground until there is market demand. This strategy is mainly used for rhizome, rhizome and tuber crops. The main drawback of this technology is that it occupies the land where the product is grown and can delay replanting [62] [63].

5.1.2. Sand and Coir

This involves covering root and tuber crops underground using sand and coir is a traditional storage practice. The crop can be stored for longer durations of time by this approach [62].

5.1.3. Pits

These are ditches in which a pit is dug. These dug holes or pit are lined with cut grass, wood shreds, stubble, or soil (**Figure 7(a)**) [64]. They are prepared at the boundaries of the field and at an elevated point where there is a chance of lesser rain accumulation in the cultivated field [62]. "The product stays cooler as compared to the air temperatures because of submersion in the pits. Tubers like potato, carrot, sweet potato, onion, turnip, parsnip, cabbages, and beets are covered up with straw and soil until the market demand for the crop arises" [63].

5.1.4. Clamps

Clamps are by tradition used in certain parts of the world to store potatoes (**Figure 7(b)**). Clamps are usually installed at the edge of the field. Width is about 1 to 2.5 m; the width is marked after the potatoes are poured into the conical pile. Potato beds are often made of bare straw. The height of the center of the pile is about one-third the width of the clamp, which is determined by the angle of inclination of the pile. Rain flows over the structure through straws with a curved top to prevent the possibility of collapse. The thickness of the compressed straw should be in the range of 15 - 25 cm. After 2 weeks, the clamp is covered with soil to a depth of 15 - 20 cm. This depends on the location and the environmental requirements [62] [63]. In India's more tropical climate, additional straw was used instead of soil to improve ventilation. In colder temperatures, a second insulation layer can also be made of soil and straw. In hot areas, a chimney air outlet can be created at the top of the clamp to ensure adequate ventilation. In heavy rain areas, you can prevent rainwater from entering by placing the clamp under trees or roofs [64].

5.1.5. Cellars/Root Cellars

Figure 8(a) and **Figure 8(b)** is a good representation of a cellar. Cellars must perfectly be dark, cold, and damp. They must be located by the basement walled-off area or garage having a significant area of optimum size and windows for proper ventilation [63]. The cellar can be used to store a wide variety of fresh product, including beet, broccoli, potato, turnip, cabbage, carrot, pear, onion, Brussel sprouts, apple, and winter radish [62] [63].

5.2. Ventilated Storage Structures

Ventilated storage structures have an inflow of air that ensures nominal storage temperature. This air can be naturally expelled or pushed into structures. The simplest system is natural ventilation storage (**Figure 9(a)**). In this storage, the heat around the product is continuously removed by the natural air along with

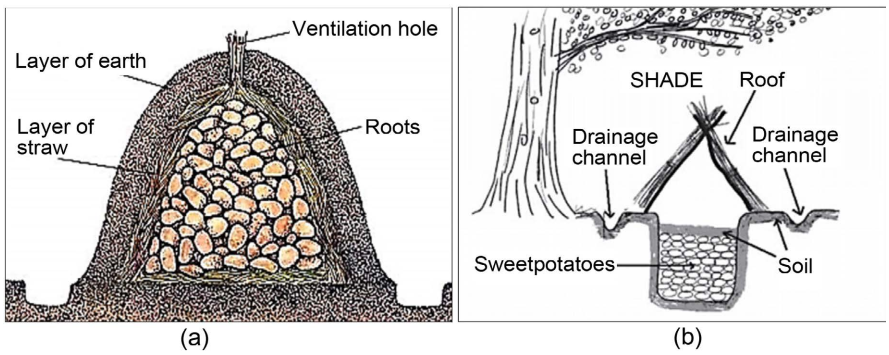


Figure 7. (a) Pit storage for potatoes [64]; (b) Root clamp cross-section [64].

the moisture produced by the produce during respiration. Forced ventilation, on the other hand, uses an additional fan to speed up heat and gas exchange. Air is extruded through stored crops at a rate of 1013 m/s [65]. Some properties include side vented storage structure (25 - 50 tons capacity), concentric structures, low volume low-cost structures (5 - 10 tons capacity) made of bamboo, Nasik type storage structure (**Figure 9(b)**) [65].

5.3. Evaporative Cooling Chamber

The cooling of crops in the evaporative cooling chamber is done based of the physical principle that when water evaporates, it results in a cooling effect which affects objects that comes in contact with it [66] [67]. The humidity of the surrounding air controls the rate of cooling and determines its effect [67] [68].

5.4. Pot Design

This is the simplest evaporative cooler design and can be used at home. The product to be cooled is stored in the inner pot [69]. The storage pot (**Figure 10**) is stored in an earthenware bowl of water. The cloth absorbs water from the bowl, which evaporates and lowers the temperature of the storage jar [63].

(a) (b)

Figure 8. (a) Storage of produce in a Cellar [65]; (b) A view of a Caller [65].

(a) (b)

Figure 9. (a) Storage of onion in natural ventilation; (b) Ventilated storage, Nasik type [65].

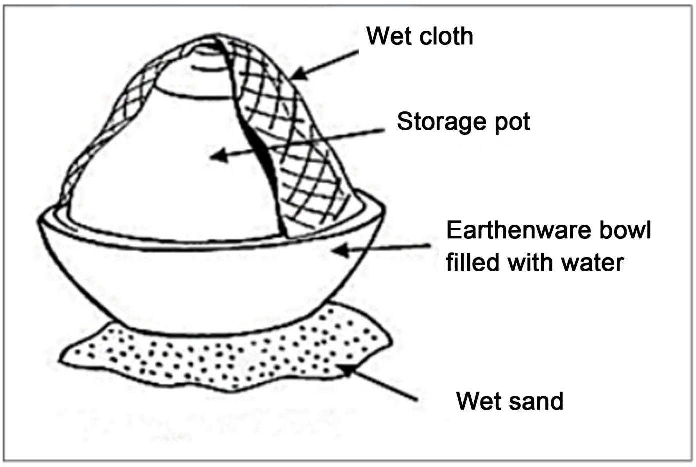


Figure 10. Pot type evaporative cooler [69].

5.5. Charcoal Cooler

Charcoal Cooler consists of an open wooden frame of approximately 50 mm × 25 mm (**Figure 11**). One side of the frame is used as a hanging door. Wrap the entire crate with a net inside and outside. A 25 mm cavity remains in the charcoal-filled net. Water is sprayed on the charcoal to achieve evaporative cooling. This frame is attached to a pole with a metal cone to prevent rot by rodents and mice. The entire setup will be installed outside the building. A good layer of fat is also used to prevent ant rot. The top of this system is generally solid and thatched, along with overhangs to keep flying insects away from stored products [62] [70].

