# Chapter 13
# Minimal Processing of Tropical and Subtropical Fruits, Vegetables, Nuts, and Seeds

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## 13.1 Introduction

Tropical climate zones of the Earth, in all 12 months, have mean temperatures above 18 $^0$C (64.4 °F). The tropical climate experiences hot, humid weather, and rainfall year round. Tropical vegetation is any vegetation in tropical latitudes. Plant life that occurs in climates that are warm year round is in general more biologically diverse than the other latitudes. Subtropical climates are often characterized by warm to hot summers and cool to mild winters with infrequent or no frost. Subtropical regions should have at least 8 months with a mean temperature greater than 10 °C (50.0 °F) and an average temperature of the coldest month between 6 °C (42.8 °F) and 13 °C (55.4 °F) (Belda et al. 2014). Tropical soils are often several meters deep, but the soils are often washed out, or strongly leached, by heavy rains, with large amounts of nutrients and minerals being removed from the subsoils. But, the very thin topsoils are made up mainly of decaying vegetal and animal remains. An amazing cycle exists between the huge body of vegetation above ground and this thin topsoil. The tropical and subtropical vegetation depends for its nutrients on the constant recycling of its enormous biomass (Tiessen et al. 2001).

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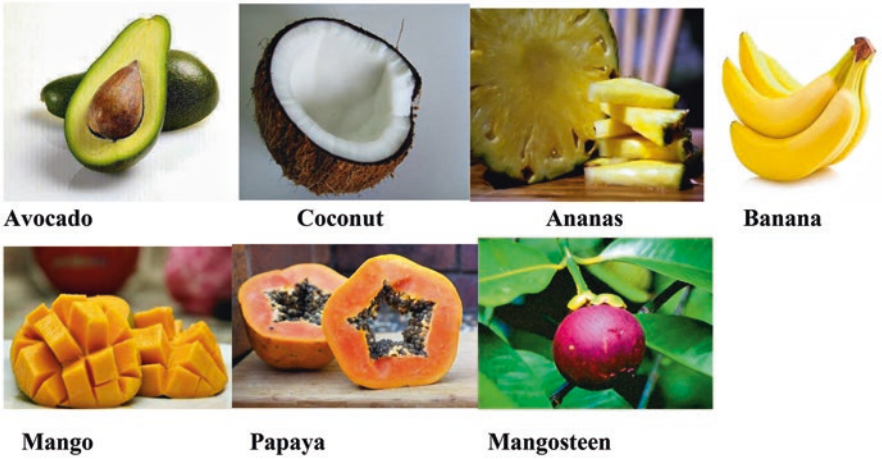


**Fig. 13.1** Selected tropical and subtropical fruits

Plants such as palms, citrus, mango, litchi, and avocado are grown within the tropics and subtropics (Fig. 13.1). Most of the edible nuts and seeds are grown in the tropical and subtropical regions of the world.

## 13.2 Tropical and Subtropical Fruits

Tropical and subtropical fruits are important sources of vitamins and minerals and many of these fruits are also high in dietary fiber. The color, flavor, and texture of these fruits are very attractive to consumers. Research findings (Patil et al. 2013) also indicate that these fruits contain micronutrients, phytochemicals, and antioxidants which could contribute to human well-being and health. However, each kind of fruit is unique in its composition. Banana yields highest calories per unit area and takes least time for digestion. Cashew nut is rich in protein (21.2%), while mango and papaya lead in vitamin A content. In many countries, these fruits are also used for the prevention and as healing remedies for a number of illnesses and diseases. With these properties, there is a vast potential for innovation and development of new products from these fruits in MPR products, the functional foods and nutraceutical industries. Fruits are the rich source of natural bioactive substances that have the property to prevent oxidative chain reaction by removal of free radicals' intermediates and even by oxidizing themselves. Research suggests (Patil et al. 2013; Yildiz 2010) that phytochemicals, working together with nutrients found in fruits, may help slow the aging process, reduce cell damage, stimulate the immune system, and reduce the risk of many diseases.

China, India, the Philippines, Indonesia, Brazil, Latin America, and the Caribbean are the world's major producer of tropical fruits, accounting for 95% of world

**Table 13.1** World fruit, vegetable, and nut market, million tons (quantity), and value in billion USD

| Period | Production (million tons) | | | Value (billion USD) | | |
|---|---|---|---|---|---|---|
| | Vegetables[a] | Fruits[b] | Tree nuts[c] | Vegetables | Fruits | Tree nuts |
| 1992–1994 | 613 | 287 | | | | |
| 2002–2004 | 903 | 527 | | | | |
| 2014–2016 | 1150 | 800 | | 1.851 | 868 | |
| 2015–2016 | | | 3.78 | | | 33 |

[a]Vegetables and fruits include all organic, fresh, fresh-cut, dried, frozen, canned vegetables and fruits
[b]Fruits include 421 million tons of tropical and subtropical fruits which include banana, grapefruit, oranges, mangoes, plantains, tangerines, pineapples, peaches, apricot, lemon, limes, papaya, dates, persimmons, and avocados
[c]Tree nuts include almonds, cashew, walnut, pistachio, hazelnut, pecan, macadamia, Brazil nuts, and pine nuts as kernel
Table calculated from the data given in references FAO (2015), International Nut and Dried Fruit Council (2015), Kazagro National Marketing Manager (2014), USDA (2016)

production in 2016. World trade and consumption of tropical and subtropical fruits and vegetables are increasing. Most of the growth in trade and consumption is fruit sector, but not in vegetables. The summary of the world trade and consumption is shown in Table 13.1 and major commodity list is given in Table 13.2.

### *13.2.1 Packaged Fresh-Cut Tropical Fruits*

Avocado-based products such as guacamole; avocado flesh, chunks, or paste; avocado-based salsas; etc., have a very short shelf life period (5–10 days) due to the spoilage effects of various enzymes over this product, particularly polyphenol oxidase (PPO) and lipoxygenase (LOX). A reduction in enzymatic activity is achieved through conventional or traditional thermal methods or addition of chemical additives, but this involves a significative loss in product quality, color, smell, and flavor in comparison with the fresh product. High-pressure processing of fresh-cut fruits with cold storage may be suitable for minimal processing. Minimally high-pressure processed avocado products being marketed include:

– Avocado halves
– Avocado chunks
– Avocado puree
– Guacamole (various recipes)
– Avocado-based salsas and sauces

The parameters used for industrial production vary between 5000–6000 bar of pressure and 2–5 min of holding this high pressure up, at refrigeration conditions (3–7 °C) (Purroy et al. 2011). Fresh-cut tropical fruits on the market today include melons, cantaloupe, watermelon, mangoes, mangosteen, rambutan, jackfruit, pummelo, papaya, durian, grapefruit, pineapples, and fruit mixes.

**Table 13.2** Economically important, selected tropical and subtropical fruits, vegetables, nuts, and seeds

| Tropical and subtropical fruits | Exotic tropical and subtropical fruits |
|---|---|
| Banana<br>Avocado<br>Pineapple, (*Ananas*)<br>Coconut<br>Papaya<br>Mango<br>Mangosteen | The cashew apple<br>Pitahaya<br>Passion fruit<br>Carambola<br>Litchi<br>Rambutan<br>Longans<br>Durian<br>Tamarinds |
| **Tropical and subtropical vegetables** | **Tropical and subtropical nuts** |
| Amaranth leaves and seeds<br>Chili peppers<br>Cayenne peppers<br>Cassava<br>Taro<br>Yam<br>Yam bean<br>Chayote<br>Artichoke<br>Sweet potatoes | Almonds<br>Macadamia nut<br>Cashews<br>Walnuts<br>Pecans<br>Brazil nuts<br>Cedar nuts/pine nuts<br>Cashews<br>Pistachios<br>Hazelnuts/filberts |
| **Tropical and subtropical seeds** | |
| Flaxseeds<br>Hempseeds<br>Sunflower seeds<br>Pumpkin seeds<br>Sesame seeds<br>Chia seeds | |

## *13.2.2 Banana*

Banana (*Musa acuminata*, *Musa balbisiana)* belongs to family Musaceae. Banana fruit has a good flavor and high nutritional properties. It has a good texture and is consumed globally. Banana fruit is minimally processed to meet consumers demand for ready-to-eat and healthy foods. This minimal processing affects the texture and color of banana slices during storage. For minimizing these undesirable effects, different preservation techniques are used. The combined effect of chemical dip and/or edible coating and/or controlled atmosphere (CA) on quality of fresh-cut banana was investigated. Slices of banana were first given treatment of solution containing 1% (w/v) calcium chloride, 0.75% (w/v) ascorbic acid, and 0.75% (w/v) cysteine by dipping slices into solution for 3 min and/or combined with a carrageenan coating and/or with controlled atmosphere of 3% $O_2$ and 10% $CO_2$. The results after storage period of 5 days at 5 °C showed that synergistic effect of dip and CA treatment reduced the product weight loss and activity of polyphenol oxidase. Microbiologically, minimally processed bananas were acceptable during 5 days of storage at 5 °C (Bico et al. 2009). Banana slices are susceptible to browning and softening. To prevent these undesirable changes in fresh-cut banana slices, different techniques have been used. In one study, the effect of atmospheric modification, exposure to 1-methylcyclopropene (1-MCP), and chemical dips on the quality of fresh-cut bananas was investigated. Atmospheric modification with low levels of $O_2$ (2 and 4 kPa) and high levels of $CO_2$ (5 and 10 kPa), alone or in combination, did not prevent browning and softening of fresh-cut banana slices. Softening and respiration rates reduced when treated with 1-MCP treatment (1 μL/L for 6 h at 14 °C) of fresh-cut banana slices (after processing), but their ethylene production and browning rates were not influenced. A 2 min dip in a mixture of 1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + 0.5% (w/v) cysteine effectively prevented browning and softening of the slices for 6 days at 5 °C. Dips in less than 0.5% cysteine promoted pinking of fresh-cut banana slices, while concentrations between 0.5% and 1.0% cysteine delayed browning and softening and extended the post-cutting life to 7 days at 5 °C (Vilas-Boas and Kader 2006).

