EFFECT OF STORAGE TEMPERATURE AND DURATION ON PHYSICO-CHEMICAL PROPERTIES, MICROBIAL GROWTH AND NUTRITIONAL COMPOSITION OF PAPAYA AND BANANA FRUITS

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In the name of Allah, Most Gracious, Most Merciful
All praise and thanks are due to Allah Almighty and peace and
blessings be upon His Messenger

The results of this effort are truly dedicated to my mother and father whose
example as devoted professionals, as well as, parents taught
me to be perseverant, responsible and loyal
to my belief.

To my brothers, and sisters, and my best friend for all their support, encouragement,
sacrifice, and especially for their love.

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ABSTRACT

Banana (*Musa sp.*) and papaya (*Carica papaya*) cultivars were harvested and stored for a month at different storage temperatures and durations. These fruits were collected from an orchard which located in Johor Bahru, Malaysia. Ripening in undesired period, change skin color, weight loss, fruits quality loss such as nutrition, high microorganisms infestation rate and fruit damage due to improper storage. The fruits were stored at different durations (0, 3, 6, 14, 30 days) and at varying storage temperatures (4 ±1, 10±2, 30±3 ºC). The color changing, weight loss, total polysaccharide and protein, total soluble sugar (TSS), titratable acidity (TA), pH, free phenolic content (FPC) and microbial growth were determined. The results revealed that parameters were significantly affected by temperature and time. For instance, banana polysaccharide was 20 at 4 ºC, 20 at 10 ºC and 16 mg/L at 30 ºC , banana protein was 1155 at 4 ºC, 1315 at 10 ºC and 1640 at 30 ºC, total soluble sugar was 6.8 at 4 ºC, 7.9 at 10 ºC and 8.2 at 30 ºC, banana pH was 4.8 at 4 ºC, 4.8 at 10 ºC and 5.9 at 30 ºC, papaya free phenolic content (FPC) was 184 at 4 ºC, 245 and 569 mg/L at 30 ºC, and papaya weight loss was 7 at 4 ºC, 15 at 10 ºC and 65% at 30 ºC. However, it was not changed at cold storages prolonged storage period. In addition, the banana peel color was affected by browning and chilling injury into cold storages. Moreover, during storage, total soluble sugar (TSS), total polysaccharide, titratable acidity (TA) and free phenolic content (FPC) increased during cold storage. However, pH, microbial growth, weight and protein estimation whereas decreased during cold storage. In conclusion, according to the obtained results, the optimum storage temperature and duration for banana were found to be 4 °C and 14 days and one month for papaya fruit. The overall findings of this research might be able to provide science-based management tools for the storage performance of banana and papaya fruits.

ABSTRAK

Kultivar pisang (*Musa sp.*) dan betik (*Carica papaya*) dituai dan disimpan selama sebulan pada suhu penyimpanan dan jangka masa berbeza. Buah-buahan ini diambil daripada kebun yang terletak di Johor Bahru, Malaysia. Masak dalam tempoh yang tidak diingini, perubahan warna kulit, penurunan berat, buah-buahan kehilangan kualiti seperti nutrisi, kadar serangan mikroorganisma tinggi, dan kerosakan buah-buahan kerana cara penyimpanan tidak wajar. Buah-buahan itu disimpan pada jangka masa berbeza (0, 3, 6, 14, 30, hari) dan pelbagai suhu penyimpanan (4 ±1, 10±2, 30±3 °C). Perubahan warna, kehilangan berat, jumlah polisakarida dan protein, jumlah gula larut (TSS), keasidan boleh titrat (TA), pH, kandungan bebas fenol (FPC) dan pertumbuhan mikrob ditentukan. Keputusan menunjukkan parameter tersebut dipengaruhi dengan ketara oleh suhu dan masa. Contohnya, polisakarida pisang adalah 20 mg/L pada 4°C, 20 mg/L pada 10°C, dan 16 mg/L pada 30°C, protein pisang adalah 1155 pada 4°C, 1315 pada 10°C, dan 1640 pada 30°C, jumlah gula larut adalah 6.8 pada 4°C, 7.9 pada 10°C, dan 8.2 pada 30°C, pH pisang adalah 4.8 pada 4°C, 4.8 pada 10°C, dan 5.9 pada 30°C, kandungan bebas fenol betik (FPC) adalah 184 pada 4°C, 245 pada 10°C dan 569 mg/L pada 30°C, dan kehilangan berat betik adalah 7 pada 4°C, 15 pada 10°C dan 65% pada 30°C. Warna betik tidak berubah pada jangka masa penyimpanan yang panjang penyimpanan sejuk. Di samping itu, warna kulit pisang terjejas akibat pemerangan dan kecederaan pendinginan ke dalam penyimpanan sejuk. Selain itu, semasa penyimpanan, jumlah gula larut, (TSS), jumlah polisakarida, keasidan boleh titrat (TA), dan kandungan bebas fenol (FPC) meningkat semasa penyimpanan sejuk. Tambahan lagi, pH, pertumbuhan mikrob, berat, dan anggaran protein pula meningkat semasa penyimpanan sejuk. Kesimpulannya, berdasarkan keputusan yang diperoleh, suhu dan jangka masa penyimpanan optimum untuk pisang didapati pada 4°C dan 14 hari dan sebulan untuk buah betik. Dapatan keseluruhan kajian ini boleh menyediakan alat pengurusan berasaskan sains untuk prestasi penyimpanan buah pisang dan betik.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

1.1.1 Papaya

Papaya (*Carica papaya* L.) belongs to Caricaceae family (Williams, 2005). It is common in central and northern South America (Whipkey *et al.*, 1999; Williams, 2005). There are about sixty countries produce papaya. The total world production of papaya in 2013 (Fact fish, 2015) has been evaluated at 12.419 million tons and 11.22 million tons in 2010. The leading papaya producing region is considered Asia. Therefore, the world production has been assessed between 2008 and 2010. So, the Asia, South America, Africa, Central America, Caribbean, North America and Oceania produced about 52.55%, 23.09%,13.16%, 9.56%, 1.38%, 0.14%, 0.13% of the global production respectively (Evans and Ballen, 2012). The fruit may be ripe when it becomes soft and its skin attains amber to orange hue. Scientific evidence has mentioned that papaya improves human health as a result of bioactive compounds such as phenolic compounds that have potent pharmacological activities, including, anti-mutagenic, antioxidant, anti-inflammatory, anti-hypertension activities anti-fungi and anti-virus (da Silva *et al.*, 2007; Nishijima *et al.*, 1987;

Parris, 1938; Evans and Ballen, 2012). Consequently, the consumption of papaya is increased.