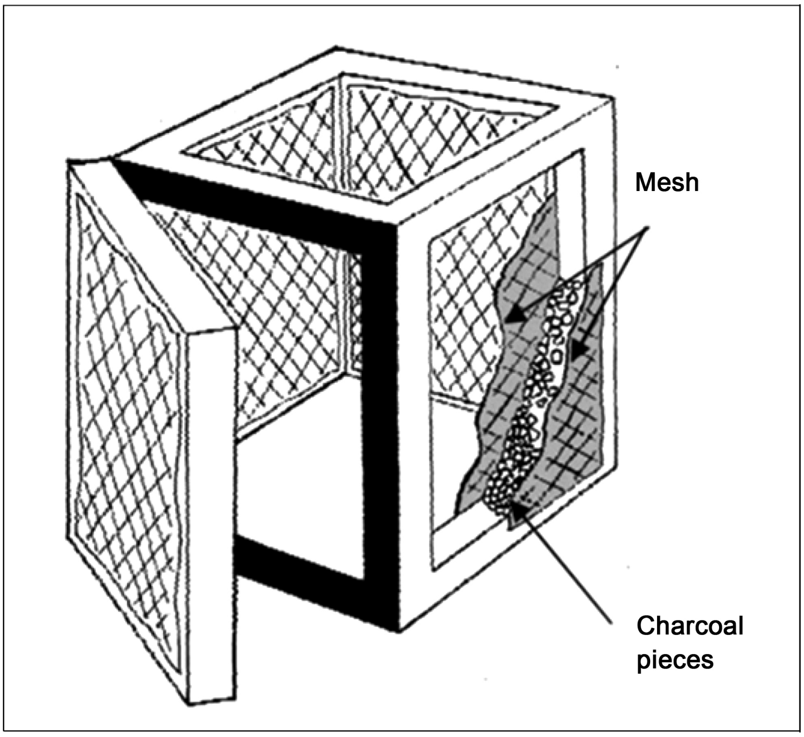


Figure 11. Charcoal cooler [70].

5.6. Zero Energy Cooling Chambers

These chambers are designed according to the principle of direct evaporative cooling. They do not require electricity to operate. The materials required for construction (brick, sand, bamboo) are also easy. The Zero Energy Cool Chamber (ZECC) has a double wall structure. The walls of the chamber are submerged in water and the dents are filled with sand. The chamber can be freely built by unskilled workers. This system can reduce the temperature of plants by 10 to 15˚C and maintain almost 90% high humidity. Therefore, ZECC helps maintain the quality of perishable products and extend their shelf life [71]. The details of the structure are shown in **Figure 12**.

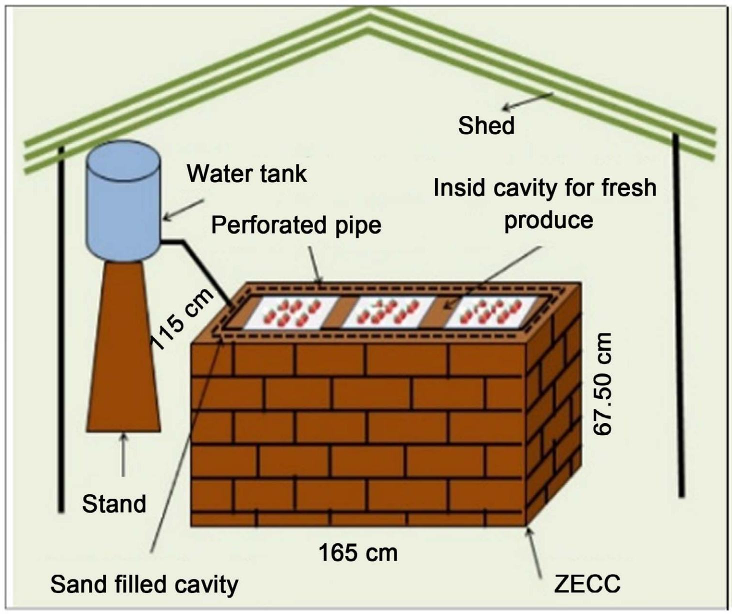


Figure 12. Zero energy cool chambers [72].

6. Advances in Food Storage System Technologies

Post-harvest shelf life and microbial contamination control strategies are oftentimes based on the use of chemical compounds that are deleterious to human health and the environs. Presently, it is essentially important to find a feasible choice to traditional technologies in order to guarantee safety and quality [73]. Some improved storage techniques for horticultural crops are described in detail below.

6.1. Cold Storage

The respiratory intensity of refrigerated products is directly related to the optimum temperature in the storage room. Lowering the temperature reduces the respiratory rate of the fruit, further slows the rate of biochemical reactions, and improves the shelf life of the product. Refrigeration system is the center of the cold chain of the fresh fruit market. The cold chain ensures quality is maintained from harvest to consumer. Old warehouses take great care to delay or prevent the occurrence of cold damage during storage [62]. Cold storage is typically a storage space maintained with the help of a non-toxic refrigerant and the walls padded with a good insulator, like polyurethane foam (PUF) to minimize heat loss [74].

When certain fruits are exposed to low temperatures, they experience chilling injuries. The chilling injuries lead to some physiological changes, including alter of the metabolism, which can lead to the appearance of bruises on the surface fruit or an abnormal ripening [75].

In today's storage facilities, awareness is being raised to delay or inhibit the development of cold sores during storage of sensitive horticultural products. Storage parameters such as changes in temperature, gas composition or relative humidity control the appearance and extent of these lesions and are taken into account when storing sensitive fruits. These techniques are commonly used in industries. Examples: high temperature pretreatment, moderate temperature conditioning, CO_2 treatment before or during storage, intermittent reheating, controlled atmosphere storage (CAS), modified atmosphere packaging (MAP) and vacuum packaging [71].

