PHYSICOCHEMICAL CHARACTERISTICS OF CALCIUM-TREATED JACKFRUIT (*Artocarpus heterophyllus*) PULPS DURING CHILLED STORAGE.

by

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SIFAT-SIFAT FIZIKOKIMIA ISI NANGKA (*Artocarpus heterophyllus*) TEROLAH KALSIUM SEMASA PENYIMPANAN DINGIN.

ABSTRAK

Penyelidikan ini mengkaji perubahan ciri-ciri fizikokimia isi nangka pada tahap kematangan berbeza, isi nangka ranum semasa penyimpanan dingin 8 C dan kesan kaedah olahan kalsium ke dalam isi nangka ranum. Kajian pada tahap kematangan berbeza menunjukkan peningkatan yang signifikan bagi jumlah pepejal terlarut dari 5^{o}Brix dalam nangka muda kepada 28^{o}Brix dalam isi nangka ranum. Jumlah keseluruhan pektin dan pektin larut-pengkelat menunjukkan penurunan yang signifikan dari kematangan muda kepada ranum, sementara pektin larut air menunjukkan peningkatan. Peningkatan pH selari dengan penurunan asid tertitrat. Walaupun aktiviti enzim poligalakturonase (PG) and pektin esterase (PE) adalah rendah dalam isi nangka muda dan matang, isi nangka ranum menunjukkan peningkatan yang tinggi dalam kedua aktiviti ini. Perubahan ini menyebabkan nangka sesuai untuk makanan manusia.

Isi nangka ranum disimpan pada 8 ^{o}C menunjukkan peningkatan aktiviti PE dan penurunan kandungan pektin dan kepejalan semasa penyimpanan dingin. Walaupun isi nangka hilang kepejalan pada hari ke 3, kehilangan kepejalan adalah signifikan menjelang hari ke 8, memyebabkan rupa yang lembik dan tidak menarik. Penulenan separa dan pencirian PG dan PE dari isi nangka ranum memberikan penulenan sebanyak 1.4% untuk PG dan 19.7 % untuk PE yang

mungkin disebabkan oleh ketidakstabilan enzim semasa penulenan. Berat melekul bagi PG adalah 46.6 kDa dan PE 46.6 dan 42 kDa. Titik isoelektrik untuk PG adalah pada pH 7.0 dan 7.7; sementara PE mempunyai titik isoelektrik pada pH 7.1 and 7.6.

Kaedah infusi kalsium yang dinilai adalah penceluran, perendaman dan olahan vakum pada dua tahap kepekatan kalsium berbeza iaitu 0.5% dan 1.0% (b/i). Isi nangka ranum yang dicelur kehilangan tekstur selepas 3 hari dan memaparkan ciri-ciri “masak”. Kajian isi nangka yang dicelur tidak diteruskan. Isi nangka ranum yang dikenakan olahan kalsium hilang tekstur lebih lambat berbanding yang tidak diolah dengan kalsium. Indeks warna menunjukkan perubahan warna yang lebih gelap. Kandungan asid askorbik dalam semua sampel menurun semasa penyimpanan dingin selama 14 hari. Isi nangka ranum yang direndam menunjukkan kehilangan cecair yang lebih tinggi berbanding kaedah bantuan vakum dan isi nangka kawalan. Dinding sel dan lamela tengah isi nangka yang divakum masih utuh, sementara lamela tengah sampel lain menunjukkan penguraian. Bardasarkan ciri-ciri tekstur dan penilaian sensori, isi nangka ranum yang dikenakan olahan kalsium sebanyak 1.0% dengan bantuan vakum mempunyai hayat penyimpanan selama 14 hari apabila disimpan pada 8^{o}C.

PHYSICOCHEMICAL CHARACTERISTICS OF CALCIUM-TREATED JACKFRUIT (*Artocarpus heterophyllus*) PULPS DURING CHILLED STORAGE

ABSTRACT

This work study the changes in physicochemical characteristics of jackfruit pulps at different maturity levels, of ripe jackfruit pulps during storage at 8 C and of the effect of different calcium-infiltration method of ripe jackfruit pulps. In the maturity study, there was a significant increase in the total soluble solid (TSS) from 5^{o}Brix in green pulps to 28^{o}Brix in ripe jackfruit pulps. The total pectin and chelator-soluble pectin registered a significant decrease from green to ripe stage, while the water-soluble pectin showed an increase. The increase in pH coincided with the decrease in titratable acids (TA). Although the polygalacturonase (PG) and pectin esterase (PE) activities were low in green and mature pulps, the ripe pulps exhibited a sharp increase in both activities. These changes resulted in the jackfruit to be suitable for human consumption.

