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A Review of Technologies to Prolong the Shelf Life of Fresh Tropical Fruits in Southeast Asia

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Abstract

Southeast Asia, a typical tropical region, plays an important role in exporting a variety of fruits worldwide. The market for fresh fruits has been growing consistently, and this is a chance for Southeast Asian countries to increase their national income. However, export of tropical fruits has limitations such as a short shelf life and difficulty in maintaining the quality because of tropical climate conditions and undeveloped postharvest technologies in Southeast Asia. An important objective for developing postharvest technologies is to extend the shelf life of fresh fruits without deterioration in fruit quality. Therefore, it is essential to determine factors that affect the shelf life of fruits. The shelf life of tropical fruits is significantly dependent on the inherent properties of the fruits, extrinsic conditions, postharvest treatment, and microbial contamination. Recently, Southeast Asian countries have supported agricultural research groups for developing new postharvest technologies and minimizing postharvest losses and maintaining export fruit quality so that the total sales of tropical fruit farms can increase. This review introduces how the primary factors for extending the shelf life of tropical fruits can be determined and discusses the development of postharvest technologies for tropical fruits in Southeast Asian countries.

Keywords: Fruit quality, Postharvest technology, Shelf life, Southeast asia, Tropical fruit

Introduction

The fresh fruit sector provides Southeast Asian countries with opportunities to enhance export diversification, poverty alleviation, and rural development. Fresh fruits contain many essential nutrients (i.e., vitamins, sugars, organic acids, fibers, antioxidants, and minerals) required for human health. Increased awareness of the health benefits of eating fresh fruits leads to an increase in the global trade of tropical fruits. International consumption of tropical fruits has increased by approximately 40% from 1995 to 2004 (FAO, 2004). With increasing population levels, the production of tropical fruits worldwide needs to be increased. The projected world population will exceed nine billion in 2050. Therefore, the current level of food production worldwide should be increased by 70% to feed the world's growing population (FAO, 2009). Southeast Asian countries such as Indonesia, Philippines, and Thailand are major producers of tropical fruits and can contribute to 66% (178 million tons in 2004) of the total global fruit production (Ahmad and Chwee, 2004).

The barriers for international trade in tropical fruits in Southeast Asia are postharvest losses that can lead to a reduction in fruit yield and deterioration in fruit quality. The limited shelf life of tropical fruits is the main cause of postharvest losses. Moreover, the hot and humid climate of the Southeast Asian region accelerates the losses. Postharvest loss of fresh fruits is 24~45% and 2~20% in developing countries and developed countries, respectively

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(Sirivatanapa, 2006). In developing countries, undeveloped postharvest technologies are a big challenge for extending the shelf life of fruits. These losses have several adverse impacts on the sales of tropical fruit farms, national income, consumer prices, and nutritional quality of the produce (Wu, 2010).

It is crucial to maintain the quality of fresh fruits after harvest. Use of appropriate postharvest technologies is a practical way to reduce postharvest losses and maintain the quality of fresh tropical fruits. The main objective of postharvest technologies is to prevent deterioration in the quality of the produce and extension of the shelf life of the fruits (Singh et al., 2014). Minimizing postharvest losses through prolonged shelf life is an effective way to increase food availability without further boosting crop production. Reduction in postharvest losses should be considered a strategic requirement, especially in Southeast Asia. In this review, challenges faced by Southeast Asian countries in international tropical fruit trade have been discussed. Furthermore, determination of primary factors and future postharvest technologies for extending the shelf life of tropical fruits has been highlighted.

Southeast Asia and International Fruit Trade

Although Southeast Asian countries are rich in natural resources, they suffer from poverty. The main reason for poverty is the impact of the tropical climate on the productivity of fresh fruits, postharvest losses, and poor postharvest technologies (Gallup and Jeffrey, 2000). Asia is the biggest region for tropical fruits, and productivity of fresh fruits in Asia is more than 50% of the world's total fruit production (Table 1) (UNIDO, 2014). A variety of fruits and vegetables can grow well in Southeast Asia because of tropical and subtropical climates with 75~85% relative humidity (RH) and 25~35°C average temperature (Chinaphuti, 2011). The high postharvest losses (45%) of fresh produce affect fruit productivity in Southeast Asia.