### *13.2.3 Avocado*

Avocado (*Persea americana*) belongs to family Lauraceae. Avocado fruits are rich sources of bioactive compounds such as monounsaturated fatty acids and sterol. The impact of minimal processing on health-promoting properties of avocados has been investigated. Avocados were first cut into slices or halves. These sliced and halved avocados were packaged in plastic bags with nitrogen, air, or vacuum. The filled plastic bags were then stored at 8 °C for 13 days. The stabilities of fatty acids and sterols as well as the effect on antioxidant activity were evaluated. The main fatty acid identified and quantified in avocado was oleic acid (about 57% of total content), whereas β-sitosterol was found to be the major sterol (about 89% of total content). In general, after refrigerated storage, a significant decrease in fatty acid content was observed. Vacuum/halves and air/slices were the samples that maintained better this content. With regard to phytosterols, there were no significant changes during storage. Antioxidant activity showed a slight positive correlation against stearic acid content. At the end of refrigerated storage, a significant increase in antiradical efficiency (AE) was found for vacuum samples. AE values were quite similar among treatments. Hence, minimal processing can be a useful tool to preserve health-related properties of avocado fruit.

Effect of high-pressure processing on the quality, physiology, biochemistry, and microstructure of avocado slices has been investigated. Avocado slices were given high-pressure treatment of >300 MPa. This treatment was seen to reduce respiration rates and ethylene production 1 h after treatment and particularly after 17 h at 20 °C. HPP treatment also resulted in some peroxidase (POD) activity reduction, particularly at higher pressures, while polyphenol oxidase (PPO) activity was generally increased. HPP (600 MPa) induced changes in the cell wall structure, disruption of the cellular network, and coalescence of oil vesicles. HPP treatment of avocado slices provides potentially beneficial reduced respiratory activity, without obvious color changes. The study of Woolf et al. (2013) demonstrated that HPP has beneficial effects by inactivating respiration and ethylene production in avocado slices, but it moderately effects POD activity and has little effect on PPO activity.

Avocado slices have been given pulsed light treatment to enhance their quality characteristics and for increasing oxidative stability. In this study, avocado slices were given pulsed light treatment on both sides (3.6, 6.0, and 14 J/cm$^2$ per side), and its effect on microbial burden, color, chlorophyll stability, and lipid oxidation for 15 days of storage at 4 °C was investigated. Exposure of fresh-cut avocado to the highest dose led to the highest reductions in aerobic mesophilic microorganisms (1.20 log CFU/g) and inhibited the proliferation of yeasts and molds for 3 days, prolonging their microbiological shelf life up to 15 days. Hue values of fresh-cut avocados were better maintained after applying PL treatments. PL treatments did not affect the stability of the lipidic fraction of processed samples and thus allowed keeping the oil acceptability for at least 15 days of storage (Aguilo-Aguayo et al. 2014).

### *13.2.4 Pineapple*

Pineapple (*Ananas comosus*) is a non-climacteric tropical fruit and belongs to family Bromeliaceae and subfamily Bromelioideae. It is the third most important tropical fruit in world production followed by banana and citrus. In market, pineapple is available as canned slices, chunks, crush, juice, and fresh fruit. Fresh-cut pineapple is found in various food service chains and supermarkets. Fresh-cut pineapple is well known for its flavor, taste, and juiciness (Gonzalez-Aguilar et al. 2005; Montero-Calderon et al. 2008). The major problems associated with fresh-cut pineapple are microbial growth and browning. So far various preservation techniques have been used to minimize deteriorations in fresh-cut pineapple. Post-cutting life of pineapple is very much dependent on temperature, ranging from a few hours at 20 °C to several weeks at 1 °C (O'Hare 1994). Marrero and Kader (2001) found that storage life of fresh-cut pineapple ranged from 4 days at 10 °C to over 2 weeks at 0 °C. Bierhals et al. (2011) reported that coating of cassava starch effectively reduced the physiological changes in fresh-cut pineapple, but the treatment was not effective in preventing the loss of ascorbic acid during 12 days of storage at 5 °C. Yeoh and Ali (2017) reported that application of ultrasound treatment increased the total antioxidant capacity in fresh-cut pineapple due to increase in total phenolic content and activity of PAL (Phenylalanine ammonia lyase). MAP has been found to increase the storage life of fresh-cut pineapple to 2 weeks at 5 °C, without undesirable changes in quality parameters (Marrero and Kader 2006). Pineapple cubes kept in polypropylene containers at 4 °C retained sensory characteristics up to 7 (O'Connor-Shaw et al. 1994). Application of methyl jasmonate (15 μL/L) to fresh-cut pineapple resulted in a 3 log CFU/g reduction of the native microbiota (Martinez-Ferrer and Harper 2005).

### *13.2.5 Coconut*

Coconut (*Cocos nucifera*) belongs to family Arecaceae. Coconut is a tropical plant native to coastal areas of Southeast Asia. Its mature kernel is eaten as food. Oil from kernel is used for cooking and various other purposes. Nut water from immature nuts is a refreshing drink. Coconut contains good amount of vitamins and minerals. Coconut is an important source of saturated fatty acid known as lauric acid that increases amount of HDL in blood. Cytokinins present in coconut water have anticarcinogenic, antiaging, antithrombotic effect. Coconut meat and coconut water contain good amount of potassium. The optimum storage temperature for freshly harvested coconuts is 0–15 °C and relative humidity is 75% or less. The white meat of kernel is prone to microbial spoilage due to its low acidity (Sinigaglia et al. 2003). Techniques such as chemical treatments, edible coating, modified atmospheric packaging, irradiation, etc., are used to maintain quality of minimally processed coconut.

In a study by Ferrentino et al. (2012), the effect of supercritical $CO_2$ treatment for 15 min at 45 °C and 12 MPa on hardness and microbiota on fresh-cut coconut was investigated. The treatment reduced mesophilic microbes, lactic acid bacteria, total coliform, yeast, and molds, and hardness was not affected by the treatment. The dehusked coconuts can be stored for 60 days at 0–5 °C and relative humidity of 75–85% (Muliyar and Marar 1963). Husked nuts can be film wrapped and waxed.

### *13.2.6 Papaya*

Papaya (*Carica papaya* L.) belongs to family Caricaceae. It is a climacteric fruit and is an excellent source of carotenoids, vitamins, proteins, and polysaccharides (Waghmare and Annapure 2013). Due to its convenience, fresh-cut papaya has become popular among consumers. However, the main problems associated with fresh-cut papaya like weight loss, loss of firmness, decrease in nutritional value, and microbial proliferation limit their storage life. In food industry, application of ozone has received a commercial interest due to its effectiveness over the shelf life extension of fresh-cut products by inhibiting the microbial growth (Sothornvit and Kiatchanapaibul 2009) and by preventing fungal decay (Ong et al. 2012). Application of 9.2 ± 0.2 μl/L gaseous ozone for 20 min to fresh-cut papaya resulted in depletion of microbial load without any depletion of major antioxidants except ascorbic acid (Yeoh et al. 2014). Edible coatings have become an important alternative to maintain the quality of fresh-cut fruits. Edible coatings may also act as carriers of food additives such as antibrowning and antimicrobial agents, colorants, flavors, nutrients, and spices (Rojas-Grau et al. 2009). Narsaiah et al. (2015) have reported that alginate (2% w/w) with bacteriocin could be used to store minimally processed papaya for 3 weeks without compromising physicochemical qualities or microbial safety. Fresh-cut papaya stored at lower temperature (14–15 °C) resulted in a shelf life of 3 days (Falaha et al. 2015). Under refrigerated condition, fresh-cut papayas packed in LDPE vacuum-sealed pouches retained a storage life of 12 days. These samples also showed minimum changes in physicochemical properties and higher sensory scores (Tirkeya et al. 2014). Waghmare and Annapure (2013) reported that MAP in combination with chemical treatment maintained the sensory and quality characteristics up to 25 days of storage in fresh-cut papaya.

### 13.2.7 Mango

Mango (*Mangifera indica* L.) is a climacteric fruit and belongs family Anacardiaceae. It is an economically important tropical fruit with a global production of about 25 million tons in 2006 (FAO 2007). Fresh-cut fruits are one of the major growing segments in food retail markets. However, marketing of such fruits is limited owing to their limited shelf life, which is due to excessive tissue softening and surface browning (Soliva-Fortuny and Martin-Belloso 2003). The demand for fresh-cut mangoes is increasing, but problems like translucency, browning, and loss of firmness affect their quality and limit shelf life. Although low temperature (<5 °C) has been reported to extend the shelf life up to 5 days (Rattanapanone et al. 2001), shelf life of such a length makes distribution and marketing difficult. So, low temperature should be used in combination with other preservation techniques in order to achieve best results. For the preservation of fresh-cut mangoes, a number of treatments have been used so far which include calcium chloride, low oxygen, high carbon dioxide, and browning inhibitors. Calcium chloride has been reported to maintain firmness (Trindade et al. 2003). Rattanapanone et al. (2001) and Izumi et al. (2003) reported that low oxygen (<5%) minimizes surface darkening associated with browning and translucency. Carbon dioxide (>3%) has been reported to maintain firmness and decrease translucency in fresh-cut mangoes (Poubol and Izumi 2005). Gonzalez-Aguilar et al. (2000) found that a combination of browning inhibitors like hexyl resorcinol, potassium sorbate, and ascorbic acid effectively delayed surface browning of cut slices. Chantanawarangoon and Kader (2000) reported that a combination of calcium chloride, low oxygen, and enhanced carbon dioxide increased the shelf life of "Keitt" and "Kent" mango slices up to 15 days at 5 °C. Combination of calcium and low oxygen has been found to extend the storage life of "Kensington" slices to 15 days at 3 °C (de Souza et al. 2006). A combination of ascorbic acid, citric acid, and calcium chloride resulted in better color retention and retarded quality loss and increased the antioxidant activity of fresh-cut mango cubes stored at 5 °C (Robles-Sancheza et al. 2009). Vilas-Boas and Kader (2007) reported that application of 1-MCP retarded surface browning and softening in fresh-cut “Kent” and “Keitt” mango slices. This treatment did not influence respiration rate, but only ethylene production was affected toward the end of shelf life.