The ripe jackfruit pulps stored at 8 ^{o}C exhibited an increased in PE activity and a decrease in pectin content and firmness during storage. Although the pulps started to lose its firmness by day 3, the lost was significant by day 8, making it appeared limp and unattractive. Partial purification and characterization of PG and PE from ripe jackfruit pulps gave purification 0f 1.4% for PG and 19.7 % for PE which could be due to the instability of the enzymes during purification. The molecular weight of

PG was 46.6 kDa and PE 46.6 and 42 kDa. Isoelectric points for PG were at pH 7.0 and 7.7; while PE had isoelectric points at pH 7.1 and 7.6.

The methods of calcium infusions evaluated were blanching, immersion and vacuum-assisted infusion at two levels of calcium concentration, i.e. at 0.5% and 1.0% (w/v). The blanched ripe pulps lost its texture after 3 days and exhibited "cooked" characteristic. Blanched pulps were not considered in further study. The calcium-treated ripe pulps lost their texture slower than untreated pulps. The colour index indicated a darkening in all samples regardless of treatment. The ascorbic acid content of all the samples reduced during the 14 days of storage. Immersed ripe jackfruit pulps gave off higher liquid loss, followed by vacuum-assisted ripe jackfruit pulps and control pulps. The cell walls and middle lamella of vacuum-infused pulps were intact, while other samples showed sign of middle lamella dissolution. Based on textural characteristics and sensory evaluation, the ripe jackfruit pulps vacuum-infused with calcium at 1.0% have a shelf life of up to 14 days stored at 8^{o}C.

CHAPTER 1: INTRODUCTION

Jackfruit is one of local fruits that are increasingly gaining popularity. The Ministry of Agriculture has identified it as one the main fruit commodity under its Agricultural-based industry and agro-food sector's Balance of Trade (BOT) Action Plan 2000-2010. The objective of this action plan is to reduce the nation's agro food trade deficit through increasing commodity products, decrease import and increase export (www.moa.gov.my). According to crop statistics produced by the Department of Agriculture in 2008, the total production of jackfruit increased from 18,510.7 metric tones in 2003 to 19,882 metric tones in 2008 (www.doa.gov.my).

Jackfruit has high marketable potential. Malaysia's jackfruit is exported mainly to Singapore, Hong Kong, Thailand and Brunei. In 2000, the value of the exports was RM5 million. During the last decade, the export value of fresh jackfruit has been on an increasing trend – registering a growth from RM2.1 million in 1994 to RM9.5 million in 2003 – a significant increase of 360% (www.doa.gov.my). Fresh jackfruits fruits are marketed locally through the following retail outlets:

- Direct sales to consumers through Pasar Tani operated by FAMA
- Sales to wholesale markets
- Direct sales to hypermarket / supermarkets
- Sales through contract farming and "pajak system"
- Direct sales to retailers and exporters
- Direct sales to household consumers

Jackfruits are marketed locally as whole-fruit or minimally processed products whereby the fruitlet are separated from the whole-fruit. The current practice does not emphasize sanitation and cleanliness aspects during preparation, which resulted in short shelf-life of only 1 day at ambient temperature and only 3-4 days at 10-15^{o}C (Abdullah, 1988). Jackfruits destined for export market are usually sent abroad as whole fruit. Transportation through air will give the produce 5-6 days of market quality when they arrived to their destination. However, the air freight is very costly and the edible part of the fruit is only 50-60% of the total cost. Furthermore, the size and shape of the fruits are not consistent, making the design of packaging very difficult (http://agromedia.mardi.gov.my)

Today's consumers are demanding for produce that are wholesome, nutritional and convenient that still retain their natural characteristics as much as possible. The thick skin and latex on jackfruit makes the minimal processing potential even more attractive (Anon, 2004). In view of the current trend, concerted effort has been made to develop new methods for minimally processed fruit and vegetable products. Physiological functions of various fruits and vegetables and their susceptibility to minimal processing, and effects of various food additives agents and modified packaging conditions are being studied (Cantwell, 2008). These include cultivar selections, effects of maturity and storage, relative respiration rates, heat-shock treatments, effects of various chemicals, packaging materials, atmosphere conditions and storage conditions (Huxsoll and Bolin, 1989).