Table 1. Main commodities of each Southeast Asian country

Country	Fruits
Indonesia	Mango, mangosteen, banana, pineapple, and rambutan
Lao PDR	Rambutan and banana
Malaysia	Melons, durian, papaya, banana, and starfruit
Myanmar	Mango
Philippines	Banana, mango, papaya, and pineapple
Singapore	Re-export of different fruits
Thailand	Longan, durian, and pineapple
Vietnam	Dragon fruit

The agricultural sector has made major contributions to Southeast Asian economies in terms of the use of land, engine of growth, creation of employment, foreign exchange receipts, capital formation, and provision of manufactured goods for the market. Approximately 40~75% of the total labor force is employed in agriculture, and about 65~80%

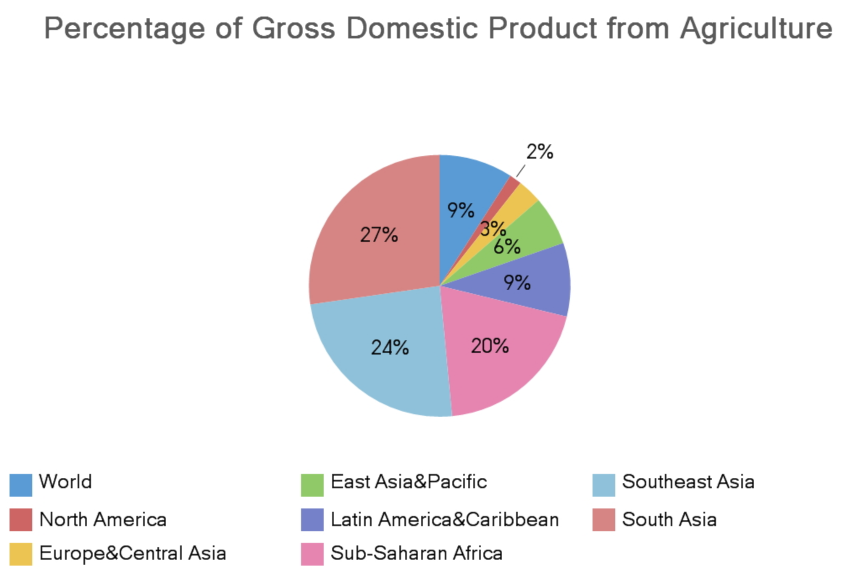

Figure 1. Importance of agriculture in Southeast Asia, as compared with other world regions, reflected by its share in the 2009 gross domestic product (World Bank, 2009; Raitzer and Mywish, 2012).

of the population lives in rural areas (Bautista, 2002). The agricultural sector's contribution to the gross domestic product (GDP) of Southeast Asian countries was about 18~20% in 2002 (Daquila, 2006). The demand of customers for fresh fruits has domestically or internationally increased because of the awareness of a healthy lifestyle and high nutritional values (Huang, 2004). Growth of sustainable and fair trade of fresh fruits in the agricultural sector is also an opportunity for Southeast Asia countries to increase GDP (Figure 1).

For decades, the major tropical fruits (i.e., mangoes, papayas, pineapples, and bananas) and minor tropical fruits (i.e., lychees, durian, rambutan, guava, and passion fruit) have been exported from Southeast Asian countries to the world (James and Ngarmsak, 2010). Several countries in Southeast Asia have different main commodities (Table 1). Southeast Asian countries such as Philippines, Indonesia, Thailand, and Vietnam fulfill the requirement for tropical fruits. More than 50% of total fruits in the world is produced in Asia (Table 2) (UNIDO, 2014). The main market is still around Southeast Asian regions like Singapore, Hong Kong, Taiwan, and Japan, while just a minor portion is in the United States, Canada, and Europe because of the lack of quality requirements for fresh fruits by the importing countries (Table 3) (Bautista, 2002). The European Union, Japan, and the United States have stringent quality criteria for importing fruits to protect their residents (Hassan, 2010). Export of fresh tropical fruits faces challenges in that quality and food safety are required in international markets as mandatory government regulations (e.g., stringent regulations concerning the use of agrochemicals and their maximum residue levels) (UNCTAD, 2007). For these reasons, the export volume of fruits from Asia tends to lag behind those of other major fruit-producing regions such as Central America, which has a 33% share in the global export, and South America, with a 37% share in the global export (ESCAP, 2007).

Challenges of Postharvest Technology in Southeast Asia

To increase fresh tropical fruit production and export volume in Southeast Asia, some problems need to be

Table 2. Fruit production of Asian countries in 2010

Countries	Total *000 ha	Total *000 tonnes	% of Asian ha	% of Asian tonnes
World	55.856	608.926	-	-
China	11.316	122.350	20.26	20.09
India	6.408	75.121	11.47	12.34
Philippines	1.228	16.182	2.199	2.657
Indonesia	607	14.598	1.087	2.397
Thailand	1.172	10.274	2.098	1.687
Vietnam	526	6.428	0.942	1.056
Pakistan	781	6.370	1.398	1.046
Bangladesh	455	4.004	0.815	0.658
Japan	197	2.883	0.353	0.473