### *13.2.8 Mangosteen*

Mangosteen (*Garcinia mangostana* L.) belongs to the family Clusiaceae. It has sweet flavor and pleasant aroma and has slightly acidic taste and purple-colored fruit with soft, white, juicy pulp (Jung et al. 2006). It is among the famous fruits in Thailand. Because of its high and instant visual and taste appeal, it is known as “Queen of Tropical Fruits.” Mangosteen is a rich source of phenolic compounds such as xanthones, phenolic acids, tannins, and anthocyanins (Fu et al. 2007). Fresh-cut mangosteen is an increasingly valuable commodity with excellent marketability. Processing mangosteen into fresh-cut products is technically challenging, as these processes affect fruit properties like color, odor, flavor, and texture negatively and thus decrease their shelf life.

The effect of 1-methylcyclopropene (1-MCP) and acidified sodium chlorite (ASC) on the quality of stored fresh-cut mangosteen was investigated. In this study, mangosteen fruit before minimal processing was treated with 1-MCP at levels of 0, 20, 40, or 80 ppm for 12 h at 28 + 2 °C. These treated fruits were then cut and packed in PP trays sealed with oriented polypropylene/linear low-density polyethylene (OPP/LLDPE) film and stored at 5 °C for 12 days. Fresh-cut mangosteen without 1-MCP treatment showed rapid softening and continuous weight loss. Ethylene production and respiration rate were lower in 1-MCP-treated fruits and both softening and weight losses were delayed. Therefore, the treatment could provide better quality in packaged fresh-cut mangosteen. The 1-MCP (40 ppm)-treated fruits were cut and dipped in tap water (control) and 500 or 1000 ppm acidified sodium chlorite (ASC) for 1 min before packing in PP trays sealed with OPP/LLDPE film for storage at 5 °C for 12 days. The results indicated that ASC could control browning. The effect of a mangosteen pericarp extract on the physical and chemical properties of fresh-cut mangosteen stored in PP trays at 5 °C with 85%

relative humidity (RH) was investigated. Fresh-cut mangosteen dipped in 0.25 g/l of the pericarp extract retained lightness and hue values better than the control (Ayudhya 2012).

## 13.3 Exotic Tropical and Subtropical Fruits

### *13.3.1 Pitahaya*

Pitahaya is commonly known as dragon fruit and belongs to genus *Hylocereus*. It is a fruit of the cactus species. Pitahayas are of three types: *Hylocereus undatus* (white-fleshed pitahaya), red-skinned fruit with white flesh; *Hylocereus costaricensis* or *Hylocereus polyrhizus* (red-fleshed pitahaya), red-skinned fruit with red flesh; and *Hylocereus megalanthus* or *Selenicereus megalanthus* (yellow pitahaya), yellow-skinned fruit with white flesh. Minimally processed pitahayas rapidly lose bright white color during storage and develop a brown surface that reduces their acceptability to consumers. Ariffin et al. (2009) reported that after cutting, shelf life of pitahayas gets rapidly reduced due to weight loss and desiccation. Matan et al. (2015) reported that application of green tea extract in combination with atmospheric RF plasma provided protection against the growth of pathogens and also improved the shelf life of fresh-cut dragon fruit. Edible coatings have been used to improve the nutritional quality of fresh-cut fruits. Chien et al. (2007) found that low molecular weight chitosan (LMWC) retarded water loss, inhibited microbial growth, and maintained sensory quality of sliced red pitahayas.

### *13.3.2 Passion Fruit*

Passion (*Passiflora edulis*) fruit is native to Brazil. It belongs to family Passifloraceae. Commercially important species include purple passion fruit and yellow passion fruit.

### *13.3.3 Carambola*

Carambola (*Averrhoa carambola*) belongs to family Oxalidaceae. It is commonly known as star fruit cultivated in tropical and subtropical regions of the world (Narain et al. 2001). Due to increasing demand of fresh-cut fruits, carambola fruits are also minimally processed. The market for fresh-cut carambola is good and its unique star shape after cutting attracts the customers. The operations used during minimal processing such as peeling and slicing result in various physiological and biochemical changes thereby destroying fruit tissue and quality (Watada et al. 1996). The deteriorative changes occur due to endogenous enzymes and microorganisms (Yoo and Lee 1999). Enzymatic browning is the main deteriorative reaction in fresh-cut carambolas which occurs due to oxidation of phenolic compounds by an enzyme known as polyphenol oxidase (PPO) present in fruit tissues (Weller et al. 1995). Therefore, in order to minimize deterioration in carambola, different preservation techniques are used.

The effect of low-oxygen atmospheres in combination with 1% acetic acid on fresh-cut carambolas was studied. The carambola slices treated with ascorbic acid and then stored under low-oxygen atmosphere (0.4% $O_2$) were seen to have storage life of 12 days without any incidence of browning. Modified atmosphere packaging has also been used to preserve quality of minimally processed carambolas. In a study by Teixeira et al. (2007), the carambola fruit was first washed, given dip treatment in NaClO solution (200 mg L − 1) for 5 min. These dipped fruits were then stored overnight at 10 °C. Then these fruits were cut manually into slices and rinsed with NaClO solution at 20 mg L − 1 and draines. The treated slices were then packaged in polyethylene terephthalate (PET) trays (Neoform® N94), polystyrene trays covered with PVC 0.017 mm (Vitafilm®, Goodyear), and vacuum-sealed polyolefin bags (PLO, Cryovac® PD900). The packages were stored at 6.8 °C and 90% RH for 12 days, with samples taken every 4 days. PET trays and PVC film did not significantly modify the internal atmosphere, and the high water permeability of PVC led to more rapid slice desiccation. PPO activity was lower when the slices were packaged in PLO vacuum-sealed bags, which reduced degreening and led to better appearance maintenance for up to 12 days.

### *13.3.4 Litchi*


Litchi (*Litchi chinensis*) belongs to family Sapindaceae. It is native to South China. It is a tropical and subtropical fruit. Its white translucent aril and attractive red color have increased its commercial value (Holcroft and Mitcham 1996). There is much demand of litchi in international market. Litchi fruit is often peeled and sliced for consumer convenience and for use in restaurants as ready-to-eat food. These processing methods make litchi susceptible to physiological and biochemical damage, which limits its marketing. Therefore, to avoid these adverse effects, litchi fruit is given various preservation treatments such as the use of edible coating. The effect of combined treatments of antibrowning agents, osmo-vacuum drying, and moderate vacuum packaging on peeled, destoned litchi was investigated. The peeled, destoned litchi fruits were treated with antibrowning agents (4.9 g/kg cysteine, 20 g/kg ascorbic acid, and 0.134 g/kg 4-hexylresorcinol) along with osmo-vacuum dehydration (OVD) and stored at 4 ± 2 °C. The samples were analyzed for physicochemical, sensory, and microbiological qualities during storage. Shelf life of 24 days was observed for the arils given a dip for 10 min at 570 mmHg vacuum followed by packing in polypropylene bags and in package vacuum of −355 mmHg. Packing in moderate vacuum along with osmo-vacuum dehydration was found to be highly effective in preserving the product against microbial proliferation and chemical changes, whereas antibrowning agents effectively controlled browning ( Shah and Nath 2008).

In another study, the manually peeled litchi fruits were coated with chitosan and overwrapped with plastic film and then stored at −1 °C. The results of chitosan coating showed retard in weight loss, higher TSS, and ascorbic acid. The coating was seen to suppress activity of PPO and POD, thereby maintaining quality and extending storage life of peeled litchi fruit (Dong et al. 2004).

### 13.3.5 Rambutan

The rambutan (*Nephelium lappaceum*) belongs to family Sapindaceae and order Sapindales. It is a medium-sized, non-climacteric tropical fruit and is native to the Malayo-Indonesian region. Dehydration and browning of skin and spinterns (long soft hair) limit its shelf life (Ketsa 1985). The darkening of skin and spinterns renders the fruit unmarketable, even though the pulp possesses a good eating quality. O'Hare (1995) reports that under ambient conditions, deterioration of rambutan skin can occur rapidly within 3 days. Various studies have been carried out on shelf life extension of rambutan. Sirichote et al. (2008a) reported that a combination of MAP (20% $CO_2$, 8% $O_2$, and 72% $N_2$) and cold storage (4 °C) maintained the physical, chemical, microbial, and sensory properties of minimally processed rambutan for 21 days of storage. Packaging rambutan in polyethylene bags (70 μm thick) under 5% $CO_2$, 5% $O_2$, and 90% $N_2$ and stored at 10 °C could extend its shelf life for 23 days (Luckanatinvong 2005). Sirichote et al. (2008b) found nylon/LLDPE package and a storage temperature of 4.0 ± 1 °C suitable for extending the storage life of minimally processed rambutans.

### 13.3.6 Longan

Longan (*Dimocarpus longan*) is a tropical fruit belonging to family Sapindaceae. Longan resembles litchi in structure but is more aromatic in taste. It is a native fruit of Southern Asia. Biew Kiew, Daw, and Chompoo are the commercially important cultivars of longan. Longan fruit is mostly consumed as fresh and dried (vacuum dried, freeze dried). There is a limited literature available on fresh-cut longan fruit. Zhao and Li (2010) studied the effects of ultra-high pressure on the quality of fresh-cut longans stored at 4 °C for 9 days and found that UHP of 600 MPa resulted in microbial destruction and product stabilization, while maintaining the sensory characteristics. Thus, UHP can be an alternative nonthermal preservation method for preservation of fresh-cut longan fruit.