6.2. Controlled Atmosphere Storage (CAS)

In a CAS system, the produce is kept at reduced O_2 and high CO_2 concentrations with an appropriate temperature range and relative humidity (RH) [43]. The shelf life of several fruits can be extended up to 24 times the normal shelf life. The composition of carbon dioxide and oxygen levels in controlled atmosphere storage is maintained at a specific and monitored level in airtight containers or stores. Leaks in the walls and doors of the storage area and the metabolic activities of the mature products cause a constant change in the gas composition of the storage area. Therefore, the gas composition is periodically monitored, and fresh air or nitrogen is introduced to maintain a predetermined level of the gas composition in the head space. It can also be done by passing a storge environment through a chemical to remove carbon dioxide. A system can be designed to initially filter the air to reduce oxygen content, then inject carbon dioxide or allow it to build up creating respiration. This atmosphere can also be maintained by washing and ventilating [71]. **Figure 13** presents a pictorial view of Controlled atmosphere room.

6.3. Modified Atmosphere Packaging (MAP)

MAP includes storage of fresh fruits in environments whose gas composition has been modified as compared to that of air to enhance the keeping quality, shelf life and to bring down the metabolic activity rate of the product [76]. **Figure 14** shows different processes taking place in a MAP. The MAP of fresh fruits includes substituting the gases in the package headspace with a composition of gases that are non-reactive and different from that of air. A CO_2, O_2 and N_2 components are introduced into the head space replacing the pack atmosphere.

Figure 13. Controlled atmosphere room.

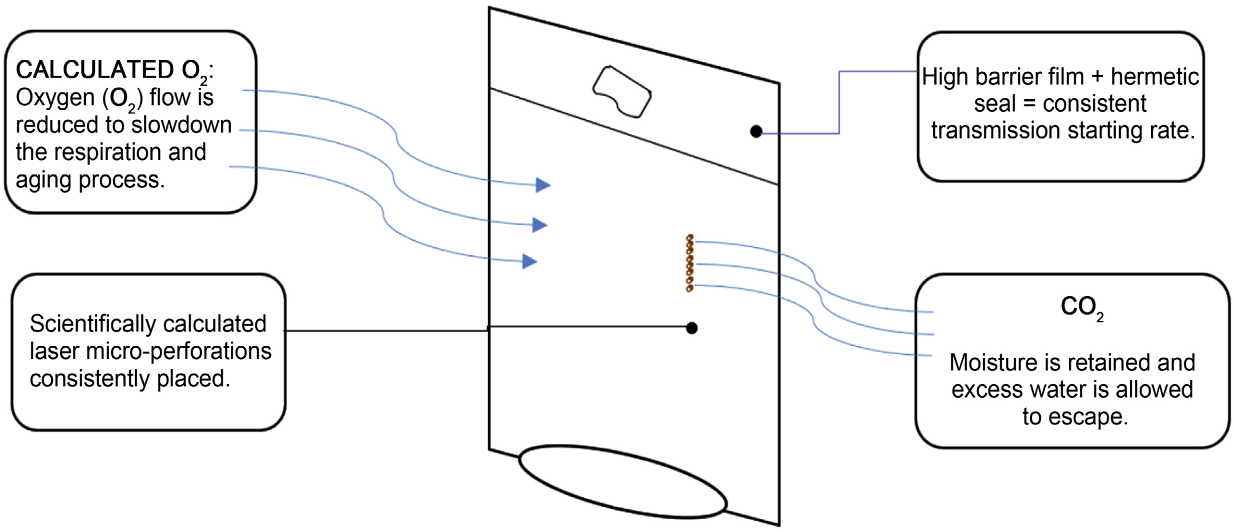


Figure 14. The principle of modified atmosphere packaging (MAP).

The nature of fresh fruit controls the composition and amount of gas used. Some of the important factors that affect the success of MAP are the respiratory rate [77]. MAP can be passively or actively modified.

6.3.1. Types of MAP

1) Passive MAP

Rate of respiration of the produce and permeability of the packaging material play a key function in passive MAP. The oxygen use is proportionate to the package atmosphere's carbon dioxide output due to the product respiration. Ultimately, the headspace gas composition reaches equilibrium between the product respiration rate and package material permeability. At steady state, the total volume of CO_2 released and O_2 use corresponds to the gas transferred across the outer surface of the membrane.

6.3.2. Active MAP

In active modified atmosphere packaging, the air in the package is emptied and replaced with the desired gas composition. This is suitable for improving gas composition changes in packages and further averts exposure to high concentrations of gases caused by stress [78].

6.3.3. Polymeric Film Applications for MAP of Horticultural Crops

Flexible package structures have seen the most significant usage of polymeric films for MAP [79]. Certain variables namely oxygen and carbon dioxide permeability through film, film density, water vapour transmission rate (WVTR), the free volume within the package and the package surface area decide the degree of modification of the gases within the package [80] [81] [82] [83]. Several types of films have been used for MAP; the most commonly used are low-density polyethylene, high-density polyethylene, polypropylene, polyvinyl chloride, polystyrene and polyester.

6.4. Vacuum Packaging

Vacuum packaging is the process of removing air around a food product and further sealing that product in an impermeable package. Removing the air that surrounds food inhibits growth of bacteria, mould, and yeast, because these and other spoilage micro-organisms need oxygen to grow [84]. Vacuum packaging has been shown to extend the shelf life for days varying from six days onwards. Notwithstanding that product may not develop rancidity in extended days of storage, it may develop undesirable odors and flavors due to bacterial activity [85].

6.5. Hypobaric/Low-Pressure Storage

Hypobaric or low pressure refers to a pressure below 101 kPa. Hypobaric storage is a relatively poorly understood type of controlled atmosphere storage in which a low-oxygen environment is created at sub-atmospheric pressure ranges; thereby reducing the respiration rate and metabolic activities of the product, resulting in extended the shelf life [86]. The decrease in total pressure is proportional to the decrease in the partial pressure of oxygen [87]. Product is stored under partial vacuum in the chamber. The chamber is continuously ventilated with absorbed air to maintain a low oxygen partial pressure range [86]. The product is stored under a partial vacuum in a chamber. The chamber is vented continuously with sopped air to maintain the low-oxygen partial pressure ranges. Normally, a 10 kPa reduction in the air pressure (equivalent to an oxygen partial pressure of 2.1 kPa) results in a 2% oxygen reduction at normal atmospheric pressure [88].