Table 3. Export of fresh fruits to principal markets ($ million) in 2005

	World	Sub-total	ASEAN	China	Japan	Hong Kong, Taiwan, and Korea	Other Asian developing countries	West Asia	EU	US and Canada
Indonesia	15.2	10.1	3.4	2.3	0.5	3.9	2.9	1.5	0.6	0.1
Malaysia	69.5	59.0	40.2	1.6	0.1	17.0	0.8	1.1	7.8	0.5
Philippines	447.7	357.5	5.7	36.5	224.2	91.0	37.0	34.5	1.6	3.9
Singapore	35.6	32.9	31.4	0.0	0.1	1.4	0.4	0.3	0.8	0.0
Thailand	288.5	231.5	67.9	98.7	14.9	50.0	2.7	7.4	16.7	22.3
Vietnam	57.5	53.8	5.8	40.6	0.4	6.9	0.0	0.0	1.7	0.5
ASEAN	914.1	744.7	154.6	179.8	240.1	170.2	43.7	44.7	29.4	27.3

resolved. There has been rapid progress in the development of postharvest processes in majority of Southeast Asia over the last 20 years. However, Southeast Asian countries still need to reduce postharvest losses (Bautista, 2002). Majority of the Southeast Asian countries have the world's lowest agricultural research intensity ratios, which affect agricultural production values, and underinvestment in agricultural research affects the development of agricultural technologies (Raitzer and Mywish, 2012).

Postharvest losses were 42% for fresh fruits and vegetables in Southeast Asian regions. The major cause is the short shelf life of the tropical fruits as well as losses during each process such as production, postharvest, and distribution. Poor infrastructure for storage, processing, and market can result in a high proportion of waste (10~40% of the total production) (Choudhury, 2006). Postharvest losses are caused by improper packaging or handling, lack of cold storage in warm and humid climates, and seasonality that results in surplus. Major infrastructural limitations also continue to impose severe constraints on domestic distribution as well as export of horticultural produce (Choudhury, 2006).

Agricultural practices in almost all Southeast Asian countries are still dependent on conventional methods, and a few practices use a mixture of traditional and modern methods on small-scale farms with limited postharvest knowledge (Marten, 1986). During the peak season for harvesting tropical fruits, there is a glut in local markets and crops are sold at very low prices because Southeast Asian countries lack storage facilities for tropical fruits. To overcome this issue in Southeast Asian countries, effective elimination in the production of tropical fruits is required through communication and idea exchange among farmers, postharvest engineers, food technologists, and the government. Reduction in postharvest losses and extension of the shelf life are possible with advanced research and development of applicable technology for postharvest processes (Kader and Barrett, 2005).

The direction of research on postharvest technologies should be established in Southeast Asian countries to use postharvest technologies on small-scale farms and improve knowledge on postharvest management. Developed countries have extensive and effective postharvest systems for extending the shelf life, educated farmers, and good chain systems in the markets. The governments of Southeast Asian countries should take initiatives and allocate resources to improve postharvest handling conditions to catch up to developed countries. Therefore, reduction in postharvest losses is possible with the help of modern techniques and advanced research.

Factors That Affect the Shelf Life of Tropical Fresh Fruits

The short shelf life of fruits is an inherent drawback of the distribution chain. A lot of transportation time for exported perishable agricultural or tropical products is required. Limited shelf life of the fresh fruits is caused by their distinct properties, external conditions, microbial contamination, physiological disorders, mechanical damage, and the level of postharvest treatment. Shelf life is often related to a combination of several factors. Although it is difficult to control all the factors that affect the shelf life of fruits, minimizing the effect of each factor on the shelf life is technically feasible.

Natural properties

Postharvest losses of tropical fruits are due to a lack of information on their nature (Table 4) (Paull and Chen, 2014). Tropical fruits have a shorter shelf life than temperate fruits because of their perishable nature. As a result, these fruits cannot be stored for more than 4~6 days under normal ambient conditions (Rajkumar and Mitali, 2009). Good initial quality of fruits encompasses appearance, firmness, aroma, taste, nutritive value, and chemical components. Therefore, it is important to harvest fruits at

Table 4. Natural properties of tropical fruits that are required for handling after harvest

Natural properties of tropical fruits
1. Product with a high moisture content (80~90%)
2. Some fruits are large and heavy (5 g to 5 kg or more), e.g., litchi, durian, and pineapple
3. High to very high respiratory rates that lead to heat emission at ambient temperatures
4. Soft tissues that are highly vulnerable to mechanical injury
5. Highly perishable with a generally limited postharvest life of days to weeks
6. Susceptibility to storage at temperatures less than 10°C to 15°C – rotting, failure to ripen, skin, and scalding
7. No kill step during handling; dependence upon layers of protection to minimize microbial contamination
8. Host to tropical insects, so disinfestation treatment is required prior to export

the proper stage, size, and peak quality. However, Thailand, Laos, and Vietnam have not established any standards or harvest indicators to determine maturity (Nissen, 2014).