### *13.3.7 Durian*

Durian (*Durio zibethinus* L.) is a climacteric fruit belonging to family Bombacaceae. It is a tropical fruit and is also called the "king of fruits" in Southeast Asia. It has a unique aroma, taste, and texture. The presence of sharp hexagonal spines on inedible thick husk makes its consumption very difficult. So, minimally processed durian can be an alternative to increase perception of quality among consumers. Minimally processed durian has been studied by a number of researchers. Booncherm and Siriphanich (1991) found that at low temperature, fresh-cut durian fruit can be stored for a longer time than its intact form, because pulp was found to be less susceptible to chilling injury than the husk. At 5 °C, fresh-cut durian was stored up to 8 weeks, with slight chilling injury observed after 4 weeks of storage. Salunkhe and Desai (1984) reported a shelf life of 30 days for durian pulp at 4 °C, with the main problems found being fungal contamination and chilling injury at the seed base. Voon et al. (2006) studied the effect of storage on physicochemical, microbial and sensory qualities of minimally processed durian fruit stored at 28 ºC for 3 days and 4 ºC for 35 days and found that durian stored at 28 ºC showed loss of texture, acidification, increase in fructose and glucose and decrease in sucrose contents. Durian stored at 4 ºC for 35 days maintained fruit firmness, pH and organic acid content, microbial growth also slowed down, however aroma loss and development of off-odours were recorded on day 21, which increased thereafter and rendered the pulp unacceptable on day 28th of storage.

## 13.4 Tropical and Subtropical Vegetables

### *13.4.1 Amaranth Leaves and Seeds*

Amaranth (*Amaranthus* L.) belongs to family Amaranthaceae. It is commonly known as pigweed. There are about 60 species of amaranth of which three main cultivated species are *Amaranthus caudatus*, *Amaranthus hypochondriacus*, and *Amaranthus cruentus*. Amaranth seeds are used as grains and its leaves are used as vegetable (Mlakar et al. 2010). Grain is used by humans in different forms. It is used in ground form in breads, noodles, cereals, etc. Amaranth leaf is used as steamed vegetable in soups and stews. It is used on large scale because of its high nutritional quality. Amaranth grain contains proteins (12–17%) and it is rich in amino acid lysine that is usually present in lesser quantities in other food grains. Amaranth grain is rich in fiber and unsaturated fatty acids and contains high amount of calcium, iron, potassium, vitamin C, vitamin A, riboflavin, and niacin. The leaves of amaranth are high in protein (15–24%), calcium, and niacin.

To avoid postharvest losses of amaranth vegetable due to poor handling and storage, different techniques have been used to increase its storage life. The effect of packaging material on shelf life of minimally processed amaranth leaves has been investigated. The amaranth leaves with or without stem were packed in polypropylene (100 and 150 gauges), polyethylene (LDPE, HDPE), pouches with or without vent, PET jar, muslin cloth, and brown paper pouches. It was seen that polypropylene 150-gauge package systems extended shelf life of amaranth leaves for up to 6 days with 84.34% retention of moisture, 21.01% physiological loss in weight, and 9.01% decay. PP 100-gauge pouches extended shelf life for up to 4 days with 86.32% moisture retention, 1.27% physiological loss in weight, and 14.52% decay. Thus PP 150 gauge was found to be the best packaging material with maximum edible leaves (Reddy et al. 2013).

Modified atmosphere packaging has also been used to extend shelf life and for nutrient preservation in vegetable amaranth. The freshly harvested amaranth samples were packed in active bags that modified internal atmosphere of packaged sample. These packaged amaranth samples were then stored in cold room. The temperature was maintained between 5–25 °C and RH of 75%. These samples were analyzed after 23 days of storage, and it was seen that loss of ascorbic acid (vitamin C) was lowest compared to control that showed 88% loss of ascorbic acid only after 4 days of storage at room temperature. Thus, it was concluded that MAP at 5 °C extends shelf life and preserves vitamin C in vegetable amaranth (Nyaura et al. 2014). Other preservation methods to maintain quality of amaranth are sun drying, blanching, etc. For storage of grain, moisture content should be approximately 11%. The seeds are dried by air or heat and then stored in wooden storage containers or a heavy duty paper bags. In one study, the effect of drying on protein content and fraction yield of starch in *Amaranthus* was investigated. The results showed that the most suitable drying temperature to increase starch with minimization of protein content in starch fraction is 40 °C with soaking using 0.05 w/v % of $SO_2$ (Resio et al. 2010).

### *13.4.2 Chili Peppers*

Chili pepper (*Capsicum annuum*) belongs to nightshade family (Solanaceae) and is native to Central American region and was later extended to other parts of world in the sixteenth and seventeenth centuries by Spanish and Portuguese explorers and is grown as major commercial crop in various parts of the world. The optimum temperature for growth of chili peppers ranges between 20 °C and 32 °C. These peppers are used in foods for their pungent flavor and aroma. The pungent flavor of chili pepper is due to the presence of an alkaloid compound known as capsaicin, which has various health benefits including anticarncinogenic, antidiabetic, antibacterial, and reduced low-density lipoproteins. Chili peppers are rich in vitamin C. Both green and red chili peppers contain approximately 76.4 mg of vitamin C/100 g. These peppers are richest in vitamin A among all spices. These also contain good amount of vitamin E and vitamin K. Minerals such as iron, phosphorus, copper, potassium, magnesium, and zinc are also present in chili peppers and thus have good antioxidant capacity. Chili peppers after harvesting undergo various changes such as shriveling, change in color, wilting, appearance of fungal diseases, and chilling injury. Therefore, proper storage conditions are required to reduce the quality losses. Optimum temperature for proper storage of chili peppers is reported to be between 7 °C and 13 °C for 2–3 weeks (Rico et al. 2002). Chili peppers are also minimally processed for consumer convenience. It has been seen that fresh-cut chili pepper slices can be stored for 12 days at 5 °C using controlled atmosphere of 3% $O_2$ and 10% $CO_2$.

To maintain quality of fresh-cut chili peppers, various preservation techniques have been used. One of the preservative treatments is the use of edible coating.

In one study, the fresh-cut green chili peppers were coated with chitosan by dipping, and these coated cut peppers were then stored for 15 days at the temperature of 5 °C. The results showed that chitosan-treated samples of cut chili peppers had good green color compared to control, and also fungal incidence was reduced in these samples. Microbiological analysis showed that total viable cell counts decreased with increasing chitosan coating (Raymond et al. 2012).

Glowacz and Rees (2016) investigated the effect of ozone on red and green chili peppers during storage. The chili peppers were exposed to ozone at 0.45, 0.9, and 2 μmol $mol^{-1}$ continuously during storage at 10 °C. The ozone levels of 0.45 and 0.9 μmol $mol^{-1}$ reduced disease incidence in red peppers. Ozone at 0.9 μmol $mol^{-1}$ extended shelf life of chili peppers.

### *13.4.3 Cayenne Peppers*

Cayenne pepper (*Capsicum annuum*), commonly known as Guinea spice, belongs to nightshade family (S*olanaceae*). Cayenne peppers have originated from a place named cayenne in French Guiana and hence its name. These peppers are mostly grown in tropical and temperate regions. Cayenne pepper is less fiery than other chili pepper varieties and is used widely in European, Creole, Cajun, Mexican, and East Asian cuisines. Cayenne pepper has similar composition as other pepper varieties. It is rich in vitamin C and also contains vitamin A, vitamin B, and vitamin E. It also contains proteins, carbohydrate, and fiber and has various health benefits like antimicrobial, antiseptic, anticarcinogenic, etc. Pungent flavor is due to the presence of active substance known as capsaicin. This capsaicin has various health benefits. Capsaicin is a pain reliever as it reduces substance "P," a substance that carries pain message from nerve endings to the skin to central nervous system.

Postharvest losses cause a lot of damages to farmers. To avoid this postharvest loss in cayenne peppers, various preservation methods have been used. The effect of polypropylene and polyvinyl chloride plastic film on the quality of "Yalova Charleston" during storage was investigated. Yalova Charleston is one of the best cayenne-type peppers. These long peppers were stored in plastic film having various $O_2$ and $CO_2$ permeabilities at 7 ± 1 °C and 90 ± 5% relative humidity (RH). The results showed that samples packed in polypropylene showed best physic chemical properties. 35 μ PP gave best results at the end of 30-day storage (Akbudak 2008).

### *13.4.4 Cassava*

Cassava (*Manihot esculenta*) belongs to family Euphorbiaceae. The cassava plant has originated in South America. It is a tropical crop. More than 500 cultivars of cassava are present worldwide. The nutrient composition of cassava varies with the cultivar. Leaves and roots are nutritionally valuable parts of cassava. The leaves of cassava are rich in proteins; vitamins $B_1$, $B_2$, and C; and carotenoids. It also contains minerals such as iron, zinc, magnesium, and calcium. Roots are rich in carbohydrates mainly starch. Maintaining postharvest quality in cassava is the major challenge faced. Roots of cassava after harvest are prone to physiological damage such as cut surface browning which results in reduction of shelf life of cassava roots. Refrigeration has been used to preserve fresh-cut cassava root sticks. The fresh-cut cassava root sticks packaged in polypropylene and stored for 12 days at refrigeration temperature of 5 ± 1 °C and relative humidity 90 ± 55 were seen to have greater concentration of carotenoids, total soluble phenolics compounds, greater antioxidant capacity, and increased activity of phenylalanine ammonia lyase (Junqueira et al. 2014). Hot water dip treatment in combination with MAP has been used to reduce browning in peeled cassava roots. The peeled roots were given hot water dip at 57–59 °C for 10 min. This reduced browning and MAP were seen to reduce weight loss in peeled roots (Acedo and Acedo 2013).