6.6. Ozone Technology

Ozone is one of the most promising treatments for the decontamination of fresh produce with several areas of application in the food industry [89] [90]. The chemical reaction required for ozone formation involves division of a diatomic oxygen molecule (O_2) and each of the two oxygen radicals (O) reacts with another diatomic oxygen to form the triatomic ozone molecule (O_3). The rearrangement of atoms to form the ozone molecule requires a large amount of energy that is usually generated by ultraviolet irradiation, electrochemical processes or electrical discharges (electrical corona effect). The first two methods are seldom used due to very high costs and low ozone yields [91].

Ozone technology for extending the shelf life of food is considered a non-thermal method of food preservation that improves food safety without compromising quality and endangering the environment. Since ozone is a highly unstable molecule that auto decomposes spontaneously and rapidly into oxygen atoms at room temperature, it cannot be collected, stored or transported and must, therefore, be continuously generated in situ [92]. The half-life of ozone (even in the absence of a catalytic destroyer) is very short, usually 30 - 40 min in water and 2 - 3 h in air, although these parameters may vary depending on temperature and pH values [93]. The disinfecting and bactericidal properties of ozone have aroused interest in the food and vegetable industry because the molecule rapidly breaks down into O_2 without leaving any residue on the product. Although it reacts with some organic compounds found in the food base, the by-products can be aldehydes, ketones or carboxylic acids, which pose no danger to human health. Ozone treatment can be applied in both the gas phase and the water phase. Once produced, ozone can be added continuously or intermittently to the product storage medium, or it can be dissolved in water to produce aqueous ozone for washing and disinfection [90]. The choice of treatment mainly depends on the type of produce to be treated and the method of application [94]. Figure 15 show a process of water treatment using ozone generated system.

6.7. Nanotechnology

Nanotechnology is emerging as a rapidly growing field with its wide application in science and technology for manufacturing of new materials at nanoscale level [95]. This technology has gained considerable momentum due to its ability to reformat metals into novel, small-sized nanoparticles of less than 100 nm. Due

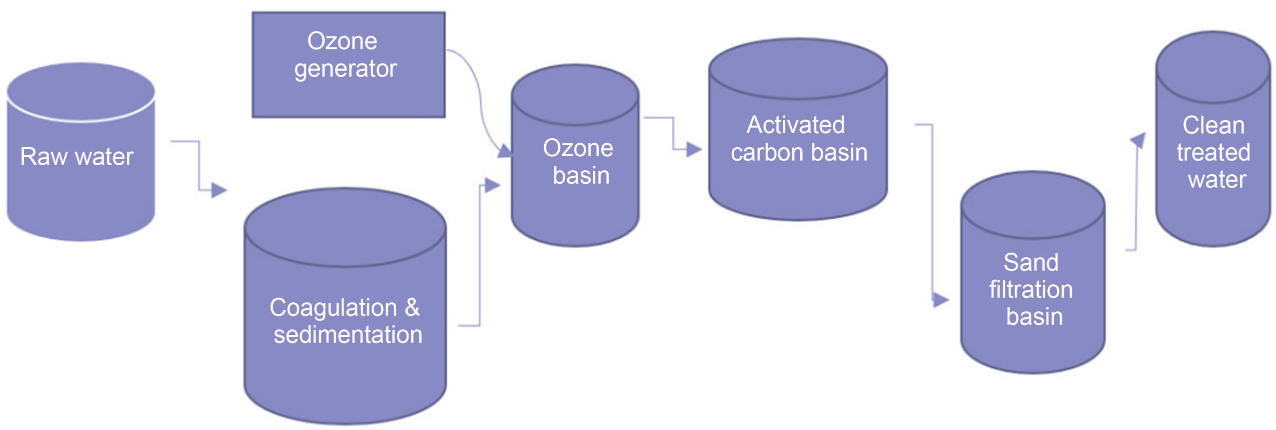


Figure 15. Water treatment using ozone generated system.

to the size of the nanoparticles, their physicochemical properties change dramatically, leading to a wide range of new applications.

Due to the antibacterial properties of nanoparticles, they are incorporated into food packaging to extend shelf life and safe for human consumption. It is predicted that the penetration of nanoparticles into the food industry market will increase significantly in the near future [96]. During food processing, nanoparticles have been used to improve nutritional properties, fluidity, flavor, color and stability, or to extend shelf life. In fact, nanotechnology could help develop healthier foods with less fat, sugar and salt to overcome many food-related diseases.

7. Conclusions

High-quality produce free of damage and of proper maturity level (not over-ripe or under-mature) is stored. Good knowledge of the requirements for the commodities to be stored and following the recommendations for proper temperature, relative humidity and ventilation. Harvesting at appropriate time is important. Roots tuber and bulb are cured before storage. Do not overload storage rooms or stack containers too close. Adequate ventilation should be provided in the storage room. Provision of shade for storage structures is important.

Storage rooms must be kept clean. Storage facilities should be protected from rodents by keeping the immediate outdoor area clean, and free from trash and weeds. Containers should not be stacked beyond their stacking strength. Temperature should be monitored in the storage room by placing thermometers at a variety of locations. Storing ethylene-sensitive commodities with those that produce ethylene should be avoided. Produce known for emitting strong odors (apples. garlic, onions, turnips. cabbages, potatoes) should not be stored with odor-absorbing commodities. Stored produce should be inspected regularly for signs of injury, water loss, damage and disease. Damaged or diseased produce should be removed to prevent contamination.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Faye, D. (2007) Safety and Quality of Fresh Fruit and Vegetables: A Training Manual for Trainers. United Nations, New York and Geneva, 10-30, 71-72.

[2] Asmaru, G., Samuel, S. and Subramanian, C. (2013) Assessment of Fruit Management Gondar Town Markets of North Western, Ethiopia. *Global Journal of Biology, Agriculture and Health Science*, **2**, 4-8.

[3] Abdullahi, N. (2015) Postharvest Management of Fruits and Vegetables: A Review. *Techno Science Africana Journal*, **11**, 93-103. http://www.researchgate.net/publication/307976552

[4] Marta, M., Alessandra, D. and Paolo, B. (2014) Control of Fruit Postharvest Diseases: Old Issues and Innovative Approaches. *Stewart Postharvest Reviewer*, **10**, 1-4. https://doi.org/10.2212/spr.2014.1.1

[5] Enyiukwu, D.N., Awurum, A.N. and Nwaneri, J.A. (2014) Efficacy of Plant Derived Pesticides in the Control of Myco-Induced Postharvest Rot of Tubers and Agricultural Products: A Review. *Net Journal of Agricultural Science*, **2**, 30-46. https://doi.org/10.15580/GJMA.2014.3.0521014241

[6] Lisa, K. and Karder, A.A. (2003) Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops, 4th Edition. Postharvest Horticulture Series No. 8E, University of California, Davis Postharvest Technology Research and Information Centre, 7-8, 91-107.