The consumption of papaya fruit in the market are largely restricted to the its quality. The lack of appropriate postharvest technology such as storage conditions may effect on fruits demand. Postharvest handling practices which include packaging and postharvest conditions such as temperature control may be used to keep the fruit quality to prolong storage periods (Rivera-Lopez *et al.*, 2005). Storage temperature is one of the very important environmental factors that affect postharvest life of fresh fruit. The temperature regulates the rate of all associated physiological processes, microbial growth and biochemical reactions (Li and Kader, 1989). Many reports have shown that physico-chemical, physiological, phytochemical, mechanical, sensory qualities and microbial properties of papaya fruits are influenced by packaging, storage temperature, and atmospheric conditions (Williams, 2005). The papaya is very popular worldwide. Furthermore, it is mainly cultivated in tropical countries. Therefore, many non-tropical countries import papaya from Malaysia and other tropical countries. The fruit may be stored at temperatures below 10 °C to extend the marketing value (Azarkan *et al.*, 2003).

The metabolism of mineral nutrients in the plants is influenced by temperature. For instance, the increasing of the transpiration rates in the plants is due to increasing of the environment temperature. The low temperature that less than 10 °C may decreases fruit development, sweetness, and size of papaya. It also influences flower and fruit setting. For instance, stamen carpellody occurs at low temperatures. Therefore, the fruits that develop under the carpellody are severely misshapen and unmarketable (Gonzalez-Aguilar *et al.*, 2003). At higher temperatures that more than 35 °C, there is a tendency of bisexual cultivars to form functional male flowers with poorly developed and non-functional female parts. This tendency may vary with cultivars. Previous study indicated that fluctuating temperatures may cause to reject the amount papaya. In addition, high and low temperature is often encountered for few hours during fruits handling operations (Nunes *et al.*, 2006).

1.1.2 Banana

Banana fruits are produced in tropical and subtropical areas in large quantities. Banana is globally important as a food crop because it is the staple food for millions of people worldwide (Sagi *et al*., 1995). The previous study reported that world production of *Musa* in 2003 was estimated at 102 million tons of which about 68% was classified as bananas and 32% as plantains (Fao and Foods, 2004). The crop of banana is very important for the human being in the growing areas that it forms a major portion of the annual income and a source of food. Production, as well as exports and imports of bananas are highly concentrated in a many countries. Ecuador, India, Brazil and China are considered the major banana-producing countries of total global production which reached about 75% in 2003. Furthermore, Latin America and the Caribbean islands are the major suppliers of banana. Malaysia, Costa Rica, Ecuador, the Philippines and Colombia are exporters countries of banana (Fao and Foods, 2004). There are four common banana cultivars widely grown in all regions in Malaysia. These cultivars are Mas (AA), Embun (AAA), Rastali (AAB) and Berangan (AAA) (Abdullah, *et al.*, 1990). The bananas are exported to Singapore and Brunei Darussalam by loading onto open conventional trucks at ambient temperature (Ratule *et al.*, 2006).

Banana is one of the sixteen fruit types that have been identified by the Malaysian Ministry of Agriculture as having commercial potential either as fresh or processed fruit. Banana is a great economic importance in the moister areas of tropical agriculture and it is an important fruit crop in Malaysia as well. Banana is a soil conservative, productive, and non-seasonal fruits. It is sweet fruits which contains staple starch and other nutrition. In addition, there are some useful secondary products such as fibers, beverage, dyes, cordage and wrappings materials. The commercial plantations are consider revenues from exporting bananas (Noor, 2002).

Banana is a general term including a number of species in the genus *Musa* of the family *Musaceae*. There are two species in the section *Musa* which are *M. acuminate* and *M. balbisiana*. These cultivars are considered diploid that contain two sets of chromosomes. Therefore, the classification of *M. acuminate* and *M. balbisiana* are AA and BB groups respectively. In addition, *M. acuminate* and *M.*

balbisiana are edible bananas (Ortiz *et al.*, 1998; Robinso, 1996; Zhang *et al.*, 2005). *M. acuminate* developed primarily in tropical of Southeast Asia. Consequently, *Musa acuminata* (AA group) has been selected in this research.

Banana is considered very important for human diets. So, the quality of this fruit can significantly affect consumer appeal, handling practice, storage potential, and market selection. In addition, the ripening changes of banana might be influenced by storage temperature. It has been reported that the storage temperature of 16 °C to 18 °C may be the better commercial ripening of banana (Ahmad, *et al*. 2006). Therefore, the control of the ripening temperature is important to obtain the best quality fruit within in specific marketable life.

1.2 Problem Statement

The cultivar Papaya (*Carica papaya* L.) and Banana (*Musa acuminate*) are the widely grown in Malaysia. Malaysian fruits industry encounters problems in quality losses after storage of banana and papaya fruits due to the lack of knowledge on optimal storage during different durations. These issues such as weight loss, fruit ripening at shipping or storage periods which is attributed to temperature (Workneh *et al.,* 2012), fruit damage, loss of fruits quality such as nutrition, peel color, browning as well as microorganisms infestation (Gayosso-García *et al.*, 2010) which cause to become unhealthy food. Consequently, papaya and banana cultivars may be exposed to harmful bacteria and other contaminants prolonged storage periods as a result of inappropriate storage conditions. Therefore, the fruits can become a source of pathogens food. So, the contaminated fruit cannot be healthy food and cause diseases to human body. To date, there is currently limited scientific knowledge on the storage requirements to keep the high quality of (banana and papaya) fruits. The storage conditions are not convenient yet to guarantee the continuous supply of fresh and healthy fruits of acceptable standards to national and international markets. The storage conditions must be convenient to guarantee the continuous supply of fresh and healthy fruits of acceptable standards to national and international markets. The papaya and banana must be in good quality and good condition at market. In other words, the fruits must be not over ripening, high rate of chilling injury, damage, infested fruits.