Harvested fruits are still alive and continue their physiological activities, such as respiration, transpiration, and developmental changes in chemical components that cause loss of color, flavor, texture, and nutritional value (Atanda et al., 2011). The rate of respiration of the harvested commodities is inversely proportional to the shelf life of the produce: higher respiration rates decrease the shelf life (Lee et al., 1995). Water loss from fresh fruits occurs through transpiration, which affects appearance, salable weight, texture quality, crispness, and juiciness. These physiological behaviors of the fruits are important concerns with respect to postharvest technologies. The quality of the tropical fruit commodities cannot be improved; however, it can be retained until their consumption if the rate of metabolic activities is reduced by using appropriate postharvest handling operations (Wu, 2010).

External condition

The external condition has a great influence on the shelf life of fruits. Factors of external condition can be subdivided into temperature, composition of the air surrounding the produce, and humidity of the environment. In general, high tropical temperatures and relative humidity in Southeast Asia regions play a major role in accelerating the rate of chemical and biological degradation as well as providing a conducive atmosphere for the multiplication of tropical insects that contribute to postharvest deterioration (Rene, 2001). All fresh produce are subjected to damage when exposed to extreme temperatures that increase the level of respiration. Gas composition surrounding fruits, such as O_2, CO_2, or ethylene, also exerts a great impact on the respiratory and general metabolism of fruits.

Relative humidity is closely associated with water loss, and the transpiration process can be minimized by increasing relative humidity. Most fruit crops retain better quality at high relative humidity (>90%) (Wu, 2010). However, fruits with a high water content are considered more perishable, and nearly 33% of fruits are spoiled during transportation because of bacterial contamination (Kader, 1986). Humidity chosen for storing produce is frequently a "trade-off" between minimizing water loss and minimizing disease (Coates and Johnson, 1997). External condition has a great effect on deterioration in fruit quality because it has a direct relationship with the moisture content in the atmosphere, which determines whether the shelf life will not be exceeded (Sheikh et al, 2013).

Microbial contamination and disease

Biodeterioration can be caused by insects, rodents, fungi, or microorganisms (Hodges et al., 2011). Biological spoilage and disease are the main causes of postharvest loss in developing countries (Spadaro et al., 2002). Two critical requirements for the growth of microorganisms are nutrients, such as organic substrates, and high water activity, and fruits are good substrates for microorganisms. Microorganisms readily contaminate fresh produce and spread rapidly owing to weak defense mechanisms in the tissues of fresh produce and the abundance of nutrients and moisture. Contamination not only affects the produce quantitatively but also qualitatively (Bhargava and Arya, 1983; Tripathi et al., 2013). Since the optimum growth temperatures for most fungi fall between 25°C and 30°C, growth above 40°C is poor and some cases of bacterial mortality may occur (Sharma and Razak, 2003; Ibrahim et al., 2011).

Tropical fresh fruits can be easily contaminated by microorganisms because the optimum temperature for microbial contamination is the average temperature in tropical countries. Mango is a climacteric fruit and has quite a long shelf life of more than 10 days if not attacked by fungi (Siriphanich, 2002). The two most serious fungal diseases of tropical and subtropical fruits such as mango, banana, papaya, and avocado are powdery mildew (*Oidium mangiferae*) and anthracnose (*Colletotrichum gloeosporioides*), which are prevalent in regions with high humidity (Kumah et al., 2011). Approximately 20~25% of the harvested fruits and vegetables decay because of pathogens during postharvest handling even in developed countries (Zhu, 2006). Physiological and storage conditions at the postharvest stage, especially under tropical conditions, accelerate the spread of the abovementioned diseases.

Handling methods

Poor handling, unsuitable packaging, and improper packing during transportation cause bruising, breaking, wounding, and other forms of injury in fresh fruits and vegetables. Simple processes for picking, transferring, and packaging tropical fruits in Southeast Asian countries make the fruits susceptible to mechanical damage (Haryanto et al., 2006). Handling methods can determine the extent of variability in maturity and physical injuries and consequently influence the composition and quality of fruits (Kader, 2002).

Mechanical damage and chilling injury not only affect appearance but also render fruits susceptible to microbial infection (Wu, 2010). For example, banana skin can be abraded (scuffed) by rubbing against the wall of a cardboard carton, and this causes dark black areas on the ripe yellow skin of the bananas (Paull and Chen, 2014). Mechanical damage can also increase moisture loss; therefore, the rate of moisture loss may be increased by as much as 40% by a single bad bruise on an apple (Bachmann and Earles, 2000). Moisture loss and contamination by microorganisms can result in the deterioration of fruit quality and reduce their shelf life. Mechanical injury is also associated with decrease in vitamin C levels or other nutrient degradation. Incidence and severity of such injuries are influenced by the harvest method and handling operations (Lee and Kader, 2000).