[7] Ooralkul, B. (2003) Modified Atmosphere Packaging (MAP). In: Peter, Z. and Leif, B., Eds., *Food Preservation Techniques*, Woodhead Publishing Limited, Cambridge, 339-341.

[8] Kader, A.A. (2002) Postharvest Technology of Horticultural Crops. 3rd Edition, University of California, Agriculture and Natural Resources, Oakland, Publication 3311, 535 p., Kader, AA.

[9] Fischer, G. (2005) Aspects of Applied Physiology in Promising Fruit Species' Culture and Postharvest Period. *Revista Comalfi*, **32**, 22-34.

[10] Wang, Y.C. (1997) Effect of Postharvest Factors on Postharvest Quality: Introduction to the Colloquium. *HortScience*, **32**, 807. https://doi.org/10.21273/HORTSCI.32.5.807

[11] Hewett, E.W. (2006) An Overview of Preharvest Factors Influencing Postharvest Quality of Horticultural Products. *International Journal of Postharvest Technology and Innovation*, **1**, 4-15. https://doi.org/10.1504/IJPTI.2006.009178

[12] Cuquel, F.L., Motta, A.C.V., Tutida, I. and De Mio, L.L.M. (2011) Nitrogen and Potassium Fertilization Affecting the Plum Postharvest Quality. *Revista Brasileira de Fruticultura*, **33**, 328-336. https://doi.org/10.1590/S0100-29452011000500041

[13] Anttonen, M.J. and Karjalainen, R.O. (2009) Evaluation of Means to Increase the Content of Bioactive Phenolic Compounds in Soft Fruits. *Acta Horticulturae*, **839**, 309-314. https://doi.org/10.17660/ActaHortic.2009.839.39

[14] Tahir, I.I., Johansson, E. and Olsson, M.E. (2007) Improvement of Quality and Storability of Apple Aroma by Adjustment of Some Pre-harvest Conditions. *Scientia Horticulturae*, **112**, 164-171. https://doi.org/10.1016/j.scienta.2006.12.018

[15] Woolf, A.B. and Ferguson, I.B. (2000) Postharvest Responses to High Fruit Temperatures in the Field. *Postharvest Biology and Technology*, **21**, 7-20. https://doi.org/10.1016/S0925-5214(00)00161-7

[16] Jagdish, R. (2009) Harvesting Techniques of Fruits and Vegetables. Agriculture Farming HTML.

[17] Beckles, D. (2012) Factors Affecting the Post-Harvest Soluble Solids and Sugar Content of Tomato (*Solanum Lycopersicum*) Fruit. *Postharvest Biology and Technology*, **63**, 120-140. https://doi.org/10.1016/j.postharvbio.2011.05.016

[18] Food and Agriculture Organization of the United Nations (2008) Basic Harvest and Postharvest Handling Consideration for Fresh Fruits and Vegetables Handling and Preservation. Food and Agriculture Organization of the United Nations, Rome.

[19] Crane, J.H., Salazar-Garcia, S., Lin, T.S., De Queiroz Pinto, A.C. and Shu, Z.H. (2009) Crop Production: Management. In: Litz, R.E., Ed., *The Mango: Botany, Production and Uses*, 2nd Edition, Centre for Agriculture and Bioscience International, Wallingford, 432-483. https://doi.org/10.1079/9781845934897.0432

[20] Yahia, E.M. (2011) Mango (*Mangifera indica* L.). In: Yahia, E.M., Ed., *Postharvest Biology and Technology of Tropical and Subtropical Fruits Cocona to Mango*, Vol.

3, Elsevier, Amsterdam, 492-567e. https://doi.org/10.1533/9780857092885.492

[21] Akbudak, B.A. (2012) Effects of Pre-Harvest Harpin and Modified Atmosphere Packaging on Quality of Cherry Tomato Cultivars 'Alona' and 'Cluster'. *British Food Journal*, **114**, 180-196. https://doi.org/10.1108/00070701211202377

[22] Ferreira, M.D., Brecht, J.K., Sargent, S.A. and Aracena, J.J. (1994) Physiological Responses of Strawberry to Film Wrapping and Precooling Methods. *Proceedings of the Florida State Horticultural Society*, **107**, 265-269.

[23] Pokhrel, B. (2020) Review on Post-Harvest Handling to Reduce Loss of Fruits and Vegetables. *International Journal of Horticulture and Food Science*, **2**, 48-52.

[24] Food and Agriculture Organization of the United Nations (1999) Handling of Fresh Fruts, Vegetables and Root Crops. A Training Manual for Grenada by Gaetano Paltrinier. Food and Agriculture Organization of the United Nations, Rome, 89.

[25] Hoa, T.T., Ducamp, M.-N., Lebrun, M. and Baldwin, E.A. (2002) Effect of Different Coating Treatments on the Quality of Mango Fruit. *Journal of Food Quality*, **25**, 471-486. https://doi.org/10.1111/j.1745-4557.2002.tb01041.x

[26] Hagenmaier, R.D. and Baker, R.A. (1994) Wax Micro Emulsions and Emulsions as Citrus Coatings. *Journal of Agricultural and Food Chemistry*, **42**, 899-902. https://doi.org/10.1021/jf00040a012

[27] Hofman, P.J., Smith, L.G., Holmes, R., Campbell, T. and Meiburg, G. (1994) Mango Fruit Quality at Harvest Is Affected by Production Conditions. *Proceedings of Mango* 2000 *Marketing Seminar and Production Workshop*, Townsville, 199-208.

[28] Cheng, G., Duan, X., Jiang, Y., Sun, J., Yang, S., Yang, B., *et al.* (2009) Modification of Hemicellulose Polysaccharides during Ripening of Postharvest Banana Fruit. *Food Chemistry*, **115**, 43-47. https://doi.org/10.1016/j.foodchem.2008.11.065

[29] Atanda, S.A. Pessu, P.O., Agoda, S., Isong, I.U. and Ikotun, I. (2011) The Concepts and Problems of Post-harvest Food Losses in Perishable Crops. *African Journal of Food Science*, **5**, 603-6013.