Minimally processed products are defined as those processed by appropriate unit operations such as washing, peeling, slicing and packaging, including chemical treatments which may have a synergistic effect when used in combination (Beuchat, 2000). Traditionally, heat treatment was used to prolong the shelf-life of the products. Although thermal processing can be beneficial in term of food preservation and the development of flavours, it can also instigate damaging effect on the products, especially in term of colour and texture (Martinez-Monzo *et al.*, 2000). Other treatments that had been used in conjunction with minimal processing include irradiation, pulsed electric field and high pressure processing.

Minimally processed jackfruit will boost the fruit's potential both locally and internationally. The unique flavour and crisp texture, coupled with the diverse ways it can be incorporated into a meal, will make minimal processed jackfruit an important export commodity of Malaysia. A method that can preserve the fresh fruit's characteristics; enhanced its shelf stability yet keep cost at a minimum will achieve this purpose.

The objectives of this research are:

- To study the changes in pectin content, acidity, total soluble solids, enzyme activities and texture of jackfruit at 3 different maturity stages, i.e. at green, mature and ripe stages.
- To determine the pectin content, acidity, total soluble solids, enzymes activities and enzymes effects on the textural characteristic of ripe jackfruit pulps during storage at 8°C.
- To determine the effects of calcium chloride treatments by blanching, immersion and vacuum-infusion on the changes in texture,

microscopic structure, colour, ascorbic acid content, liquid loss, pectin characterization and sensory evaluation of the ripe jackfruit pulps during storage at 8°C .

CHAPTER 2: LITERATURE REVIEW

2.1 Agriculture in Malaysia

Agriculture represents about 26% of the Gross Domestic Product. Fruit production expanded from 18, 511 metric tonnes in 2002 to approximately 19, 882 metric tonnes in 2008 (http://moa.gov.my). The Ministry of Agriculture, in line with the 9th Malaysia Plan (RMK 9), is promoting agriculture as a source of income (http://agrolink.moa.my/moa). The RMK 9 aims to lessen dependency on imported food produce. This is done through giving better incentives such as technical and research and development support, loan, the setting up of collection, processing and distribution centres.
(http://www.utusan.com.my/utusan/SpecialCoverage/RMK9/htm.)

This is in line with the National Agriculture Policy (NAP), introduced in 1984, which emphasizes increased food production, both for national self-sufficiency and export. Before the introduction of NAP, the fruit farms were quite small, ranging between one to two hectares, except in Penang, which averaged around three hectares. The percentage of area planted with fruit was less than 50%, with farmers concentrating more on livestock such as cattle and poultry (Mohd. and Mohd, 1981). The decline in the traditional, industrial and export crop such as oil palm, rubber and cocoa has given an added force to the development of fruits and vegetables in this country. In 1993, there were about 90 large commercial fruit plantations run by big corporations such as Federal Land Development Authority (FELDA), Federal Land Consolidation and Rehabilitation Authority (FELCRA), Golden Hope, Dunlop, East Asiatic and Guthrie (Mohayidin and Mohamed, 1993). The prospect of fruit cultivation is bright in term of its return investment and there is high demand for domestic and export markets.

It is realized that besides the production of higher quality produce, the industry also depends greatly on the availability of appropriate post-harvest handling technology (Abdullah, 1988). Currently, temperature control is the most common method for extending the shelf life of fruits and vegetables. However some tropical fruits are prone to chilling injury when kept at low temperature while higher temperature accelerates the rate of deterioration.

Furthermore, low temperature preservation can contribute to higher cost. Appropriate steps must be taken to ensure the increase in plant produce will reach the consumers in acceptable qualities. Loss of up to 20-40% has been reported for fruits and vegetables (Abdullah, 1988).

Losses due to post harvest mismanagement could be due to factors such as, climate, infrastructure facilities, knowledge, socio-economic and targeted market. Researches in various sectors to tackle these limitations have been extensive. The scope extends from harvesting practises; produce handling, storage and pre-processing methods (Bourne, 1986).