Technologies to Extend the Shelf Life of Tropical Fruits in Southeast Asia

Primary factors for maintaining and extending the quality and shelf life of fruits are the determination of optimum harvest maturity, minimization of mechanical injuries, use of proper postharvest treatment, and optimum temperature and relative humidity during all market steps (Kader et al., 1989). Postharvest technologies in Southeast Asia are expected to be used for the enhancement of productivity and quality. Such technologies can extend the shelf life of fruits, consequently enabling the distribution of high-quality produce to distant markets. Recently, many postharvest technologies such as cooling chain, packaging, controlled atmosphere (CA), heat treatments, and coating have been developed in real commercial areas or agricultural laboratories. Postharvest technologies should be applied on the basis of usability, fruit characteristics, and environmental conditions.

Cooling chain

Delays between harvesting and cooling or processing can result in direct quality losses due to water loss and decay and indirect losses such as those in flavor and nutritional quality (Lee and Kader, 2000). In Southeast Asia, small-scale farmers do not use cooling process after harvesting, and several fruit companies use room storage cooling for extending the shelf life of tropical fruits (Maneepun, 2010). Cooling of fruits is necessary at different stages to control degradation: after harvesting (pre-cooling), during storage (cold storage), and during transportation (vehicle with freezer) (Singh et al., 2014). It extends the shelf life of fresh produce by reducing the rate of physiological changes and by delaying or preventing the growth of microorganisms.

Precooling is a process that removes field heat from freshly harvested produce by using cooling treatments, i.e., room cooling, forced-air cooling, hydro-cooling, and vacuum cooling; each treatment has different advantages (Wu, 2010). A forced air-cooling system is used for the treatment of exported durian, and hydro-cooling is used for vegetables in Thailand (Chinaphuti, 2011). Cooling treatment is recommended for most fruits (Intelligent Supply Chain Information, 2010). Refrigeration or cold storage is considered the most efficient method to maintain the quality of most fruits (Wu, 2010). Figure 2 shows the effect of storage temperature on bananas; the best temperature for banana was 10°C (Chikkasubbanna, 2006). Durian is a climacteric fruit that is very sensitive to chilling injury; therefore, the storage temperature should not be lower than 15°C (Wisutiamonkul et al., 2015). Cold storage is the most effective treatment for extending the shelf life for distribution.

During the handling stage, proper temperature and relative humidity based on fruit characteristics are important. In general, lower the storage temperature, longer the storage life of the commodity, as long as it is not reached the freezing temperature (Rahemi, 2006). However, the lowest safe storage temperature is not the same for all commodities because a number of tropical fruits are sensitive to low temperature and inappropriate storage

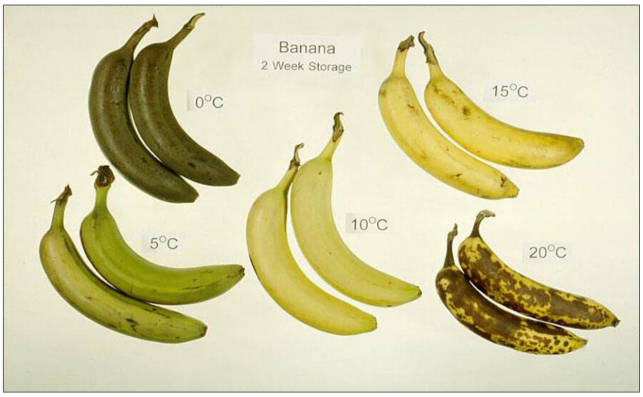

Figure 2. Changes in bananas at different storage temperatures.

temperature may cause chilling injuries such as irregular ripening, failure to ripen, pits on the skin surface, and increased susceptibility to decay. Sensitivity to chilling injury is commonly associated with subtropical produce and fruits of tropical origin like banana, pineapple, and tomato, which should be stored below 8°C (Singh et al., 2014). Another way to minimize damage due to low temperature storage is the use of a combination of two different treatments (such as good packaging, edible coating, or radiation treatment). For example, preservation of coated papayas at their ambient storage temperature (10~13°C) extends their shelf life (Marpudi et al., 2011). In Malaysia, cooling room and water cooling are used to minimize the damage during the transportation process (Ibrahim and Omar, 2010).

Thermal treatment

Thermal treatment is a relatively simple method to control deterioration in food quality. Heat treatment between 30°C and 50°C for 10 min to 24 h is commonly used for tropical and subtropical fruits, and it is effective against a wide variety of insects and fungi (Department Agriculture of Malaysia). However, hot water treatment is limited to a narrow range of temperatures and time intervals, and the values are highly dependent on the commodity (Costa and Erabadupitiya, 2005). High temperature affects the nutritional quality and sensory properties of fruits. The best combination of suitable temperature and exposure time should be determined to prevent quality loss (Lurie, 1998). Inappropriate set-up of temperature and dipping time during heat treatment causes accelerated fruit ripening, increase in weight loss, reduction in fruit firmness, and increase in the brix of fruits (Mansour et al., 2006).