[30] Arah, I.K., Ahogtrrbo, G.K., Anku, E.K., Kumah, E.K. and Amaglo, H. (2016) Methods for Tomato Handlers in Developing Countries: A Mini Review. *Advances in Agriculture*, **2016**, Article ID: 6436945. https://doi.org/10.1155/2016/6436945

[31] Zhang, S. and Farber, J.M. (1996) The Effects of Various Disinfectants Against *Listeria Monocytogenes* on Fresh-Cut Vegetables. *Food Microbiology*, **13**, 311-321. https://doi.org/10.1006/fmic.1996.0037

[32] Kim, J.G., Yousef, A.E. and Chism, G.W. (1999) Use of Ozone to Inactivate Microorganisms on Lettuce. *Journal of Food Safety*, **19**, 17-34. https://doi.org/10.1111/j.1745-4565.1999.tb00231.x

[33] Park, C.-M., Hung, Y.-C., Doyle, M.P. and Kim, C. (2001) Pathogen Reduction and Quality of Lettuce Treated with Electrolyzed Oxidizing and Acidified Chlorinated Water. *Journal of Food Science*, **66**, 1368-1372. https://doi.org/10.1111/j.1365-2621.2001.tb15216.x

[34] Sapers, G.M. (2001) Efficacy of Washing and Sanitizing Methods for Disinfection of Fresh Fruits and Vegetable Products. *Food Technology and Biotechnology*, **39**, 305-311.

[35] Venkitanaraynana, K.S., Lin, C.H., Bailey, H. and Doyle, M.P. (2002) Inactivation of *Escherichia coli* O157:H7 and *Listeria monocytogenes*, on Apples, Oranges, and Tomatoes by Lactic Acid and Hydrogen Peroxide. *Journal of Food Protection*, **56**, 100-105. https://doi.org/10.4315/0362-028X-65.1.100

[36] Rodgers, S.T., Cash, J.N., Siddiq, M. and Ryser, E.T. (2004) A Comparison of Different Chemical Sanitizers for Inactivating *Escherichia coli* O157:H7 and *Listeria*

monocytogenes in Solution and on Apples, Lettuce, Strawberries, and Cantaloupe. *Journal of Food Protection*, **67**, 721-731. https://doi.org/10.4315/0362-028X-67.4.721

[37] Prakash, A., Guner, A.R., Caporaso, F. and Foley, D.M. (2000) Effects of Low-dose Gamma Irradiation on Shelf Life and Quality Characteristics of Cut Romaine Lettuce Packaged under Modified Atmosphere. *Journal of Food Science*, **65**, 549-553. https://doi.org/10.1111/j.1365-2621.2000.tb16046.x

[38] Ahmad, M.S. and Siddiqui, M.W. (2015) Postharvest Quality Assurance of Fruits: Practical Approaches for Developing Countries. Springer, Cham, 224. https://doi.org/10.1007/978-3-319-21197-8

[39] Alao, S.L. (2000) The Importance of Post-Harvest Loss Prevention. Graduation Ceremony of School of Food Storage Technology. Nigerian Stored Products Research Institute, Kano, 1-10.

[40] Kochhar, P.P. (2014) Active Packaging in Food Industry: A Review. *Environmental Science, Toxicology and Food Technology*, **8**, 1-7.

[41] Thompson, J.F. and Mitchell, F.G. (2002) Packages for Horticultural Crops. In: Kader, A.A., Ed., *Postharvest Technology for Horticultural Crops*, University of California, Agriculture and Natural Resources, 85-95.

[42] Idah, P. and Yisa, E.A. (2007) Fruits and Vegetables Handling and Transportation in Nigeria. *AU Journal of Technology*, **10**, 175-183

[43] Dhatt, A.S. and Mahajan, B.V.C. (2007) Horticulture Post Harvest Technology Harvesting, Handling and Storage of Horticultural Crops. Punjab Horticultural Postharvest Technology Centre, Punjab Agricultural University Campus, Ludhiana.

[44] Wills, R.B.H. and Golding, J.B. (2016) Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables. 6th Edition, Centre for Agriculture and Bioscience International, Wallingford, Oxon; Cambridge, MA. https://doi.org/10.1079/9781786391483.0000

[45] Paul, V., Pandey, R. and Srivastava, G.C. (2012) The Fading Distinctions between Classical Patterns of Ripening in Climacteric and Non-climacteric Fruit and the Ubiquity of Ethylene—An Overview. *Journal of Food Science and Technology*, **49**, 1-21. https://doi.org/10.1007/s13197-011-0293-4

[46] Farcuh, M., Toubiana, D., Sade, N., Rivero, R.M., Doron-Faigenboim, A., Nambara, E., *et al.* (2019) Hormone Balance in a Climacteric Plum Fruit and Its Non-climacteric Bud Mutant during Ripening. *Plant Science*, **280**, 51-65. https://doi.org/10.1016/j.plantsci.2018.11.001

[47] Jia, H., Wang, Y., Sun, M., Li, B., Han, Y., Zhao, Y., *et al.* (2013) Sucrose Functions as a Signal Involved in the Regulation of Strawberry Fruit Development and Ripening. *New Phytologist*, **198**, 453-465. https://doi.org/10.1111/nph.12176

[48] Li, Y., Lu, Y.G., Li, L.L., Chu, Z.N., Zhang, H.Y., Li, H.X., *et al.* (2019) Impairment of Hormone Pathways Results in a General Disturbance of Fruit Primary Metabolism in Tomato. *Food Chemistry*, **274**, 170-179. https://doi.org/10.1016/j.foodchem.2018.08.026

[49] Chen, Y., Grimplet, J., David, K., Castellarin, S.D., Terol, J., Wong, D.C.J., *et al.* (2018) Ethylene Receptors and Related Proteins in Climacteric and Non-Climacteric Fruits. *Plant Science*, **276**, 63-72. https://doi.org/10.1016/j.plantsci.2018.07.012

[50] Bakshi, P., Masoudi, F.A., Chauhan, G.S. and Shah, T.A. (2005) Role of Calcium in Postharvest Life of Temperate Fruits: A Review. *Journal of Food Science and Technology-Mysore*, **42**, 1-8.