In addition, the fruits taste, texture and appearance may suffer as well. The fruits may lose their pharmaceutical properties and nutrition such a proteins, sugar, phenolics which are considered antioxidant compounds as a result of spoilage. In the current time, many diseases have been globally increasing. As a result of this, the consumption of fruits has been increased by human being because the research studies referring that fruits may help prevent particular sorts of illnesses, due to their potentially high antioxidant properties (Gayosso-García, *et al.*, 2010). Consequently, it is necessary to indicate that if fruit storage conditions are not convenience, metabolism accelerates and could exhaust its energetic reserves, resulting in the loss of nutritional value of the fruit (Gonzalez-Aguilar *et al.,* 2009; Gayosso-García, *et al.*, 2010). In this case, the technology of postharvest is essentially required to reserve the harvested fruits otherwise, the rate of deterioration of this produce might be augmented. Furthermore, the fruits cannot be satisfactory to customers which leads to reduce salesman income.

To develop quality standards for the export market, the knowledge of the optimum storage conditions are required to get more understanding of postharvest quality improves and consumer organoleptic perceptions. The Malaysian Papaya (*Carica papaya* L.) and Banana (*Musa acuminate*) industries are currently classed with fruit quality loss as a result of inappropriate storage. Currently, there has been a little scientific information on the storage requirements for the Malaysian *Papaya (Carica papaya L.)* and Banana (*Musa acuminate*). These fruits have been selected for this research because high rate of papaya and banana consumption at market (Fao and Foods, 2004; Ratule *et al.*, 2006). In order to take full support of the existing export market. Therefore, this study focused on storage to find out the optimum storage conditions for papaya and banana fruits.

1.3 Objectives of Research

The objectives of the study are as follows:

1. To evaluate papaya and banana fruits physico-chemical properties (weight loss, peel color), (TSS, TA, PH, TSS:TA, FPC), total polysaccharide and total protein content responses under different temperatures of storage and durations.
2. To evaluate the effect of temperature and storage period on the microbial growth in papaya and banana fruits.
3. To recommend the optimum storage conditions for papaya and banana fruits in tropical setting.

1.4 Scope of the Study

The domestic papaya and banana cultivars fruits are considered a common food in Malaysia. So, these fruits has been subjected to experimental evaluation in this research. Therefore, the scope of this research is to study the effects of different storage temperatures of 4 ±1, 10±2, 30±3 °C and durations of 0, 3, 6, 14, 30 days on physico-chemical properties of papaya and banana such as skin color of fruits, weight loss, soluble sugar, titratable acidity, pH, total soluble sugar to titratable acidity ratio and total phenolic concentration. In addition, the experiments has been conducted to evaluate the effectiveness of temperatures of 4 ±1, 10±2, 30±3 ºC and durations of 0, 3, 6, 14, 30 days on the total polysaccharide concentration and total protein content. The ambient conditions was selected because fruits are sold at most markets in this conditions and 4 and 10 °C were selected because this range have been tested for other foods in the previous studies. Furthermore, one of the most important study is the microorganisms contamination such as bacteria and fungus growth which has been investigated and correlated it to the temperatures of 4 ±1, 10±2, 30±3 °C and periods of 0, 3, 6, 14, 30 days.

1.5 Significance of the study

This study has focused on some factors that may have effectiveness such as temperature and time on the papaya and banana fruits into the storage. The deterioration of the food in the storage is an indicator to the responsible competent authorities to take into consideration the temperature and storage period and find out the best resolution to protect the stored products against deterioration, harmful bacteria, fungi, which cause diseases to human body as well as loss of quality and weight during storage and transportation.

Papaya and banana are considered nutritious fruits and consumed widely and particularly throughout tropical regions. Therefore, the accomplishment of this research would greatly contribute into the research community. The outcome of this research might provide a further insight into the stored papaya and banana fruits. Good comprehension study on total polysaccharide, protein estimation, total soluble sugar, titratable acidity (TA), pH, total phenolic content (FPC), fruits weight and microbial growth needed, consequently, it may improve this research approach on these parameters prolonged storage period and enable the authors to add more information to find out the convenient storage conditions. Extensive research on stored papaya and banana fruits can improve the probability of this study into a full scale large quantities of banana and papaya application in a near future in Malaysia.

Consequently, this significance of evaluation of total polysaccharide, protein estimation, total soluble sugar, titratable acidity (TA), pH, free phenolic content (FPC), fruits weight and microbial growth will surely become a factor of attraction in implementation in order to reduce losses, clean, fresh quality hygienic produce providing customer satisfaction, increase sale and increase farmer income which leads to improve marketing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Papaya (*Carica papaya* L.) and Banana (*Musa acuminata*) are a tropical crops that capable to grow in different soil types (Sagnia *et al.*, 2014; Sahaa *et al.*, 2013). The commercial farming of papaya and banana fruit significantly increases, because it has multifunctional and nutritional benefit in the human diet, satisfying the medicinal of consumers in many countries (Finkel, 2003; Floyd, 1990; L. Huang *et al.*, 2011; S.-S. Huang *et al.*, 2013; Kumar *et al.*, 2012; Morris *et al.*, 2013; C. Rao *et al.*, 2007; Sripanidkulchai *et al.*, 2001; Valko *et al.*, 2007; Valko *et al.*, 2006). Therefore, the requirements are necessary for development of optimum postharvest storage conditions for papaya and banana. The literature review discussed the past and current knowledge on the effects of storage duration and temperature on sensory properties, nutritional composition and microbial growth of papaya and banana.

2.2 Papaya

Papaya is a fast growing tree that may reach three to ten meters high. It has only one stem without branches at initial growth. Some new shoots appear after about one year at the lower trunk and some branches may grow (Jiménez *et al.*, 2014). Figure 2.1 shows the papaya tree and fruits. The mass of leaves at the apex and along the top of the stem. The leaves are about fifty (50) to seventy (70) centimeter in diameter, deeply palmate lobed, with about seven to eleven lobes. The leaves contain white milk latex. Papaya flowers appear in the axils of leaves. The fruit is ripe when it feels soft and its skin has attained an amber to orange hue (Gross *et al*., 2014; Nakasone and Paull, 1998).

Figure 2.1: Papaya tree and fruit (Jiménez *et al.,* 2014)

2.2.1 Papaya Maturity

The papaya fruits maturity can be determined by property of texture which include some characteristics such as firmness, color and latex. In addition, the taste of papaya can be one of the properties that determines the maturity of it. For example, sweetness, acidity and total soluble solid (TSS) (Basulto *et al*., 2009).