Table 2.1 gives an estimation of these losses in some countries. Most of the countries are the third world countries and/or in the tropic region where postharvest practices are still old-fashioned.

Table 2.1: Estimation of post harvest loss of fruits and vegetables for various countries (Bourne, 1986)

CONTINENT	COUNTRY	(%) LOSS
ASIA	Sri Lanka	20 – 40
	Thailand	23 –28
	Indonesia	15 – 25
	Malaysia	10 – 50
	India	20
	Jordan	20 – 30
	Iran	2 – 3
AFRICA	Ghana	30 – 35
	Nigeria	10 – 50
	Rwanda	5 – 40
	Sudan	50
LATIN AMERICA	Dominican Republic	25
	Chile	30
	Brazil	8 – 10
	Bolivia	17 – 30

Agricultural products are very perishable due to their high water content, which ranged from 60 –95% (Bourne, 1986). Fruits and vegetables continue with their metabolic reactions/processes, such as respiration and transpiration even after harvest. These processes will use up their food and water reserves, making them less fresh and start to deteriorate.

External factors, such as storage condition and temperature, mechanical injury and attack of pest and diseases, will further render the produce to depreciate (Peleg, 1985). Respiration, transpiration, low humidity and warm environment cause a product to lose water. According to Peleg (1985), a 5 – 10% weight loss will affect the texture, taste and general appearance of the product.

The maturity of the produce when it was harvested plays an important role in determining the final quality (Ahmad, 1999). Fresh produce, which was harvested too early, may not ripen as expected. If harvested too late, the marketability of such produce will decrease due to shorter shelf life.

Internationally, temperature control is the customary method for maintaining fruit quality. This is considered to be the best way to increase storage life because it slowed down the respiration, ethylene production, ripening, senescence, decay and other undesirable metabolic changes. However, low temperature storage is more harmful than beneficial for some tropical fruits as they are more susceptible to chilling injury. Some tropical fruits do not keep well at low temperature. Kiwi and papaya can only keep for 2 days at 4^{o}C, pineapple 11 and honeydew 14 days (O'Connor-Shaw,*et al.*, 1994).

Tomatoes develop chilling injury when kept at below 12 to 13^{o}C (Lurie and Klein, 1991). This can be prevented by keeping mature green tomatoes at a temperature of 36 to 40^{o}C for 3 days before storage at 2 to 3^{o} C for 3 weeks. After storage, the fruits had a lower potassium ion (K^+) leakage and higher phospholipids content than the unheated fruits. The heat-treated tomatoes also ripen as normal, although slower than freshly harvested fruits.

Chilling injury of unheated tomatoes was manifested by failure to turn red and the development of brown areas under the peel. Lurie and Klein (1991) postulated that heat stress caused an inhibition of ripening and that this inhibition was maintained at 2.5^{o}C and removed only after transfer to 20^{o}C. They also found that heat stress inhibited the loss of phospholipids leading to a lower rate of potassium leakage and gave protection against chilling injury.

The ripening method practiced currently by most fruit farmers is crude and gives unpredictable effect (Abdullah, 1988). Usually fruit is ripen in small rooms, or in wooden boxes or rattan baskets lined with newspaper. The ripening agent used by most fruit farmers is calcium carbide, which some customers dislike because of the unpleasant odour.

Ethylene gas and better ripening facilities have been used on the FIMA Plantation for mangoes (Mohayidin and Mohamed, 1993). Ethylene has also been used in the Boh Plantation in Cameron Highland to de-green citrus.

2.2 Jackfruit

Jackfruit (*Artocarpus heterophyllus*) is believed to originate from West Ghat, India. It belongs to the family Moraceae (Nakasone and Paull, 1998). It is an evergreen tree that can grow to up to 30 m high. Bud-grafted tree are usually smaller, only 3 – 4.5 m high. The leaves are dark green and shiny on top, and pale green beneath. They are also hairy to the touch. Jackfruit can produce 20-250 fruit per tree per year, sometimes up to 500. The maximum production is usually after the 10th year. The fruit can weigh as much as 10-30kg. The skin is rough and thick.