[51] Garcia, J.M., Herrera, S. and Morilla, A. (1996) Effects of Postharvest Dips in Calcium Chloride on Strawberry. *Journal of Agricultural and Food Chemistry*, **44**, 30-33. https://doi.org/10.1021/jf950334l

[52] Manganaris, G.A., Vasilakakis, M., Diamantidis, G. and Mignani, I. (2007) The Effect of Postharvest Calcium Application on Tissue Calcium Concentration, Quality Attributes, Incidence of Flesh Browning and Cell Wall Physicochemical Aspects of Peach Fruits. *Food Chemistry*, **100**, 1385-1392. https://doi.org/10.1016/j.foodchem.2005.11.036

[53] Luna-Guzman, I. and Barrett, D.M. (2000) Comparison of Calcium Chloride and Calcium Lactate Effectiveness in Maintaining Shelf Stability and Quality of Fresh-Cut Cantaloupe. *Postharvest in Biology and Technology*, **19**, 61-72. https://doi.org/10.1016/S0925-5214(00)00079-X

[54] Rettke, M.A., Pitt, T.R., Maier, N.A. and Jones, J.A. (2006) Quality of Fresh and Dried Fruit of Apricot (cv. Mooprark) in Response to Soil Applied Nitrogen. *Australian Journal of Experimental Agriculture*, **46**, 123-129. https://doi.org/10.1071/EA04211

[55] Sharples, R.O. (1980) The Influence of Orchard Nutrition on the Storage Quality of Apples and Pears Grown in the United Kingdom. In: Atkinson, D., Jackson, J.E., Sharples, R.O. and Waller, W.M., Eds., *Mineral Nutrition of Fruit Trees*, Butterworths, London, 17-28. https://doi.org/10.1016/B978-0-408-10662-7.50008-9

[56] Khemira, H. 1991. Influence of Canopy Orientation on Fruiting of 'Anjou' Pears and Postharvest Urea Spray on Ovule Longevity and Fruit Set of 'Cornice' Pears. MS Thesis, Oregon State University, Corvallis.

[57] Raese, J.T. (1986) Nitrogen and Calcium Important in Determining Yield, Fruit Quality, and Disorders of 'Anjou' Pears, In: *Pear Production in the Pacific Northwest*, Shortcourse, University of Washington, Seattle, 156-168.

[58] Tripathi, K., Pandey, S., Malik, M. and Kaul, T. (2016) Fruit Ripening of Climacteric and Nonclimacteric Fruit. *Journal of Environmental and Applied Bioresearch*, **4**, 27-34.

[59] HuffPost (2017) How to Ripen Fruit Faster. December Edition. https://www.huffpost.com/entry/how-to-ripen-fruit-faster

[60] Singal, S., Kumud, M. and Thakral, S. (2012) Application of Apple as Ripening Agent for Banana. *Indian Journal of Natural Products and Resources*, **3**, 61-64.

[61] Pendharkar, P.Y., Hiwale, S.S. and Patilstudies, H.B. (2011) Studies on the Effect of Post-Harvest Treatmets on Chemical Changes during Ripening of Banana Fruits Cv. Grand Naine. *International Journal of Processing and Post-Harvest Technology*, **2**, 32-34.

[62] El-Ramady, H.R., Domokos-Szabolcsy, É., Abdalla, N.A., Taha, H.S. and Fári, M. (2015) Postharvest Management of Fruits and Vegetables Storage. In: Lichtfouse, E., Ed., *Sustainable Agriculture Reviews*, Springer, Cham, 65-152. https://doi.org/10.1007/978-3-319-09132-7_2

[63] Elansari, A.M., Yahia, E.M. and Siddiqui, W. (2019) Storage Systems. In: Yahia, E.M., Ed., *Postharvest Technology of Perishable Horticultural Commodities*, Woodhead Publishing, Sawston, 401-437. https://doi.org/10.1016/B978-0-12-813276-0.00012-2

[64] Rees, D., Westby, A., Tomlins, K., Van Oirschot, Q., Cheema, M.U., Cornelius, E. and Amjad, M. (2012) Tropical Root Crops. In: Rees, D., Farrell, G. and Orchard, J., Eds., *Crop Post-Harvest: Science and Technology*, John Wiley & Sons, Ltd., Hobo-

ken, 392-413. https://doi.org/10.1002/9781444354652.ch18

[65] Kale, S.J., Nath, P., Jalgaonkar, K.R. and Mahawar, M.K. (2016) Low-Cost Storage Structures for Fruits and Vegetables Handling in Indian Conditions. *Indian Horticulture Journal*, **6**, 376-379.

[66] Basediya, A.L., Samuel, D.V. K. and Beera, V. (2013) Evaporative Cooling System for Storage of Fruits and Vegetables—A Review. *Journal of Food Science and Technology*, **50**, 429-442. https://doi.org/10.1007/s13197-011-0311-6

[67] Ndukwu, M.C. and Manuwa, S.I. (2014) Review of Evaporative Cooling in Preservation of Fresh Agricultural Produce. *International Journal of Agricultural and Biological Engineering*, **7**, 85-102.

[68] Liberty, J.T., Okonkwo, W.I. and Echiegu, E.A. (2013) Evaporative Cooling: A Pyostharvest Technology for Fruits and Vegetables Preservation. *International Journal of Scientific & Engineering Research*, **4**, 2257-2266.

[69] Roy, S.K. and Khurdiya, D.S. (1985) Zero Energy Cool Chamber. Research Bulletin No. 43, India Agricultural Research Institute, New Delhi, 23-30.

[70] Odesola, I.F. and Onyebuchi, O. (2009) A Review of Porous Evaporative Cooling for the Preservation of Fruits and Vegetables. *Pacific Journal of Science and Technology*, **10**, 935-941.

[71] Khan, F.A., Bhat, S.A. and Narayan, S. (2017) Storage Methods for Fruits and Vegetables. Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar.

[72] Khalid, S., Majeed, M., Ullah, M.I., Shahid, M., Riasat, A.R., Abbas, T., Aatif, H.M. and Farooq, A. (2020) Effect of Storage Conditions and Packaging Material on Postharvest Quality Attributes of Strawberry. *Journal of Horticulture and Postharvest Research*, **3**, 195-207.