Hot water, vapor heat, and hot air are commonly used for the thermal treatment of tropical fruits. Hot water is often used in combination with fungicides to control postharvest diseases and physiological and biological activities, extending the shelf life of mango, papaya, and melon (Coates and Johnson, 1997). Hot water treatment at 53°C for 9 min is suitable for banana in terms of weight loss, color, firmness, soluble solid, sugar, and β-carotene. However, thermal treatment at 57°C significantly affects the shelf life of banana because it causes burning of skin and damage of tissues (Amin and Hossain, 2012).

In the Philippines, most exporters use hot water treatment

Table 5. Maintenance guides for tropical fruits

Fruits	Pre-cooling Conditions	Optimum Storage Conditions	Chilling Sensitivity	Respiration Rates	Shelf life in room days
Papaya	Room cooling, forced-air cooling, Hydro-cooling and rapid cooling	7°C to 13°C (45°F to 55°F) with 90 to 95% relative humidity	After 14 days at 5°C	70 to 90 mg CO_2 $kg^{-1}h^{-1}$ at 20°C during ripening	4–7
Pineapple	Room cooling or forced-air cooling	7°C to 12°C and 85% to 95% relative humidity	Develop after fruits are returned to physiological temperatures of 15°C to 30°C	19 to 29 mg CO_2 $kg^{-1}h^{-1}$ at 20°C	3–7
Durian	Forced-air or room cooling to 15°C	15°C and 85% to 95% relative humidity	Stored at less than 15°C	80 to 450 mg CO_2 $kg^{-1}h^{-1}$ at 22°C	6–10
Mangosteen	Room cooling	12°C to 14°C with 85% to 90% relative humidity	Less than 10°C (50°F) for more than 15 days	21 mg CO_2 $kg^{-1}h^{-1}$ at 25°C	7–10
Longan	Room or forced-air cooling	7°C to 9°C at 90% to 95% relative humidity	Less than 5°C	30.0 to 53.0 mg CO_2 $kg^{-1}h^{-1}$ at 20°C	3–5
Rambutan	Room cooling	8°C to 15°C with 90% to 95% relative humidity	Less than 5°C	40 to 100 mg CO_2 $kg^{-1}h^{-1}$ at 25°C	3–5
Dragon Fruit	Room cooling and hydro-cooling are possible	10°C and 90% to 95% relative humidity	Less than 6°C	95 to 144 mg CO_2 $kg^{-1}h^{-1}$ at 20°C	4–8
Banana	Room or forced-air cooling	13°C–14°C at 90% to 95% relative humidity	Below 13°C for a few hours to a few days	20-70 ml CO_2 $kg^{-1}h^{-1}$ at 20°C	7–10
Mango	forced-air or room cooling	10°C to 13°C with 85% to 90% relative humidity	Below 10°C	75 to 151 mg CO_2 $kg^{-1}h^{-1}$ at 20°C	5–7

Reference: Publication of Paull, R. E. (2014) for each tropical fruit.

for harvested mangoes; they dip fresh mangoes in hot water (52~55°C) for approximately 10 min. This treatment reduces the incidence of anthracnose and stem-end rot by 10%, resulting in almost a 100% recovery rate and an increase in sales and income (Aveno and Excelsis, 2010). Kumah et al. (2011) reported that hot water treatment at 52°C for 5 min was the best treatment for controlling anthracnose in Keitt mangoes during 21 days of storage. Thermal treatment is suitable for tropical fruits because tropical fruits tolerate heat well (Mansour et al., 2006). Furthermore, thermal treatment is more effective if it is combined with other treatments such as storage in low temperatures.

Packaging technologies

In Thailand, fresh tropical fruits such as avocadoes, mangoes, and oranges are generally packaged in plastic crates, plastic bags, or corrugated paper boxes. They are easily handled throughout distribution and marketing by minimizing the impact of rough handling and protecting the fruits from microbial contamination and transport damage. Often, the fruits are transported in an unpackaged form. Development of packaging suited for the handling of fresh produce requires an understanding of the physiological characteristics of the produce that exert significant impacts on shelf life (Opara and Mditshwa, 2013).