### *13.4.5 Taro*

Taro (*Colocasia esculenta*) belongs to family Araceae. It is an important tropical crop in developing countries in Asia, Pacific, Africa, and the Caribbean. Underground stem known as corm is the edible part of taro. Taro contains about 7% protein on dry weight basis containing essential amino acids. Fresh taro corm contains 13–29% carbohydrate and is also rich in vitamin C. Taro leaf is rich in proteins (23%), calcium, phosphorous, iron, vitamin C, thiamine, riboflavin, and niacin. As the demand of fresh-cut fruits and vegetables is increasing due to consumer awareness about health benefits of fruits and vegetables, taro is also minimally processed to meet consumer demands. The minimal processing techniques like peeling, slicing, cutting, coring, etc., cause various physiological and biochemical changes such as browning and proliferation of microorganisms that in turn decrease its storage life. Different preservation methods have been used to inhibit these deteriorative reactions in minimally processed taro. These techniques include irradiation, modified atmospheric packaging, heat treatment, edible coatings, etc.

The effect of combined treatment of ascorbic acid and chitosan coating to prevent browning in fresh-cut taros has been studied. In this study, the fresh-cut taro slices were treated with 0, 1.0, 5.0, and 10.0 g/L ascorbic acid and coated with 15.0 g/L chitosan. The results showed that the chitosan coating reduced weight loss in taro slices and also inhibited browning process. This treatment was also seen to polyphenol oxidase (PPO), peroxidase (POD), and amylase activity, thereby decreasing browning in fresh-cut taro slices and maintaining their quality (Wei-rong et al. 2011). Hot water dipping treatment has also been used to prevent browning in minimally processed taro. Taro slices were dipped in hot water (55 °C) for 45 seconds, air-dried at room temperature, and packed in polyethylene films or vacuum sealed in nylon/polyethylene films, stored at 4 °C for 12 days. The hot water dip treatment reduced browning of taro and improved its organoleptic properties (Chang and Kim 2015). Onion extract has also been used to prevent browning in taro slices. In this study, the taro slices were cut into 5 mm slices and then immersed in distilled water, fresh onion extract, and heated onion extract. The heated onion extract was prepared at 100 °C for 10 min. After immersion into these, the surfaces of taro slices were coated with 1.0 ml of 0.2 M catechol. This heated onion extract was seen to have higher inhibitory effect on polyphenol oxidase activity of taro than unheated onion extract, and those treated with distilled water showed rapid browning. Thus, onion extract both heated and unheated inhibited browning thereby maintaining quality of taro slices (Lee et al. 2007).

### *13.4.6 Yam*

Yam (*Dioscorea*) is an edible tuber belonging to family Dioscoreaceae. Yam tubers are important dietary sources of carbohydrate in tropical and subtropical regions. Currently in urban population, the demand for minimally processed roots and tubers such as yam and potato has significantly increased (Donega et al. 2013). The operations involved in minimal processing (peeling and cutting) induce some physical changes that reduce the shelf life of minimally processed products (Lunadei et al. 2011). Yam darkens quickly after cutting. The earlier signs of deterioration include the presence of brownish stains on the surface. Tissue dehydration results in deposition of starch on the surface, resulting in a whitish appearance (Donega et al. 2013). There are very few research studies on the preservation of minimally processed yam. Luo et al. (2015) found that nano-$CaCO_3$-based low-density polyethylene (nano-$CaCO_3$-LDPE) package maintain the quality of fresh-cut Chinese yam by inhibiting browning and microbial load. Ascorbic acid and calcium chloride (AACCl) dip in combination with UV-C dosage of 6.84 KJ $m^{-2}$ prevented browning of minimally processed yam slices under storage at 4 ± 1 °C (Teoha et al. 2016). Chun et al. (2013) observed that a combination treatment of aqueous chlorine dioxide (ClO2) and ultraviolet-C (UV-C) maintained the color, retained sensory quality, and reduced the preexisting microbial load of minimally processed yam during storage.

### *13.4.7 Yam Bean (Jicama)*

Jicama (*Pachyrhizus erosus*) is a tropical legume native to Mexico and Central America. Mechanical damage to jicama pieces causes surface browning that is associated with increased phenolic content and activity of phenylalanine ammonia lyase (PAL) enzyme (Aquino-Bolanos et al. 2000). Jicama is processed by osmotic dehydration and freezing and also juice preparation has been reported (Juarez-Goiz and Paredes-Lopez 1994). As jicama is usually consumed as raw, the production of fresh-cut jicama provides an interesting processing alternative. High-quality fresh-cut jicama should be white, crisp, juicy, free from visible defects, and microbiologically safe and possess characteristic odor and flavor. Aquino-Bolanos et al. (2000) reported that controlled atmosphere ($CO_2$–5 to 10%) and storage temperature of 5 °C were effective in maintaining the quality of fresh-cut jicama by retarding the microbial growth and discoloration. Rangel et al. (2014) studied the effect of modified atmosphere packaging, oxygen permeable films, and storage temperatures on the quality of minimally processed jicama and concluded that fresh-cut jicama packed and stored at 10 °C showed lower crispiness, visual quality, and higher $CO_2$ accumulation during 12 days of storage in comparison to those stored at 5 °C, and also its sensory quality was acceptable to less than 8 days.

### *13.4.8 Chayote*

Chayote (*Sechium edule*) is an edible plant belonging to the family Cucurbitaceae. It is known by different names like christophine, cho-cho, vegetable pear, etc. Chayote is native to Mesoamerica. It is a good source of vitamin C. Besides fruit, the root, stem, seeds, and leaves are edible as well. Chayote is consumed mostly in cooked form. As raw, it is added to salads. Chayote is also available as fresh cut. Alves et al. (2010) conducted a study on the effect of storage time on the quality of fresh-cut vegetables including chayote. It was concluded that fresh-cut vegetables packed in low-density polyethylene maintained the quality at 5 °C and RH of 99% during 8 days of storage. The vegetables maintained firmness and color and also showed lower weight loss and respiratory activity up to day 8 of storage. Hernandez et al. (2014) reported that the selective barrier technology (disinfection, heat treatment, edible coating, modified atmosphere, and cooling) was useful in maintaining the overall quality of minimally processed vegetables including chayote (*Sechium edule*) which was maintained during 12 days of storage under refrigeration (4 °C and 95% HR).

### *13.4.9 Artichoke*

The artichoke (*Cynara cardunculus*) is a perennial rosette plant grown for its large, fleshy heads. Due to nutritional benefits and healthy gastronomic properties, the demand for artichoke has increased, so appropriate postharvest technologies are required to make its marketing successful. Minimal processing (washing, removing external leaves, slicing, and packaging) can offer great advantages for artichoke commercialization. However, these operations induce physical damage leading to softening, water loss, microbial contamination, and enzymatic browning that negatively influence its marketability. Control of enzymatic browning can be achieved by combining chemical and physical methods, such as the use of antioxidant agents, modified atmosphere packaging (MAP), and proper temperature control. Gimenez et al. (2003) found that the use of MAP with low $O_2$ (5–10 kPa) and elevated $CO_2$ (5–18 kPa) showed little or no effect on visual quality of artichoke heads in comparison to samples stored under normal atmospheric conditions; however, artichoke heads were considered acceptable after 8–10 days of storage at 4–5 °C. Cabezas-Serrano et al. (2013) reported L-cysteine (Cys) and L-cysteine hydrochloridemonohydrate to be the most effective antioxidants for fresh-cut artichoke. However, the antioxidants were not sufficient to improve the shelf life for commercialization. Lattanzio and Linsalata (1989) reported that application of ascorbic acid and citric acid delayed browning and improved quality and shelf life of artichoke heads stored in polyethylene bags at 4 °C. Application of cysteine in combination with soy protein isolate and beeswax (SPI-BW)-edible coating controlled enzymatic browning and extended the storage life of fresh-cut artichokes up to 4 days without producing off-odors (Ghidelli et al. 2015). Del Nobilea et al. (2009) found that sodium alginate-coated fresh-cut artichokes packed in biodegradable film (NVT2) maintained a shelf life of 3 days.

### 13.4.10 Sweet Potatoes

The sweet potato (*Ipomoea batatas*) is an edible tuberous root belonging to family Convolvulaceae. It is long and tapered, having smooth skin with colors ranging between yellow, orange, red, brown, purple, and beige. Fresh-cut sweet potatoes which are a good source of polysaccharide are marketed on a limited scale. Fresh-cut sweet potatoes suffer from surface browning. Common methods to control browning involve dipping of fresh cuts in aqueous solution containing antioxidants, such as sulfites, ascorbic acid, and citric acid (Sgroppo et al. 2010). Ojeda et al. (2014) reported that edible coating of cassava starch in combination with ascorbic acid prevented enzymatic browning, retained freshness, and also improved nutritional value of minimally processed sweet potatoes stored at 4 °C for 16 days. McConnell et al. (2005) reported no changes in surface color of minimally processed sweet potatoes under MAP. Degree of browning also depends upon the potato cultivar. Moretti et al. (2002) found vacuum-packed minimally processed sweet potatoes "*brazlandia branca*" and "*brazlandia roxa*" to be less susceptible to browning than "princesa" during storage at 3 °C. Fresh-cut sweet potatoes dipped in 200 ppm chlorine and stored at 1 °C resulted in a reduction of microbial load (Erturk and Picha 2006). Sgroppo et al. (2010) reported that minimally processed sweet potatoes treated with sodium metabisulfite of 2% and citric acid packed in polystyrene trays can be stored for 14 days at 5 °C.

### *13.4.11 Fresh-Cut Packaged Vegetables*

Fresh-cut salads on the market include shredded leafy vegetables and salad mixes. Fresh-cut vegetables for cooking include peeled cut sweet potatoes, cut pak choi, cut pumpkin, baby corn, broccoli and cauliflower florets, cut chayote, cut celery stalks, shredded cabbage, cut asparagus, and stir-fry mixes. Fresh-cut ginger and herbs are also marketed widely.