Jackfruit plays an important role in the country's economy. Extensive planting is done for local and export markets. The total land planted with jackfruits increased from 1419 hectares in 1984 to 4000 in 2003 (http:// agrolink.moa.my). Table 2.2 showed the total hectarage of land planted with jackfruit in Malaysia. In Peninsular Malaysia, Johor (886 ha) has the largest hectarage of jackfruit plantation, followed by Kelantan (374 ha) and Kedah (227 ha). Sabah and Sarawak are large growers too, with 446 hectares and 560 hectares respectively. However in term of production, Johor is the major jackfruit producer, followed by Selangor and Terengganu. Higher yield of jackfruits are obtained by Selangor and Terengganu may be due to better agricultural practices and the use of jackfruit clone that give higher yield.

Table 2.2: Land (hectares) planted with jackfruit in Malaysia.
Source: Department of Agriculture, (2003).
(Percentage compared to total hectares are given in brackets)

State	Hectares	Production (Metric tonnes)
Johor	865.9 (24.2%)	3,467.7
Kedah	226.9 (6.3%)	665.5
Kelantan	374.3 (10.4%)	721.9
Melaka	90.9 (2.5%)	454.5
N.Sembilan	191.6 (5.4%)	332.3
Pahang	188.4 (5.2%)	402.5
Perak	168.6 (4.7%)	910.4
Perlis	50.2 (1.5%)	6.6
Pulau Pinang	65.6(1.8%)	166.4
Selangor	168.0 (4.6%)	1 315.2
Terengganu	188.1 (5.3%)	1 144.5
Peninsular	**2578.5 (71.6%)**	**9 587.5**
Sabah	445.5 (12.5%)	-
Sarawak	560.0 (15.6%)	-
Total	**3 584.0**	**9 587.5**

Jackfruit should be harvested at the right stage of maturity (Kader, 2001). Optimum maturity for jackfruit ranges between 12 and 16 weeks after flower anthesis, depending on the clone. Fruit is considered mature to harvest when the leaf on the stem wilted and the fruit green colour changes to green yellowish. Optimum harvest for long-distance transport is when the colour is yellowish-green. When the mature fruit is tapped, it sounds hollow. Beside that, the colour and development of spikes; colour of the stalk or fruit shape can also be used as an index to determine maturity.