2.2.2 Skin Color of Papaya Fruits

The skin color of papaya can be used to determine its maturity. Figure 2.2 shows different stages of maturity papaya. These stages are classified by the skin color of papayas. Figure 2.2 (a1) and (a2) depict green skin without yellow stripe; pulp very hard and white in color; seeds well-formed but white or slightly dark in color. Figure 2.2 (b1) and (b2) show green skin with a light yellow stripe; pulp exhibits some areas with orange color, is very hard and contains large amounts of latex. Figure 2.2 (c1) and (c2) show green skin with well-defined yellow stripe; pulp is orange in color near seed cavity and light green near skin, although still hard and with large amounts of latex. Figure 2.2 (d1) and (d2) demonstrate one or more orange-colored stripes in skin; pulp almost completely orange in color, except near skin, still hard but contains less latex. Figure 2.2 (e1) and (e2) show skin clearly orange in color with some light green areas; pulp completely orange, except near peduncle, softer than in stage 3, but still too hard for consumption, low latex content. Figure 2.2 (f1) and (f2) show skin displays orange color characteristic of Maradol variety; pulp firmness appropriate for consumption, latex no longer present. Figure 2.2 (g1) and (g2) depict the conditions similar to stage 5, but with more intense orange color in skin and softer pulp still adequate for consumption (Basulto *et al*., 2009).

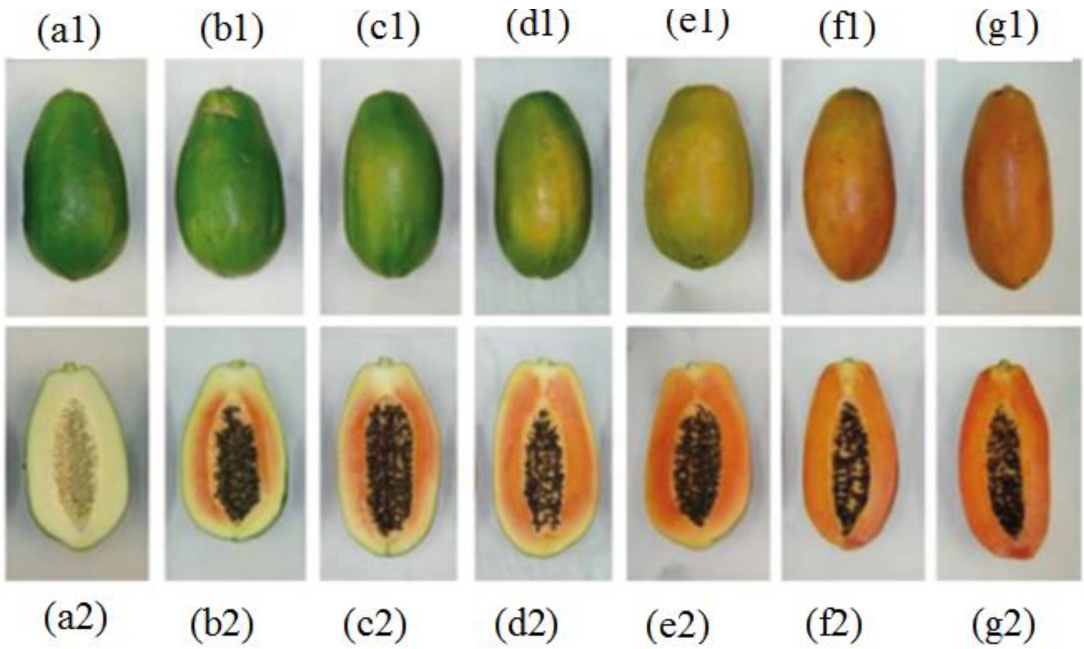

Figure 2.2: Papayas maturity stage description (Basulto *et al*., 2009)

2.3 Banana

The word banana is a general term embracing a number of species or hybrids in the genus *Musa* of the family *Musaceae* (Zhang *et al.*, 2005). Banana cultivars are yellow when it is ripe. Consequently, the ripe banana may be damaged and lost its quality during transportation from farm to the market. Banana is one of important foods that source of energy, mineral salts and vitamins. Furthermore, sensorial attributes of the banana, as flavor, taste, texture, and color, are significantly influenced by its chemical composition, especially by acids, sugars, and phenolic compounds (Carvalho *et al.*, 2009).

The potential life of fruit after harvest depends on factors such as maturity, care and storage conditions (airflow and temperature). Several pre-harvest parameters may indeed contribute to successful development of good quality fruit and vegetables. Agricultural practices, soil, climate and harvesting conditions all affect the banana. The disease effectiveness such as *Fusarium* wilts and damages banana leafs (Jamaluddin, 2000). Usually, such disease outbreaks in bananas which associated with the presence of plant-parasitic nematodes in the cultivation areas, as nematode infection in turn predisposes plants to fungal pathogen infections as well (Rahman *et al*., 2008).

2.3.1 Ripening Process of Musa sp.

The composite of the processes that occur from the last stage of growth of fruit and development through the early stages of senescence is called ripening process (Johnson, 2009). The process will results in characteristic visual fruit quality. It can be changed in composition, color, texture, or other sensory attributes (Johnson, 2009). Figure 2.3 shows the banana's ripening stages.