[73] Tzortzakis, N. and Chrysargyris, A. (2017) Postharvest Ozone Application for the Preservation of Fruits and Vegetables. *Food Reviews International*, **33**, 270-315. https://doi.org/10.1080/87559129.2016.1175015

[74] Sahoo, K., Bandhyopadhyay, B., Mukhopadhyay, S., Sahoo, U., Kumar, T.S., Yadav, V. and Singh, Y. (2019) Cold Storage with Backup Thermal Energy Storage System. In: Sahoo, U., Ed., *Progress in Solar Energy Technologies and Applications*, Wiley, Online Library, 181-232. https://doi.org/10.1002/9781119555650.ch4

[75] Sevillano, L., Sanchez-Ballesta, M.T., Romojaro, F. and Flores, F.B. (2009) Physiological, Hormonal and Molecular Mechanisms Regulating Chilling Injury in Horticultural Species. Postharvest Technologies Applied to Reduce Its Impact. *Journal of the Science of Food and Agriculture*, **89**, 555-573. https://doi.org/10.1002/jsfa.3468

[76] Coles, R., McDowell, D. and Kirwan, M.J. (Ed.) (2003) Food Packaging Technology (Vol. 5). CRC Press.

[77] Soltani, M., Alimardani, R., Mobli, H. and Mohtasebi, S.S. (2015) Modified Atmosphere Packaging: A Progressive Technology for Shelf-life Extension of Fruits and Vegetables. *Journal of Applied Packaging Research*, **7**, 33-59.

[78] Zhang, M., Meng, X., Bhandari, B., Fang, Z. and Chen, H. (2015) Recent Application of Modified Atmosphere Packaging (MAP) in Fresh and Fresh-Cut Foods. *Food Reviews International*, **31**, 172-193. https://doi.org/10.1080/87559129.2014.981826

[79] Ares, G., Lareo, C. and Lema, P. (2007) Modified Atmosphere Packaging for Postharvest Storage of Mushrooms. A Review. *Fresh Produce*, **1**, 32-40.

[80] Beaudry, R.M. (1999) Effects of O_2 and CO_2 Partial Pressure on Selected Phenome-

na Affecting Fruit and Vegetable Quality. *Postharvest Biology and Technology*, **15**, 293-303. https://doi.org/10.1016/S0925-5214(98)00092-1

[81] Cameron, A.C., Beaudry, R.M., Banks, N.H. and Yelanich, M.V. (1994) Modified Atmosphere Packaging of Blueberry Fruit: Modeling Respiration and Package Oxygen Partial Pressures as Function of Temperature. *Journal of the American Society for Horticultural Science*, **119**, 534-539. https://doi.org/10.21273/JASHS.119.3.534

[82] Mahajan, P.V., Oliveira, F.A.R., Montanez, J.C. and Iqbal, T. (2008) Packaging Design for Fresh Produce: An Engineering Approach. *New Food*, **11**, 35-36.

[83] Gatellier, P., Hamelin, C., Durand, Y. and Renerre, M. (2001) Effect of a Dietary Vitamin, E. Supplementation on Color Stability and Lipid Oxidation of Air and Modified Asmosphere-Packed Beef. *Meat Science*, **59**, 133-140. https://doi.org/10.1016/S0309-1740(01)00063-8

[84] Purushotam, K. and Ganguly, S. (2014) Role of Vacuum Packaging in Increasing Shelf-life in Fish Processing Technology. *Asian Journal of Bio Science*, **9**, 109-112.

[85] Mangaraj, S., Goswami, T.K. and Mahajan, P.V. (2009) Applications of Plastic Films for Modified Atmosphere Packaging of Fruits and Vegetables: A Review. *Food Engineering Reviews*, **1**, Article No. 133. https://doi.org/10.1007/s12393-009-9007-3

[86] Stenvers, N. and Bruinsma, J. (1975) Ripening of Tomato Fruits At Reduced Atmospheric and Partial Oxygen Pressures. *Nature*, **253**, 532-533. https://doi.org/10.1038/253532a0

[87] John, J. (2008) A Handbook on Post-Harvest Management of Fruits and Vegetables. Daya Publishing House, Delhi, 119.

[88] Vithu, P. and Moses, J.A. (2017) Hypobaric Storage of Horticultural Products: A Review. In: Goyal, M.R. and Sivanappan, R.K., Eds., *Engineering Practices for Agricultural Production and Water Conservation*, Apple Academic Press, 155-170.

[89] Khadre, M.A., Yousef, A.E. and Kim, J.-G. (2001) Microbiological Aspects of Ozone Applications in Food: A Review. *Journal of Food Science*, **66**, 1242-1252. https://doi.org/10.1111/j.1365-2621.2001.tb15196.x

[90] Kim, J.G., Yousef, A.E. and Dave, S. (1999) Application of Ozone for Enhancing the Microbiological Safety and Quality of Foods: A Review. *Journal of Food Protection*, **62**, 1071-1087. https://doi.org/10.4315/0362-028X-62.9.1071

[91] Miller, F.A., Silva, C.L.M. and Brandão, T.R.S. (2013) A Review on Ozone-Based Treatments for Fruit and Vegetables Preservation. *Food Engineering Reviews*, **5**, 77-106. https://doi.org/10.1007/s12393-013-9064-5

[92] Guzel-Seydim, Z.B., Greene, A.K. and Seydim, A.C. (2004) Use of Ozone in the Food Industry. *LWT—Food Science and Technology*, **37**, 453-460. https://doi.org/10.1016/j.lwt.2003.10.014

[93] Carletti, L., Botondi, R., Moscetti, R., Stella, E., Monarca, D., Cecchini, M. and Massantini, R. (2013) Use of Ozone in Sanitation and Storage of Fresh Fruits and Vegetables. *Journal of Food, Agriculture and Environment*, **11**, 585-589.

[94] Cullen, P.J., Valdramidis, V.P., Tiwari, B.K., Patil, S., Bourke, P. and O'Donnell, C.P. (2010) Ozone Processing for Food Preservation: An Overview on Fruit Juice Treatments. *Ozone: Science & Engineering*, **32**, 166-179. https://doi.org/10.1080/01919511003785361

[95] Albrecht, M.A., Evans, C.W. and Raston, C.L. (2006) Green Chemistry and the Health Implications of Nanoparticles. *Green Chemistry*, **8**, 417-432. https://doi.org/10.1039/b517131h

[96] Heinlaan, M., Ivask, A., Blinova, I., Dubourguier, H.-C. and Kahru, A. (2008) Toxicity of Nanosized and Bulk ZnO, CuO and TiO_2 to Bacteria *Vibrio fischeri* and *Crustaceans daphnia* Magna and *Thamnocephalus platyurus*. *Chemosphere*, **71**, 1308-1316. https://doi.org/10.1016/j.chemosphere.2007.11.047