## 13.5 Minimal Processing Line for Tropical and Subtropical Fruits and Vegetables

Fresh-cut processing involves peeling, trimming, and deseeding fresh produce and cutting it to specific size (Fig. 13.1). Fresh-cut products must not only look fresh but must have the sensory properties – aroma, taste, texture, and visual appeal – associated with freshly prepared produce. Thus, only fresh produce of good quality must be used as the starting material in fresh-cut processing. Fresh-cut products must also be safe, wholesome, and nutritious.

## 13.6 Tropical and Subtropical Nuts

**Minimal Processing of Nuts and Seeds** All phytosanitary tests are properly done**.** Phytosanitary certificate with no treatment is required but must be free from any pest disease and pesticide residues. Raw, organic, whole, shelled nuts and seeds are distributed in consumer packages with a shelf life of 3–6 months. Typical processing of nuts and seeds is given in Fig. 13.2.

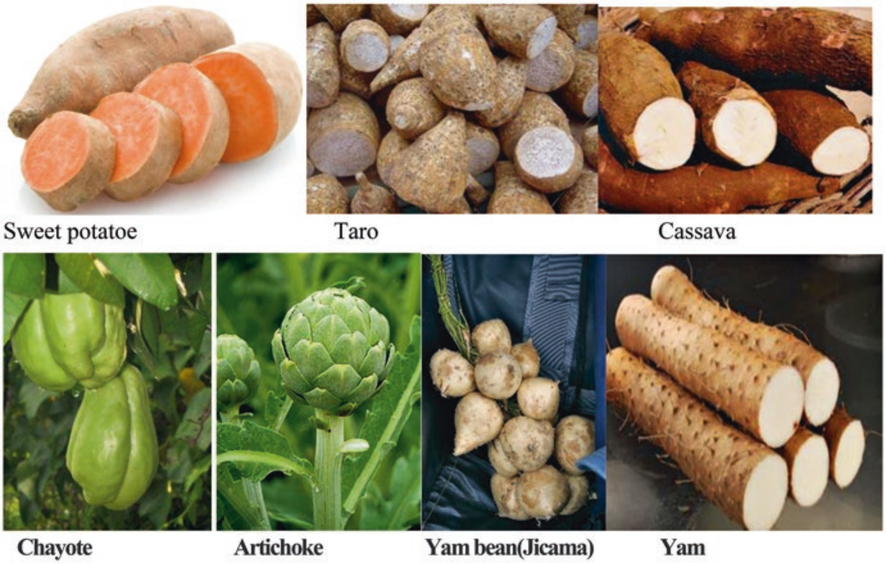


**Fig. 13.2** Selected tropical and subtropical vegetables

### *13.6.1 Almonds*

The almond (*Prunus dulcis*) belongs to family Rosaceae and is native to the Middle East, Indian subcontinent, and North Africa. Almonds are utilized as shelled, peeled or unpeeled, raw or roasted, whole or ground kernels. Due to high levels of unsaturated fatty acids, almonds are prone to oxidation. Lipid oxidation is the main cause of off-flavor development in almonds. Mexis and Kontominas (2010) reported a shelf life of 12 months for whole unpeeled almond kernels packed in polyethylene terephthalate/low-density polyethylene (PET/LDPE) and low-density polyethylene/ethylene vinyl alcohol/low-density polyethylene (LDPE/EVOH/LDPE) pouches under $N_2$ with an oxygen absorber. Mexis et al. (2011) reported a storage life of 12 months for irradiated raw unpeeled almond kernels packaged in PET-SiOx/LDPE pouches under $N_2$ with an $O_2$ absorber stored at 20 °C for 12 months. Sanchez-Bela et al. (2008) studied the effects of irradiation on sensory and chemical quality of almonds and found irradiation doses up to 7 kGy to be suitable for postharvest sanitation of almonds. Ziaolhagh

(2013) evaluated different packaging materials and packaging conditions for shelf life extension of almond kernels and found PA-PE-PE-PA laminate as the best packaging material and vacuum packaging conditions as most suitable for the storage of almond kernels. Thomas (1988) reported that almonds irradiated with 0.1 kGy had no adverse flavor and mouthfeel during 6 months of storage.

### *13.6.2 Macadamia Nut*

*Macadamia* is a genus of four species of trees belonging to family Proteaceae. It is native to northeastern New South Wales and Central and South East Queensland. Macadamia nuts can be eaten as raw, roasted, coated, salted, and flavored. Higher ratio between unsaturated and saturated fatty acids makes macadamia nuts susceptible to oxidation, thereby affecting their quality and shelf life (Frankel 1998). Colzato et al. (2011) suggest that zein/oleic acid edible coatings can be used for large-scale applications to improve the oxidative stability and enhance the shelf life and quality of macadamia nuts. Bowden and Reeves (1983) studied the effect of different packaging materials on the quality of raw Australian macadamia nuts and found that nuts packed in biaxially orientated nylon/aluminum foil/LLD polyethylene showed no deterioration for 18 months. Storage temperature is an important factor governing the quality of macadamia nuts; the lower the storage temperature, the longer the shelf life of the product (Cavaletto 1966). At 1–5 °C, storage life of vacuum-packed raw kernels (2–3% moisture content) was 16 months, but at 37 °C, a rapid deterioration of kernel quality and also storage life of less than 8 months were observed.

### *13.6.3 Walnuts*

Walnut is the nut of the tree of genus *Juglans* and family Juglandaceae. Walnuts are utilized as shelled whole kernels or ground kernels. Walnut kernels contain 65% lipids, out of which 73% include polyunsaturated fatty acid (PUFA) (Crews et al. 2005). High level of PUFAs makes walnuts prone to oxidation. Oxygen concentration, temperature, and relative humidity are some other factors influencing the oxidation potential of walnuts. Lopez et al. (1995) found that at 10 °C temperature and 60% relative humidity, walnut quality was maintained for a period of 12 months. Jensen et al. (2001) did not find any trace of rancid taste in walnut stored in dark at 5 °C during 25 weeks of storage at accelerated storage conditions (50% oxygen). However, significant oxidative changes were observed in walnuts stored at 21 °C in light. In another study, Jensen et al. (2003) obtained a shelf life of 13 months for walnuts with a high-barrier packaging material combined with $N_2$ flushing. Mexis et al. (2009) studied the effect of temperature, degree of $O_2$ barrier, and lighting conditions on quality of shelled walnut and reported that the effect of parameters observed followed the order: temperature > degree of $O_2$ barrier > lighting conditions. Bakkalbas et al. (2012) studied the effects of storage temperature and oxygen permeability of package on oxidative stability of vacuum-packed walnut kernels and concluded that oxidation was sufficiently protected in vacuum-packed walnut kernels in polyamide/polyethylene PA/PE film pouches at 20 °C for 12 months. Chlebowska-Smigiel et al. (2008) found that pullulan coating inhibited hydrolytic rancidity and oxidation of fat in nuts including walnut. It also slowed down weight loss of nuts.

### *13.6.4 Pecans*

Pecans (*Carya illinoinensis)* belong to family Juglandaceae which also includes walnuts (*Juglans* sp.). Pecan is mainly distributed in America, Israel, Australia, South Africa, and China. Pecans are rich in proteins, lipids, tocopherols, and antioxidants. Pecan kernels contain about 65% lipids, out of which 90% are unsaturated fatty acid (UFA). UFA besides having health-promoting properties also makes pecans prone to oxidation. Jigang et al. (2016) reported that fresh pecans exposed to microwaves for 2.5 min duration can be stored at up to 120 days at 2 ± 0.5 °C without any adverse effects on fatty acid composition or tocopherol content. Taipina et al. (2009) found that pecans irradiated by 1 kGy dose showed no significant changes in aroma, flavor, appearance, and texture. The vitamin E content of irradiated pecans also remained stable. Maness (2004) studied the effect of temperature on storage of pecans and reported that shelled pecans can be stored for 3 months at 22 °C, 9 months at 0 °C, and 18 months at −18 °C.

### *13.6.5 Pine Nuts*

Pine nuts (*Pinus pinea*) are the edible seeds of pines belonging to family Pinaceae. It is widely grown in Mediterranean regions, mainly in Spain, Portugal, Italy, Greece, Albania, and Turkey. Pine nuts are consumed as raw or roasted. Pine nuts contain 5.6% moisture, 31.1% protein, 47.4% fat, 10.7% carbohydrate, and 4.3% ash, and these also contain vitamins ($B_1$ and $B_2$) and minerals, especially phosphorus and potassium (Nergiz and Donmez 2004). Due to high content of fats, pine nuts are prone to oxidative and hydrolytic rancidity (Kaijser et al. 2000). Deterioration of pine nuts also depends on storage conditions such as temperature, moisture content, and gas composition. Cai et al. (2013) found that low-moisture conditioning and freezing temperature storage can be a viable alternative for maintaining the postharvest quality and extending the storage life of pine nuts. Mehyar et al. (2012) studied the effect of a combination of edible coatings (pea starch, whey protein isolate, and carnauba wax) on rancidity and sensory properties of pine nuts and concluded that the coating was effective in preventing oxidative and hydrolytic rancidity of pine nuts stored at 25 °C during 12 days of storage. Golge and Ova (2008) studied the effect of gamma irradiation (0.5, 1.0, 3.0, 5.0 kGy) on the chemical, physical, and sensory attributes of pine nuts during 3 months of storage period and found that irradiation had no effect on the quality parameters such as texture and color, fatty acid composition, and sensory attributes.