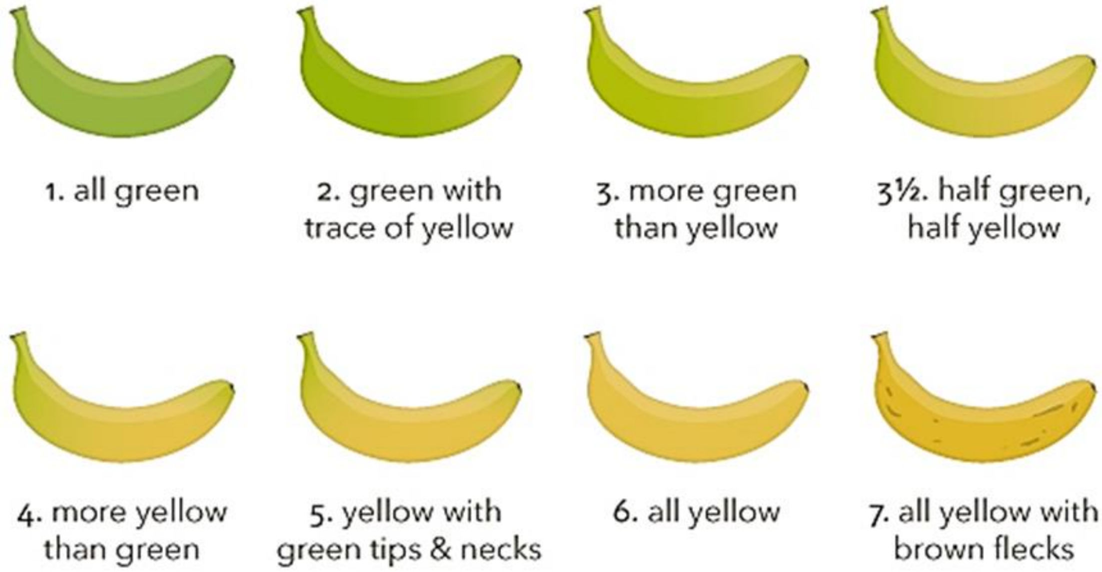

Figure 2.3: Banana ripening (adapted from Chiquita Brands International web)

Furthermore, banana fruit is hard and green at the harvested time. Therefore, the banana fruit needs few days for onset of ripening. In addition, the products progressively soften, change color and develop aroma at a certain rate into the storage.

Consequently, the fruit is picked, treated, packed and transported while it is hard and green. It arrives at retail markets at some predetermined stage of color development. The rate at which ripening will occur under particular storage conditions depends upon the stage of ontogeny at harvest. More mature fruit will ripen more rapidly than less mature fruit. The ripening schedules were customarily five to eight days from date of delivery of bananas to the ripening rooms (Johnson, 2009). The temperature is maintained inside the ripening room in the range of 16 to 18 °C. Consequently, the bananas do not overheat and spoil at delivery time (Johnson, 2009).

2.4 Effect of Temperature on Fruits

Banana fruit is cultivated in large areas of tropical countries. The optimum fruit ripening temperature is about 20 °C (Ahmad *et al.,* 2001). Growth ceases at 10 °C and can lead to disorders and poor fruit development occurs (Nelson *et al.,* 2006; Abuhamra *et al*., 2016). Temperatures slightly above 30 °C may cause extensive heat damage. At temperatures above 37 °C, growth cessations will occur (Nelson *et al.,* 2006). These temperatures effect the quality of harvested products during storage. However, the lower temperatures can lead to chilling injury. In addition, the banana fruit may be susceptible to chilling injury below temperature of 13 to 14 °C (Nelson *et al*., 2006; Ahmad *et al.,* 2001; Facundo *et al.,* 2015). The chilling injury is characterized by changes in the fruit ripening physiology and the appearance of brown spots in the pulp and dark spots in the skin. Similarly, the most favorable temperature for papaya growth is ranged from 21 °C to 33 °C (Chan, 2009; Nakasone and Paull, 1998). Papaya is significantly sensitive to frost. Therefore, the growth and production of papaya may be affected when temperature falls below 12 to 14 °C for several hours (Chan, 2009; Nakasone and Paull, 1998). Consequently, this indicates that temperature plays a role in a ripening that can influence the physical banana and papaya during ripening process. The Keitt, Kent and Ataulfo mango have been stored at 5 °C to investigate the browning, decay and to extend shelf life for 21 days. Therefore, the results shown a reduction of browning and deterioration in during storage at this condition (Gonzalez-Aguilar *et al.*, 2008). In adiition. The antioxidant capacity, total anthocyanins, total phenolics and postharvest quality of strawberry fruit stored at 0 °C, 5 °C, and 10 °C have been investigated for

0, 5, 7, 11, and 13 days after harvest. The obtained results shown higher antioxidant capacity, total phenolics, and anthocyanins at 5 °C and 10 °C than those stored at 0 °C. However, the postharvest life based on overall quality such as decay, TSS, TA, pH, fruit color, and aroma compounds was longer at 0 °C than at 5 °C and 10 °C (Ayala-Zavala *et al.*, 2004).

2.5 Ethylene Production from Fruits

Ethylene gas (C_2H_4) is produced by many plant species. It is generated naturally by fruits metabolism. The plant release ethylene and diffuses quite quickly in the air. This gas may regulate fruits development and senescence. The production rate of ethylene can increase with ripening (Müller, 2000), physical injuries, disease occurrence caused by microorganisms such as bacterial and fungal which infect fruits (Müller, 2000) and increasing of temperatures as high as 30 °C (Aharoni, 2004; Irtwange, 2006). In contrast, there are some means can decrease the ethylene production rate such as cold storage, low oxygen concentration and reduction in carbon dioxide in the storage which lead to delay ripening stages (Aharoni, 2004; Ali, 2011; Irtwange, 2006) and increase the time of preservation of the produces (Lis *et al.*, 2000). In addition, climacteric fruits including banana and papaya that produce ethylene at high rate at onset of increasing in respiration rate (Irtwange, 2006).

2.6 Fruits Respiration

Carbone dioxide may be generated by utilizing oxygen throughout the respiration at atmospheric pressure. For instance, the chemical equation of the metabolic oxidation of glucose can be expressed as follows (Irtwange, 2006):

$$C_6H_{12}O_6 + 6O_2 \dashrightarrow 6CO_2 + 6H_2O + \text{Energy (heat)}. \quad (2.1)$$

Consequently, it can be found out from this process that the waste of stored food reserves such as glucose may be occurs because the energy is released as a heat as well as sweetness (Irtwange, 2006). Therefore, the organic substances in the stored fruits such as fats, carbohydrates and proteins can be degraded into simple compositions during respiration process which lead to release heat (energy). In this case, the technology of postharvest is essentially enfluenced by the harvested fruits as a result of deterioration rate of this produce which might be augmented along of storage period (Irtwange, 2006).