Plastic material used in the bagging of fresh produce is unsuitable owing to poor moisture and gas permeability. This often leads to condensation, high CO_2 levels, and low O_2 levels in the bagged produce and results in flavor deterioration and fermentation or failure of the fruit to ripen (El-Ramady et al., 2015). Thus, low-density polyethylene film is generally used for the packaging of fresh fruits and vegetables because of its high permeability and softness. Polyethylene that can be easily sealed has good permeability, low temperature durability, good tear resistance, and good appearance. This film is, therefore, used for the production of modified atmosphere packaging (MAP), which can be manipulated to match the characteristic respiration of produce by reducing O_2 levels in order to slow down the respiration rate, metabolic rate, and senescence of the produce (Sirivatanapa, 2006). For fresh fruits with a high respiratory rate, the packaging should have sufficiently large openings to allow gas exchange.

Recent success in using MAP for transportation by sea was observed in export from Manila to Japan. Bananas have 5~7 days of shelf life when stored at room temperature; however, the shelf life can be extended by up to 45 days when stored at low temperatures (13~14°C) by using MAP (Sirivatanapa, 2006). MAP is necessary for achieving better quality of particular packed products to eliminate factors responsible for a high rate of deterioration (Jong and Jongbloed, 2004). Sterilized or properly cleaned packaging can also help in enhancing fruit quality and preventing excessive respiration of the packed fruits.

Controlled atmosphere

Controlled atmosphere (CA) treatment refers to the best combination of gases for extending the shelf life of fruits within the manipulated levels of CO_2, O_2, N_2, and ethylene during storage. The composition of the gases are determined depending on the type of tropical fruit. Important factors for extending the shelf life are high CO_2 content and low O_2 content (Tripathi et al., 2013). To optimize the benefits of CA, other methods such as low temperature storage and irradiation treatment are needed to prevent decay and extend the shelf life of the fruits (Spadaro et al., 2002). MAP and CA packaging can be simultaneously used. MAP creates a steady atmosphere of O_2 and CO_2 around the produce, while CA provides an optimum atmosphere of O_2 and CO_2 around the packaged produce.

Sirivantanapa (2006) has reported that the shelf life of mangoes transported at low temperatures in the CA storage system with 3~5% O_2 and 5~8% CO_2 at 10°C by using MAP was extended by up to 20 days, when compared with the 5~7 days for the control fruits. The beneficial effects of CA and MAP are prolonged storability of fresh fruits by arresting respiration and senescence, reducing ethylene biosynthesis and sensitivity of produce, decreasing decay, and controlling fungi, bacteria, and pests in the selected commodities. However, when used incorrectly, the potential harmful effects of CA and MAP are aggravation of physiological disorders, abnormal ripening, and development of off-flavor due to fermentation and susceptibility to decay. The high cost for the controlled atmosphere makes this treatment difficult to apply in most Southeast Asian countries.

Edible coating

The main objectives of surface coating on fruits are to reduce water evaporation from the fruits and thereby slow down weight loss, which ultimately extends the shelf life of the fruits. Surface coating reduces weight loss of avocado by up to 50%, depending upon coating type and concentration (Banks et al., 1997). Hu et al. (2011) has reported that wax coating of pineapple during cold storage is more effective in alleviating chilling injury and delays changes in firmness, flesh color, weight loss, and deterioration in quality. However, use of wax coatings for this purpose is a high-risk strategy. When respiratory gas exchange through fruit skin is excessively impaired, fruit fermentation may occur (Banks et al., 1997). This risk can be minimized through the selection of coatings with appropriate permeability characteristics.

Edible coatings are one of the most innovative and eco-friendly strategies for extending the shelf life of fruits and vegetables; such coatings act as barriers to gas transport and produce similar effects to storage in a controlled atmosphere (Cerqueira et al., 2009). Edible coatings are usually made from materials such as proteins, lipids, and polysaccharides; the main polysaccharides used are starches and modified starches, cellulose derivatives, chitosan, pectin, alginate, and other gums (Soarez et al., 2011). Thin edible films act as barriers to external elements (such as moisture, lipids, and gases) and improve mechanical properties during handling and transportation. They may also serve as food additive carriers such as anti-browning agents, colorants, flavors, nutrient, spices, and anti-microbial compounds that can extend shelf life and reduce the risk of pathogen growth on fruit surfaces (Sheikh et al, 2013).

Jiang and Li (2001) have reported that the coating treatment in concentrations of 0.5%, 1%, and 2% for longan fruits during storage at 2°C and 90% relative humidity is effective for reducing respiration rate, pathogen growth, and weight loss by increasing the concentration of chitosan coating and that it enhances the beneficial effects of chitosan on postharvest life and quality. An edible coating, compared to MAP in terms of extending the quality and shelf life of fruits, is beneficial for the fresh fruit industry as well as the retail market and consumer (Fuchs et al., 2008). A combination of chitosan coating and 1-MCP prolongs the storage life of mangoes by up to 29 days after storage at 10°C, which is significantly longer than a single treatment and control (Wingmetha and Ke, 2012). *Aloe vera* application for papayas during low temperature storage has yielded good results, and it enhances the storage and quality maintenance of the fruits (Marpudi et al., 2011).