### 13.6.6 Cashews

Cashew (*Anacardium occidentale*) belongs to family Anacardiaceae. Cashew nuts have a characteristic odor and taste and are consumed as raw, salted, or unsalted. Cashew nuts are a good source of fats (45%), carbohydrates (23%), and proteins (20%) (Bhattacharjee et al. 2003a). High fat content makes cashews prone to oxidation. Besides, cashew nuts are also susceptible to infestation by molds, insects, and larvae. Among molds, *Aspergillus* species responsible for the production of aflatoxins render cashew nuts unsuitable for consumption. Irradiation can be a viable alternative to control pests in cashew nuts due to its ability to kill insects. Das et al. (2014) reported a shelf life of over 6 months for microwave-treated cashew nuts. The nuts were found to be from infestation and rancidity in comparison to untreated nuts that were heavily infested at the end of 1 month of storage. Mexis and Kontominas (2009a) evaluated the quality parameters of cashew nuts irradiated at 0, 1, 1.5, 3, 5, and 7 kGy doses and reported that cashew nuts remained organoleptically acceptable at doses <3 kGy. Bhattacharjee et al. (2003b) reported that irradiation doses (0.25–1.00 kGy) arrest insect infestation in cashew nuts during 6 months of storage. Sajilata and Singhal (2006) reported a reduction in the antioxidative activity of cashew nuts irradiated by 0.25–1.00 kGy dose.

### 13.6.7 Pistachios

The pistachio (*Pista ciavera* L.) is a member of the cashew family Anacardiaceae. Pistachio nut is one of the major agricultural products in Iran. It is consumed as raw and roasted. Pistachio is a highly nutritious nut. It is a rich source of unsaturated fatty acids (89.1%). High lipid content makes it very sensitive to rancidity and mold contamination. Gecgel et al. (2011) studied the effect of γ-irradiation on fatty acid composition of shelled pistachios and reported that free fatty acid and peroxide value of nuts increased as the dose increased. Moreover, the concentration of total saturated fatty acids increased while total monounsaturated and total polyunsaturated fatty acids decreased with the irradiation dose ($p < 0.05$ and $p < 0.01$). Georgiadou et al. (2015) reported that pistachio kernels stored under modified atmosphere packaging (MAP) retained acceptable sensory attributes after 47 days of storage. MAP also prevented oxidative rancidity. Tavakolipour et al. (2011) evaluated the effect of coating based on whey protein concentrate (WPC) and thyme essential oil on aflatoxin production in pistachio kernel and reported that thyme essential oil at a concentration higher than 5000 ppm in WPC edible coating could prevent aflatoxin production in pistachio kernels.

### *13.6.8 Hazelnuts*

Hazelnut is the nut of the tree of genus *Corylus* belonging to family Betulaceae or Corylaceae. It is also known as cobnut or filbert nut. Turkey is the leading producer of hazelnuts. Hazelnuts are available as blanched, roasted, chopped, sliced, and diced, grinded into flour, and made into meal, butter, or paste. Fat is the main constituent of hazelnuts ranging from 56.4% to 64.1% which increases its susceptibility to oxidation. Hazelnuts are also susceptible to infestation by molds, fungi, and insects. Application of zein coating reduced oxidative rancidity of roasted hazelnuts and prevented changes in its color, texture, and moisture content at ambient storage conditions (Yildirim and Mazi 2016). Basaran (2011) evaluated the effects of various acids and surface active compounds to control *Aspergillus* and found benzalkonium chloride, disodium-ethylenediaminetetraacetic acid, and sodium hypochlorite most effective in combating fungal growth. Mexis and Kontominas (2009b) found that hazelnuts retained acceptable sensory quality upon irradiation by a dose of 1.5 kGy. Guler et al. (2017) reported that hazelnuts treated with 0.5 kGy had highest vitamin E and lowest free fatty acid and peroxide values which was also reflected in sensory analysis.

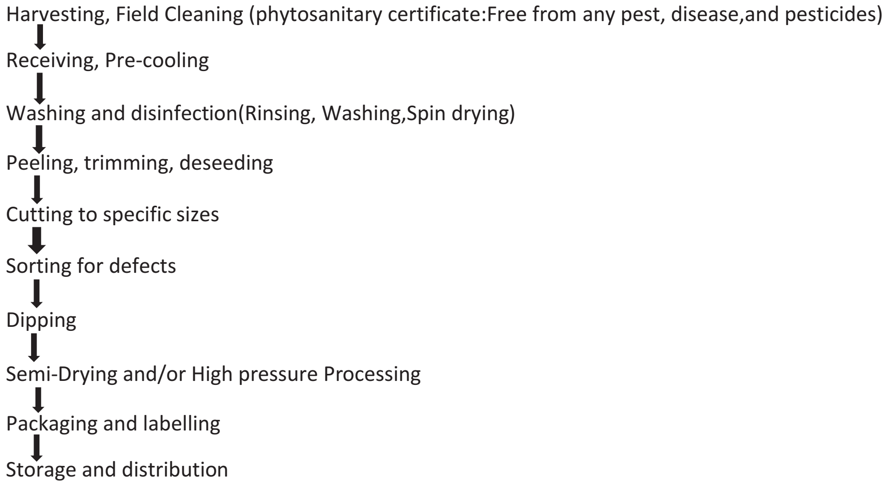


**Fig. 13.3** Typical fresh-cut process flowchart for fruits, vegetables, and root crops

### *13.6.9 Brazil Nuts*

The Brazil nuts come from the *Bertholletia excelsa* tree, which is found throughout the Amazon rain forest. It is seeds of the Brazil nut tree. Brazil nuts are commonly eaten raw or blanched and are high in protein, dietary fiber, thiamin, selenium, copper, and magnesium. During the blanching process, if high temperatures (above 50 °C) are not used, it may be called raw blanched Brazil nut; otherwise, it will be called blanched Brazil nuts. Brazil nut production is summarized in Fig. 13.3.

A Brazil nut a day supplies the human body with its daily requirement for selenium, an important trace mineral high in antioxidants. The Recommended Daily Allowance (RDA) for selenium for adults 19 years and up is 55 μg a day. According to the USDA National Nutrient Database for Standard Reference, one Brazil nut delivers 95.8 μg of selenium, well over the daily requirement for the mineral (Thompson Christine et al. 2008). Optimum dietary selenium intake related to optimum glutathione peroxidase activity in serum reduces the risk of coronary heart disease in human (Luoma et al. 1984) (Figs. 13.4 and 13.5).