2.7 Benefits of Papaya and Banana Fruits

Many studies illustrated the contribution of the fresh quality hygienic fruits to reduce several diseases such as neurological, carcinogenic illnesses and cardiovascular (Sancho *et al.*, 2011). Papaya and banana are considered nutritious fruits and consumed widely and particularly throughout tropical regions. These cultivars can lower human body risk of many health conditions. For example, these fruits contain amount of antioxidant compounds including phenols which reduce the oxidative stress produced by free radicals that cause to damage the calls (Bico *et al.*, 2009; Zuhair *et al*., 2013). In addition, papaya contains many active compounds including papain, chymopapain, cystatin, α-tocopherol, ascorbic acid, flavonoids, cyanogenic glucosides and glucosinolates that can utilized as a pharmacological effects such as anti-inflammation, anti-platelet, anti-thrombotic, and antiallergic effects (Ming *et al*., 2012). Similarly, the banana has benefits such as neutralize the acidity of gastric juices, so reducing ulcer irritation by coating the lining of the stomach as well as promote healing and relieve painful (Kumar and Bhowmik, 2012). In contrast, the reduction protein level in the fruits can cause protein deficiency in mankind who usually depends on fruits as a stable food (Kumar and Bhowmik, 2012). Consequently, the both fruits have positive effects on general health preventing diseases, so these cultivars are considered as a pharmaceutical food.

2.8 Physico-Chemical Properties

Knowledge of the sensory properties of storage fruit such as color, flavor, sweetness, sourness and overall acceptance is essential for the product development, design and evaluation of the process equipment such as optimum temperature (Zuhair *et al.*, 2013; Vitali and Rao, 1984). Sensory measurements have also been considered as an analytical tool to provide fundamental insights on the structural organization of banana and papaya. Numerous studies have been conducted on the sensory properties of papaya and banana fruits (Ahmed *et al.*, 2002). Therefore sensory parameters of papaya and banana are required for research and engineering applications as design and optimization of cooling units. For example, the change in fruits peel color including increase of degree of browning and decrease of color values (Carvalho *et al.*, 2009), chilling injury occurrence which is considered physiological damages under cold storage conditions (Ratule *et al*., 2006).

Consequently, the sensory quality attributes of fruit play an important role in consumer satisfaction and repeated purchase (Alasalvar *et al.*, 2001; Almora *et al.*, 2004). Like other fruits, papaya and banana encounter postharvest quality losses during storage too. The quality assessment of papaya and banana fruits at harvest is based on a wide range of physico-chemical characteristics including fruit color and titritable acidity (Almora *et al.*, 2004; Choo and Aziz, 2010). The flavor sensation and aroma produced from non-volatile compounds generates a characteristic saltiness, sweetness, bitterness, sourness and pungent (Choo and Aziz, 2010).

2.8.1 pH and Titratable Acidity

Titratable acidity and pH in banana and papaya are different which depends on the cultivar, growing region, maturity at harvest and postharvest storage practices (Anyasi *et al.*, 2013). Non-volatile organic acids are form the major portion (80 to 90%) of total acidity in fruits. Citric and malic acids are the predominant acids, but tartaric, malonic, fumaric and succinic acids could also be present (Mitra, 1997). It has been observed that a slight increase in total acidity during ripening, which is believed to be associated with an increase in free galacturonic acid in papaya fruit (Workneh *et al.*, 2012). Furthermore, it has been reported an increase in total acidity of Solo papayas during twenty days of storage at ambient condition (Cámara *et al.*, 1993).

The pH of papaya pulp ranges from 4.55 to 5.9, and the total titratable acidity (TA) calculated as citric acid is 0.2 to 1.4% (Cámara *et al.*, 1993). There are about 80% of the titratable acidity (TA) of papaya which is made up of ascorbic acid which together with malic, citric and β-ketoglutaric acid. These acids make the total titratable acid (Paull *et al.*, 1999). Total volatile acids contribute 8% of the total titratable acidity. Malic and citric acid are formed in about equal amounts which being ten times more abundant than β-ketoglutaric acid, malonic acid, fumaric acid and succinic acid. Ascorbic acid of papaya quadruples during fruit ripening. It has been reported that ascorbic acid content of papayas increased 20 to 30% during ripening, independent of the maturity stages at harvest (Bron and Jacomino, 2006). In addition, the study showed that the ascorbic acid content increased before the fruit developed full yellow color (Wills and Widjanarko, 1995). Furthermore, titratable acidity (TA) showed increasing trend to a maximum about the time of attaining full yellow color (Wills and Widjanarko, 1995). It was indicated that, seal packaging of papaya with polyethylene film reduced the amount of titratable acidity (TA) during ripening at 24 to 28 °C (Lazan *et al.*, 1995). Total acidity content in papaya can be used to determine its maturity. In some researches, it is evident that the physic-chemical such as acidity parameter of papaya differed from one another which are supposed to be due to different genetic makeup the variety and also because of difference in their total fruit development and ripening period (Bron and Jacomino, 2006).

Generally, pH in banana depends on the cultivar, growing region, maturity at harvest and postharvest handling practices (Ratule *et al.*, 2006). In addition, previous study showed that the acidity content in papaya was slowly increase during storage under different temperature storage conditions and also decrease in pH during measurement until shelf-life products was occurred (Falah *et al.*, 2015).

2.8.2 Total Soluble Sugar Content (TSS)

Sugars are the major soluble solids in fruit juice (Magwaza and Opara., 2015: Chope *et al*., 2007: Wardowski *et al.*, 1979). Soluble solids concentration, °Brix) can be determined in a small sample of fruit juice using a hand held refractometer. Consequently, soluble sugar content may express to the percentage (%) of fresh soluble sugar into the fruit juice and it might be referred by °Brix. Therefore, Brix technically refers only to the sugar content of fruit juices. In principle, the unit °Brix, which has been in common use in industry for many years, represents the dry substance content of solutions containing mainly sucrose **(**Wardowski *et al*., 1979; Echeverria and Ismail, 1987; Dongare *et al.*, 2014). For instance, a juice sample that has 25 degree of Brix is assumed to contain 25 g of sugar/100 g of solution (Ball, 2006).

In addition, the term of total soluble solid is another term may be expressed as a percentage of fresh matter mass, shows high positive correlation with sugars content, and is therefore generally accepted as an important quality trait of fruits (E Silva *et al*., 2006). Moreover, total soluble solid may be measured on expressed fruit juice and in percent using handheld refractometer (Rivera-López, 2005; Fawole *et al.*, 2013). The change of total soluble solids contents in papaya during different storage situations, depending on the storage conditions, agro-climatic regions, cultivar types and fruit maturity at harvest (Agar *et al.*, 1999; Ayala-Zavala *et al.*, 2004; Lamikanra *et al.*, 2000). Soluble solids content was affected by temperature and storage period. Papaya cubes and slices stored at 20 °C had the lowest soluble solids content after 6 days of storage. Total soluble solids in papaya cubes and slices stored at 5 °C and 10 °C also decreased. The difference in total soluble solid loss between papaya cubes stored at 5 °C and 10 °C was larger compared with papaya slices stored at the same temperature (Rivera-López *et al.*, 2005).