Future Approach

Current issues of postharvest development are focused on eco-friendly treatment to reduce the use of chemicals for extending the shelf life of fresh fruits. Fruits should be free from microbial toxins and pesticide residues. Consumers are becoming increasingly conscious of the health and nutritional benefits of foods, and there is an increasing tendency to avoid the consumption of chemically treated foods (Kumah et al., 2011). Irradiation is a physical treatment of exposing food to a defined dose of ionizing radiation. It is now used in more than 40 countries worldwide for fresh fruit sterilization. Irradiation can control insect infestation, reduce the number of pathogenic or spoilage microorganisms, and delay or eliminate natural biological processes such as ripening, germination, or sprouting in fresh food (Nissen, 2014). Like all preservation methods, irradiation supplements rather than replaces good food hygiene, handling, and preparation practices (Follett and Weinart, 2012).

Radiant energy electron beams such as UV rays, gamma rays, and infrared are used as radiation sources. UV-C treatment using a wavelength between 190 and 280 nm is effective in controlling microbial growth on the surface of fresh produce, and it is used in the postharvest handling of some fruits. Application of a low dose of UV-C light reduces postharvest decay in horticulture crops such as onion, sweet potato, apple, peach, citrus fruits, bell pepper, tomato, carrot, and strawberry. The problem of irradiation technology is the use of gamma irradiation to increase shelf life. Higher doses cause excessive softening of the flesh. A low dose of gamma irradiation increases shelf life; however, it reduces the levels of ascorbic acid. Fruit commodities must be able to tolerate the doses of irradiation required to achieve disease control. The optimum dose of irradiation for different fruits varies depending on the nature of the commodity, and some fruits are surprisingly tolerant.

Conclusion

Southeast Asian countries need postharvest technologies to extend the shelf life of fresh fruits to increase export. With a long shelf life, the international tropical fruit trade can be expanded in Southeast Asia, contributing to national income growth and prosperity. Southeast Asian countries

Table 6. Technologies and their applicability for each tropical fruit

Fruits	Cold storage	Heat Treatment	Packaging	CA	MAP	Coating	Irradiation
Mango	o	o	o	o	o	o	X
Mangosteen	o*	o	o	v	x	x	X
Banana	o	o	o	o	o	x	X
Pineapple	o*	o	o	o	o	x	V
Rambutan	o	o	o	o	x	v	X
Melons	o	v	o	o	x	v	V
Durian	o*	v	o	o	v	o	V
Papaya	o	o	o	o	o	o	X
Starfruit	o	v	o	o	x	x	X
Longan	o	x	o	o	x	x	X
Dragon fruit	o	o	o	o	v	v	V

o = capable; x= research scale; v= no research available; *=sensitive (chilling injury/damage)

Table 7. Available technologies based on the factors for extending shelf life

Factors	Main problems	Technologies available	Technologies and information needed
Natural Properties	Physiological activities like respiration and transpiration	Coating, packaging, MAP, CA	Type of coating materials, cost, fermentation risks
External condition	High temperature and relative humidity	Cool storage, CA, MAP	Chilling injury, fermentation risks, cost, temperature, relative humidity, CO_2, O_2 requirement for some produce, physiological disorders, and alternate storage methods
Disease and microbial contamination	Tropical climate is the host for microorganisms and disease	Pre-cooling, heat treatment, irradiation, MAP, coating	Physical treatments, non-chemical treatments, adaptation of available technology, fruit sensitivity
Handling methods	Improper postharvest handling, resulting in bruise and damage	Packaging	Type of retail pack, improve package performance

face a big challenge in developing tropical fruit productivity and need to develop postharvest technologies. New postharvest technologies with rich natural resources are currently being developed. The main objectives of postharvest technologies are to prevent deterioration in produce quality along the postharvest chain and ensure the maximum quality value for tropical fresh fruits.

Efforts of Southeast Asian countries to reduce postharvest losses through postharvest technologies such as cooling chain, packaging, hot treatment, and coating do not yet appear to have resulted in an increase in tropical fruit productivity. Furthermore, not all these treatments can be applied to tropical fruits because of the complicated characteristics of tropical fruits. Table 6 shows which postharvest technology was established for individual tropical fruits. In Table 7, growth conditions, status, and development of shelf life technology for each fruit in Southeast Asia have been summarized. Current issues in postharvest development are focused on eco-friendly treatment to reduce chemical use in extending the shelf life of fresh fruits. Combination treatments are more effective than single treatments because each treatment has its inherent drawbacks. Thus, combination treatments have great potential for producing the best result for extending the shelf life of fruits.

Conflict of Interest

The authors have no conflicting financial or other interests.

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