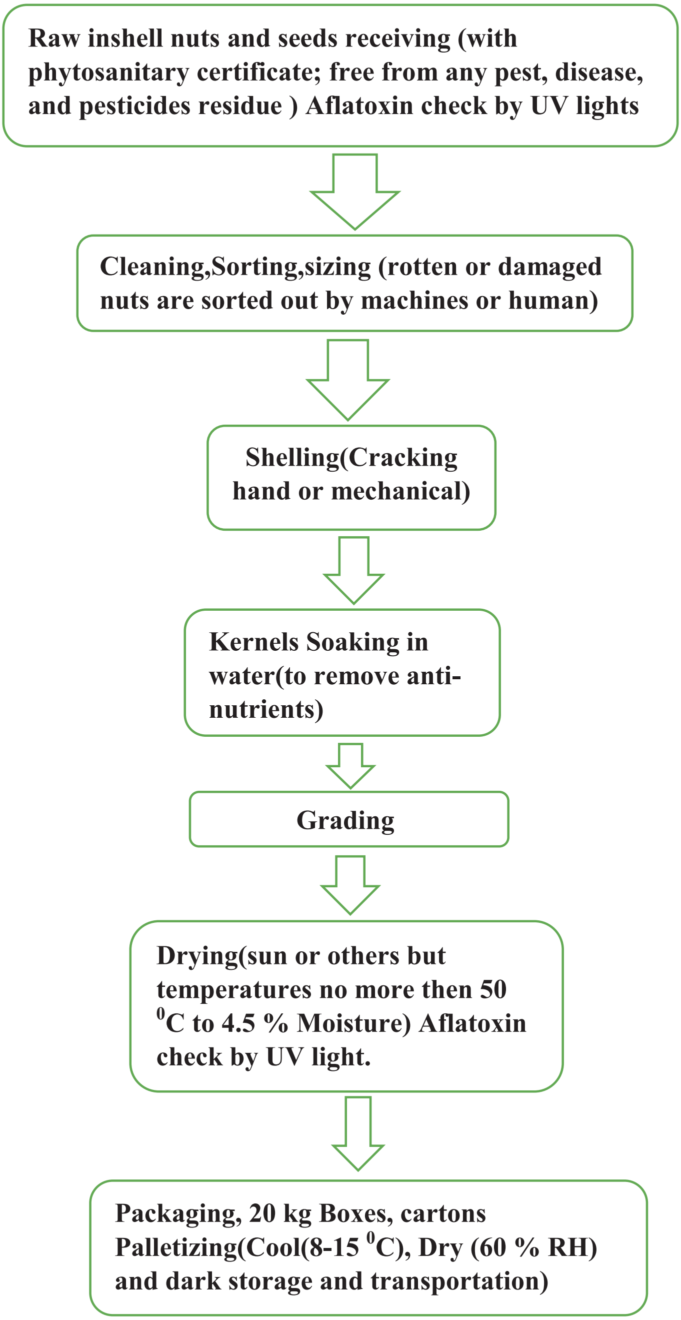


**Fig. 13.4** Typical minimally processed flowchart for nuts and seeds

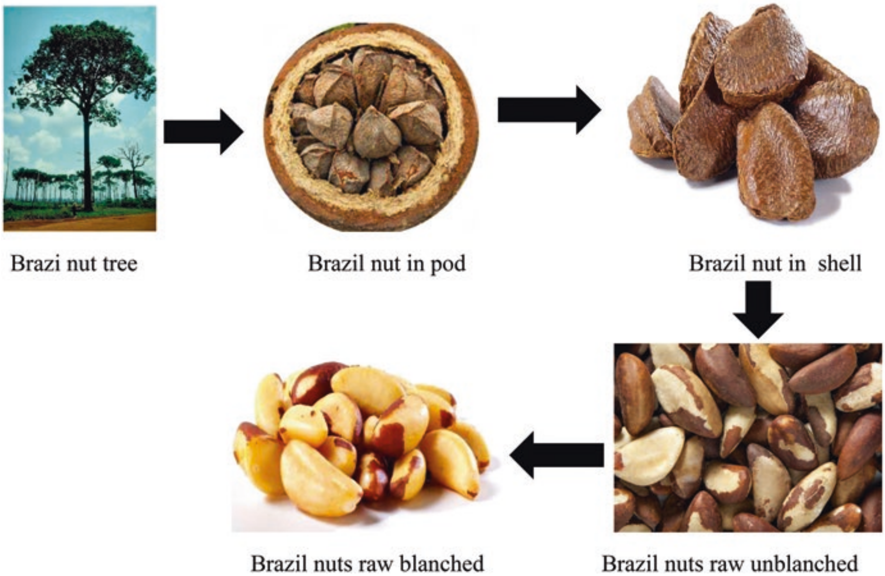


**Fig. 13.5** Minimal processing steps of commercial Brazil nuts

## 13.7 Tropical and Subtropical Seeds

### *13.7.1 Flaxseeds*

Flax (*Linum usitatissimum*) belongs to family Linaceae. It is cultivated in more than 50 countries and Canada is the major producer of flaxseeds. Flaxseed contains good amount of α-linolenic acid (ALA), omega-3 fatty acid, protein, dietary fiber, and lignan, specifically secoisolariciresinol diglucoside (SDG) having antioxidant activity and free oxygen radical-scavenging activity. Flaxseed is grown as either oil crop or a fiber crop with fiber linen derived from the stem of fiber varieties and oil from the seed of linseed varieties (Diederichsen and Richards 2003; Vaisey-Genser and Morris 2003). Flaxseed can be found in brown and gold color. The brown flaxseed is grown in warm and humid climates like Brazil and has the shell a bit tougher than the golden linseed. The texture of flaxseed is crisp and chewy possessing a pleasant nutty taste (Carter 1996).

Various deteriorative changes occur during storage of flaxseeds. These deteriorative changes result from various factors such as high moisture content that increases the rate of deteriorative reactions. Heat produced by respiration also aggravates deteriorative reactions. Different techniques have been used to inhibit these undesirable effects in flaxseeds. In one study, flaxseeds were divided into three lots, of which one lot was treated with ethylene chlorohydrins in concentration of 0.38% on dry weight basis of seed and then was placed in an insulated chamber. The other two lots of flaxseed were untreated, of which one was placed in insulated chamber under conditions similar to those under which treated seed lot was stored. Third lot of untreated flaxseeds was stored in a refrigerator. After 138 days of storage, it was seen that treated samples of flaxseeds had no mold growth, while unrefrigerated untreated samples had mold growth and were in advanced stage of putrefaction. Refrigerated samples showed little evidence of mold growth. The treated samples also had fresh odor of flaxseeds (Altschul et al. 1952).

Flaxseeds are prone to contamination by toxigenic fungi as tropical climates are ideal for their growth. Gamma irradiation has been used to inhibit contamination by aflatoxigenic fungi in flaxseeds. The samples of flaxseeds packed with PVDC film were subjected to the gamma irradiation doses of 2.5, 5.0, 7.5, and 10 KGy and then stored in a cool dry place in laboratory for 6 months. After 6 months, the treated samples were sown in DRBC to check growth of aflatoxigenic fungi. The results showed no growth of aflatoxigenic fungi in irradiated flaxseed samples (Costa et al. 2013).

### *13.7.2 Hempseeds*

Hemp (*Cannabis sativa*) belongs to family Cannabaceae. It is native to Central Asia and cultivated in Asia, Europe, and China. It is grown in tropical, temperate, arctic. Hemp is mainly used for fiber and oil. Seed of cannabis is an important source of nutrition. Hempseed contains high amount of proteins, mainly edestin and albumin, that contain all essential amino acids. Hempseed oil contains high amount of polyunsaturated fatty acids, mostly linoleic acid and alpha linolenic acid. Gamma-linolenic acid is also present in hempseed oil that has vital health benefits in humans. GLA alleviates psoriasis, atopic eczema, and mastalgia and also prevents cardiovascular disorder and also has beneficial effect on psychiatric and immunological diseases. Hempseed also contains small amount of stearidonic acid (Callaway et al. 1996) and eicosenoic acid (Molleken and Theimer 1997). It contains a group of chemicals known as cannabinoids. Tetrahydrocannabinol (THC) is the major cannabinoid present in hempseed. These cannabinoids are potent lipophilic antioxidants and has been used for various therapeutic purposes from ancient times (Hampson et al. 2000). It is also a rich source of vitamin E.

Hempseed has been used as food by humans generally of lower classes. In the past, whole hempseed was used for the preparation of foods such as peanut butter as these foods had gritty texture due to the presence of hempseed hull. Nowadays, the seeds are dehulled using mechanical hullers. The dehulled seeds produce smooth, white seed meal. Vacuum packaging and canning are used for hempseed storage. In a study by Suriyong et al. (2015), it was concluded that storage of hempseeds at 15 °C or cooler down to 4 and −4 °C maintains seed quality for 1 year.

### *13.7.3 Sunflower Seeds*

Sunflower (*Helianthus annuus*) belongs to family Asteraceae. It has originated in North America. It is an annual flowering plant. It is the leading oilseed crop. Sunflower seeds are nutrient rich that are used to produce edible oil that ranks second after soybean oil (Robertson and burns 1975; Stefansson 2007). Sunflower seeds are rich source of proteins having favorable amino acid distribution. Sunflower seeds contain unsaturated fatty acids mainly oleic and linoleic acid. Sunflower seed is also rich in vitamin E, niacin, pyridoxine, pantothenic acid, and folic acid. Sunflowers seeds are also rich in minerals like calcium, copper, iron, magnesium, manganese, selenium, phosphorous, potassium, sodium, and zinc and also contain good amount of phytosterol that has various health benefits, for example, it reduces risk of cancer due to high antioxidant content, is antifungal and antibacterial, and reduces risk of heart diseases.

After harvesting, the seeds are sorted according to size and color; the larger ones are used as inshell and medium-size sunflower seeds are usually hulled for kernel market. Smaller seeds are used as feed for birds and pet. Seeds of different classes and grades require different packaging system. For storage of seeds for short time, moisture content should be below 12%, and for long storage, it should be below 10%. Abreu et al. (2013) investigated the deterioration of sunflower seeds under different storage conditions. The packaging material used in this study consisted of multiwall kraft paper and plastic packaging with and without vacuum, under cold chamber and conventional storage conditions. The results showed that the physiological quality of seeds stored under cold chamber conditions packaged in paper bags is more efficient and those packaged in plastic bags under conventional storage had better physiological quality.

### 13.7.4 Sesame Seed

Sesame (*Sesamum indicum*) belongs to family Pedaliaceae. It is a very ancient oilseed crop grown in tropical and subtropical regions. It is cultivated in 60 countries of world. Asian and African countries are major producers of sesame. The sesame seeds have some potential nutraceutical compounds such as phenolic and tocopherols with antioxidant activity that have significant effect on reducing blood pressure, lipid profile, and degeneration of vessel impact reducing chronic diseases. During storage, sesame seeds are prone to deteriorative changes. To inhibit deteriorative reactions in stored seeds, various preservation methods are used. The sesame seed samples were given irradiation dose of 10 kGy and stored for 1 year at ambient temperature 20–28 °C. At the end of storage period, irradiation dose of 10 kGy greatly reduced the counts of total bacterial count and total fungal count and spore former bacterial to less than 10 cfu/g (Swailam 2009).

### 13.7.5 Pumpkin Seeds

Pumpkin (*Cucurbita pepo*) belongs to family Cucurbitaceae. It is native to North America. Pumpkin seeds are edible kernels of pumpkin. The seeds of pumpkin are used as food and for extraction of oil. In some parts of central Europe, pumpkin is used as major oilseed crop. Roasted pumpkin seeds are used as snack food. Pumpkin seeds are rich in unsaturated fatty acids mainly oleic 29% and linoleic 47% and also contain vitamin E (Younis et al. 2000). Pumpkin seeds are valuable food supplements as it contains good amount of minerals such as potassium, phosphorus, and magnesium and trace minerals such as calcium, sodium, manganese, iron, and copper (Lazos 1986). Pumpkin seeds are rich source of vitamins A, C, and E and good source of B complex vitamins. Flavonoid compounds such as α- and ß-carotenes, cryptoxanthin, lutein, and zeaxanthin are also present in pumpkin seed. The study on the effect of drying on pumpkin fruit (with and without rind), whole pumpkin seeds, and pumpkin seed kernels showed that pumpkin fruit contains high moisture levels, while seed contains low moisture levels and therefore can be stored for over longer periods and also seeds contain high content of proteins approximately 35–40% compared to fruits that contain low amounts of protein (4–4.9%) (Fedha et al. 2010). Conditioning of pumpkin seeds at 25 °C is suitable for faster germination of seeds under field conditions (Salmasi 2006).

### *13.7.6 Chia Seeds*

Chia (*Salvia hispanica*) belongs to family Lamiaceae. It is an annual herbaceous plant. Chia seeds are good source of omega-3 and omega-6 fatty acids. Average protein content in chia seeds varies from 15% to 23%. The total dietary fiber in chia seed varies from 36 to 40 g per 100 g. Chia seeds contain about 60% omega-3 unsaturated fatty acids that have various health benefits including hyperlipidemia, hyperglycemia, and hypertension. Chia seeds are rich in polyphenols that have antioxidant activity. Chia seeds contain bioactive compound quercetin, myricetin, kaempferol, cholorgenic acid, and 3,4dihydroxyphenyl ethanol-elenolic acid dialdehyde (DHPEA-EDA) that have protective effect against diseases such as cardiovascular diseases, cancers, and diabetes. Chia seed also contains minerals such as zinc, calcium, phosphorus, and magnesium and also contains high amount of niacin.

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