The concentration of total soluble solid in bananas Kluai Hom Thong remained lower than that of bananas Kluai Khai after storage at low temperature. After that, the bananas stored at room temperature (Srisuvor *et al.*, 2013). The level of total soluble solid was not different during six days of storage at any of the temperatures. On the other hand, total soluble solid in both banana cultivars stored at

10 °C slowly decreased while it remained at higher level in bananas stored at 14 °C (Srisuvor *et al.*, 2013).

Therefore, considering the sugars (sucrose, glucose and fructose) and sugar alcohols (sorbitol and manitol) constitute the majority (approximately 85%) of total soluble solids in many fruits. Consequently, it is not surprising that both terms of total soluble solids and total soluble sugar have become synonymous. However, this does not hold true for fruit such as limes, in which sugars constitute only 25% of the total soluble solid content (Wardowski *et al.*, 1979). A previous study showed that the removal of anthocyanins and phenolic compounds before measuring soluble sugar of blueberry and strawberry fruit with a refractometer increased the reliability of soluble solids as an indicator of sweetness during storage (Kader *et al.*, 2003). It has been shown that total soluble solid was two-fold higher with higher total sugars (Chope *et al*., 2007).

2.8.3 Total Soluble Solids to Titritable Acidity

The fruit quality can be measured by total soluble solids to titritable acidity ratio. Consequently, the tota soluble sugar TSS:TA ratio is very important, because it provides information on the balance of sugars and acids in the fruit (Voča *et al.*, 2008). It is generally realized that quality fruits benefit from a higher sugar:acid ratio which refers to sweetness (Muhtaseb, 2007). In the contrary however, the lower sugar:acid ratio may indicate to lower fruit quality which refers to sourness (Muhtaseb, 2007; Rodríguez *et al.*, 2011). Furthermore, increase total soluble solids to titritable acidity ratio ratio indicates to fruit maturity and better taste (flavor) (Muhtaseb, 2007). Consequently, the maturity index of total soluble solids to titritable acidity ratio illustrated to be a good indicator of fruit maturity as it increased significantly during fruit ripening. It has been noted that total soluble sugar of banana fruits increased after 25 days of storage which indicated to the ripening (Carvalho *et al.*, 2009).

The TSS:TA ratio is currently used as a maturity index for some types of fruit. However, it has been recognized that this measurement does not always correlate well with the perception of sweetness or tartness in others (Baldwin *et al.*, 1998; Jordan *et al*., 2001). One difficulty is that the same ratio may be derived from different concentrations of TSS and TA, leading to different flavor perceptions for the same ratio.

2.8.4 Taste of Fruits

Taste and aroma are the main sensory characteristics of papaya including volatile compounds such as benzylisothiocyanate, terpenes, hydrocarbons, esters, aldehydes, ketones, alcohols, and organic acids (De Oliveira and Vitória, 2011). Consequently, the aroma is derived from combinations of volatile components (Ayala-Zavala *et al.*, 2004). In addition, changes in texture, peel, and pulp´s color, organic acid levels, and synthesis of volatile compounds usually occur during papaya ripening. The sucrose, glucose, and fructose concentration are usually used as an index because these sugars associate the ripening process (Gómez and Lajolo, 2002). For instance, banana starch concentration may be metabolized to sucrose at postharvest period which causes to fruits sweetness. Therefore, the sweet taste is an important quality parameter for fruits.

2.8.5 Weight Loss

In general, the water loss and shelf life period of papaya fruit may be significantly delayed during low temperature storage. The treatments did not modify the rate of water loss of packaged fruit. The weight loss of papaya fruit can be reduced by the seal-packaging and wrapping papaya during storage time (Lazan *et al.*, 1995). It was reported that weight losses greater than 8% considerably diminished the postharvest quality of papaya (Paull and Chen, 1999). In addition, it was observed that more than 8% of weight loss of papaya after fourteen days at 10 °C (Ali *et al.*, 2011; Karakurt and Huber, 2003). Therefore, the studies proved that there is a water loss of in the postharvest fruits during the experiments.

2.9 Nutritional Quality of Papaya and Banana

Papaya contains relatively high levels of vitamins A, B1, B and C (De Oliveira and Vitória, 2011; Sancho *et al.*, 2011; Tripathi *et al.*, 2011; Wall, 2006). The papaya fruit is also known to be an excellent source of glucose, fructose and sucrose (De Oliveira and Vitória, 2011). Some nutritional compositions of Rainbow papaya and SunUp papaya such as protein content which was similar pedigree for both studied cultivars (Tripathi *et al*., 2011). The investigations showed that the β-cryptoxanthin esters such as laurate and caprate were already present in early ripening stages of papaya and both esters may be form about 42% of total carotenoids (Bunea *et al*., 2014; Schweiggert *et al.*, 2011).The result indicated that the building up of carotenoids such as β-cryptoxanthin laurate and total lycopene contents significantly correlate with a subsequent fruit maturation (Schweiggert *et al.*, 2011). On the other hand, the aroma of papaya is mainly due to esters, ethyl acetate, ethyl butanoate, ethyl 2-methyl butanoate and ethyl hexaonateare the most potent odor compounds (De Oliveira and Vitória, 2011). Papaya is also considered as a functional food fruit and the consumption of ripe papaya fruit has been associated with a curing effect to a certain diseases. For example, it was reported that papaya has a pharmacological functions such as antifertility agent, laxative, meat tenderizer and many other uses (De Oliveira and Vitória, 2011).

Banana is one of the high calories of tropical fruits. Besides, it contains a perfect amount of health benefiting which are anti-oxidants such as lutein and a-carotenes (Wall, 2006), minerals, and vitamins such as Vitamin A1, B1, B2 and vitamin C (Anyasi *et al*., 2015; Choo and Aziz, 2010). Banana fruit have simple sugars including fructose, glucose, and sucrose (Der Agopian *et al.*, 2011). It contains health promoting phenolic antioxidants (Anyasi *et al*., 2015). Banana is good source of vitamin-B6 (Pyridoxine) in which Pyridoxine is an important B-complex vitamin. The fruit is also a moderate source of vitamin-C. Consumption of foods rich of vitamin C that may has a benefit for human body and develop resistance against infectious agents. In addition, fresh bananas provide adequate levels of minerals like copper, magnesium, manganese and potassium (Anyasi *et al.*, 2015; Englyst and Cummings, 1986).

2.10 Enzymes

Enzymes may be defined as proteins with catalytic activity. These enzymes have ability to accelerate reactions from 10^3 to 10^{11} times more than the non-enzyme catalyzed reactions (Whitaker, 1993; Ortega, 2011). The enzymes might be part of many reactions, because enzymes may not be consumed by the reaction. Another important characteristic of enzymes is their specificity, when enzymes bind the substrate in the active site to convert it into product; enzymes that are highly specific catalyze only one particular reaction, while others catalyze reactions involving specific types of chemical bonds or functional groups (Whitaker, 1996). Enzymes are also responsible for several chemical reactions that are indispensable for living organisms. These enzymes have the same physical and chemical characteristics as all other proteins found in nature (Ortega, 2011).

2.11 Post-Harvest Microbiology

Postharvest decays of crops has been estimated that about 20 to 25% of the harvested fruits are deteriorated by pathogens throughout postharvest handling (Sharma *et al.*, 2009). So, postharvest decays of fruits are considered of significant postharvest losses. Therefore, the deterioration of horticultural commodities by microorganisms can be rapid and severe, particularly in tropical areas where high temperature and high relative humidity which lead to increase microbial growth. Furthermore, ethylene produced by rotting can cause premature ripening and senescence of other products in the same storage. Therefore, the other stored fruits may be contaminated by rotting organisms which cause to spoilage the entire products. Fruits may be infected by direct penetration of certain fungi through intact cuticle or through wounds and natural opening in their surface (Wills *et al.*, 1981).

Storage and market preparation requirements of papaya are greatly influenced by the susceptibility to certain diseases. The most important of these is anthracnose which is caused by the fungus *Colletotrichum gloeosporioides* (Rahman *et al.*, 2008; Gonzalez-Aguilar *et al.*, 2003). Anthracnose is a pre-harvest infection as well as fruit-surface rot and a harvest-wound rot that are two most common post-harvest rots of papaya (Alvarez *et al*., 1987). The presence of the disease is characterized by small black or light brown spots, which gradually enlarge and may coalesce and sink. The major post-harvest diseases that caused by fungi in papaya are stem-end rot (*Lasiodiplodia theobromae*), anthracnose (*Colletotrichum gloeosporioides*), and *Phomopsis* rot (*Phomopsis caricae-papayae*) which result in relatively high postharvest losses (Abeywickrama *et al*., 2012; Gonzalez-Aguilar *et al.*, 2003; Peña *et al.*, 2002). In addition, the bacterial diseases also cause damage of papaya such as purple-stain disease that caused by pigment-producing strains of *Erwiniaherbicola* (Loehnis) and internal yellowing disease that caused by *Enterobacter cloacae* (Alvarez *et al*., 1987).

Decay reduction and disease control may be through sanitation, careful handling, cooling of produce and use of approved chemicals such as fungicides which prevent or delay the appearance of rots and molds in the products. Others include use of metabolic inhibitors that block certain biochemical reactions that normally occur, ethylene absorbents, physical treatments such as heat treatments, and modified atmosphere (replacement of air with water vapor (Irtwange, 2006). Modifications of the storage atmosphere can be advantageous in retarding postharvest disease development. Furthermore, modified atmosphere has been a solution to improve quality of fresh products by reducing microbial decay (Irtwange, 2006). It was noted that, shredded green papaya in modified atmosphere conditions had longer shelf life by reducing respiration rate, ethylene production, color change and microbial growth (Lichanporn and Kanlavanarat, 2006).

2.12 Relative Humidity

Relative humidity may effect on fruit during storage. Relative humidity levels close to saturation of 100% might increase the rot incidence and cause disorders such as browning (Pinto *et al.,* 2015). It has also been shown that moisture loss of fruit depends on some factors such as size, maturity, storage temperature and relative humidity (Salunkhe *et al.,* 1991). It has been reported that bananas have been stored for 10 days at low humidity which showed greater weight loss than those stored at high humidity. Therefore, there is an interaction between fruit size and relative humidity (Ahmed *et al.,* 2006). This can be concluded that fruits at low humidity levels lost more weight due to their faster rate of respiration and transpiration than that of high humidity levels (Ahmed *et al.,* 2006). The interaction between temperature and relative humidity showed greater effect at high relative humidity. It could be due to the ability of high relative humidity to reduce the respiration rate an transpiration processes (Ahmed *et al.,* 2006). The other study demonstrated that pomegranate fruit weight loss was high into storage due to a lower relative humidity during storage resulting in a marked fruit weight loss between 20 and 25% (Fawole *et al.,* 2013). Therefore, relative humidity must be maintained to reduce excessive water loss. In addition, papaya and banana have been stored at relative humidity storage of 90 % and low relative humidity may reduce green life period of fruits (Praeger *et al.,* 2013; Ali *et al.*, 2011).

2.13 Conclusion

Comprehensive review of literature showed that various banana and papaya cultivars are available globally. In addition, these cultivars are distinguished by distinctive characteristics such as fruit size, weight, sweetness, acidity, flavor and peel color. Furthermore, fruits are hard and green at the harvested time. So, the cultivars needs few days for ripening. The skin color can be used to determine the ripening stages due to its gradually change from green to yellow color. The both cultivars respond differently to optimum storage conditions. Therefore, the storage temperature may significantly influence the stored fruits. In other words, storage temperature can accelerate or delay ripening process as well as it may damage the fruits. For example, the change in fruits peel color including increase of degree of browning and decrease of color values, chilling injury occurrence which is considered physiological damages under cold storage conditions. Moreover, ethylene gas is produced during ripening process which is an indicator of increasing in respiration rate. Carbon dioxide may be generated by utilizing oxygen throughout the respiration at atmospheric pressure. The taste and aroma are the main sensory characteristics of fruits including volatile compounds. For instance, banana starch concentration may

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