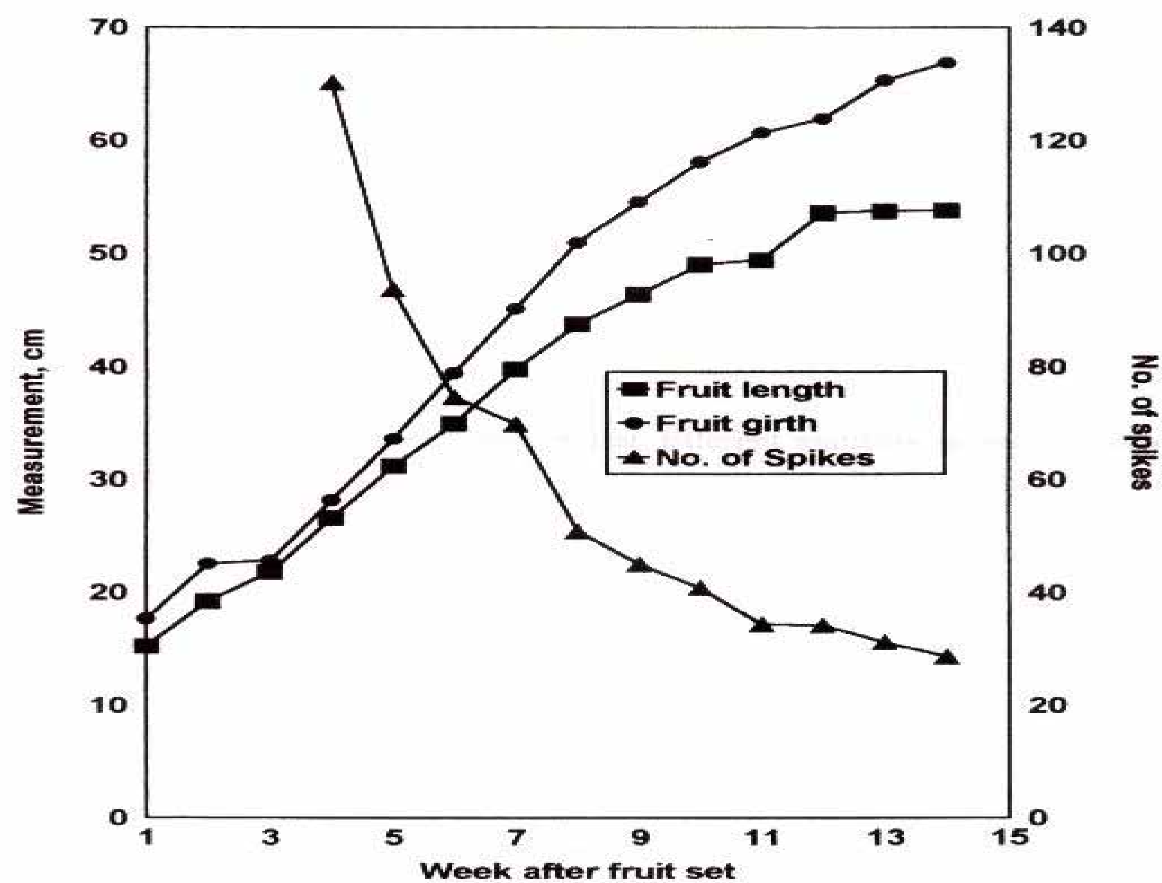

Figure 2.1: Changes in fruit length, girth and number of spikes in jackfruit during development (Pauziah *et al.*, 1996).

Study on jackfruit NS1 by Pauziah *et al.* (1996) showed that the further along the fruit sets, the number of spikes on the outer skin decreased, while fruit length and girt increased as shown in Figure 2.1. As jackfruit matures, the spikes become flatter and reduced in number (Pauziah *et al.,* 1996). The fruit is sometimes allowed to fall. This can cause damage, loss of shelf life and premature ripening. Ripening advances with the change in texture from hard to soft and a typical ripe aroma is released.

Jackfruit is categorised as a climacteric fruit (Kader, 2001). The rates of respiration are between 20-25ml CO_2/kg.hr at preclimacteric stage and 50-55 ml CO_2/kg.hr at the climacteric peak, at 20^oC. Depending on the cultivar, the optimum storage temperature is 13 $\pm$ 1^oC, with potential postharvest life of 2-4 weeks.

Tropical fruits are not normally stored at temperature lower than 13^oC (Kader, 2001). Fruits exposed to temperature below 13^oC exhibits chilling injury symptoms, shown by dark-brown discolouration of the skin, pulp browning and development of off-flavour, followed by susceptibility to decay. Study by Malaysian Agriculture Research and Development Institute (Mardi) found that whole jackfruit stored at 10^oC (85-90% humidity) might last approximately 2 weeks (Anon, 2004). The storage life is influence by the initial quality and maturity of the jackfruit.

Jackfruit is a good source of carbohydrate, vitamin A and a fair protein source (Narasimham, 1990). The nutritional composition of jackfruit pulps typically found in Malaysia is given in Table 2.3. The Malaysia's jackfruit pulps analysed by Tee *et al.* (1997) contain quite high amount of carbohydrates, fibre, potassium and carotene.

Table 2.3: Nutritional composition of jackfruit pulp (Tee *et al.*, 1997)

Nutrient	Composition per 100 g edible portion
Energy	37 kCal
Moisture	83.1 g
Protein	1.6 g
Fat	0.2 g
Carbohydrate	7.3 g
Fibre	5.6 g
Ash	2.2
Calcium	37.0 mg
Phosphorus	26.0 mg
Iron	1.7 mg
Sodium	48 mg
Potassium	292 mg
Carotene	110 μg
Vitamin B1 (Thiamine)	0.06 mg
Vitamin B2 (Riboflavin)	0.06 mg
Niacin	0.4 mg
Vitamin C (Ascorbic acid)	7.9 mg

Jackfruit can be categorized into 2 major types, based on the quality of the pulp (Anon, 2004). The first type is fibrous, thin, soft and musky; can range from sour to very sweet and emits a strong aroma when ripe. The second type has thick edible pulp, which is firm and crisp and less odorous. The second type is more accepted.

In Malaysia, there are about 30 cultivars of jackfruit. Among the cultivars are J29, J30, NS1, NS3, 'Mantin Isi Merah' and 'Kuning Rangup' (Anon, 2004).

Mature jackfruits are cooked as vegetables, either in curries or salad (Narasimham, 1990). Ripe fruits can be eaten raw, or cooked in creamy coconut milk as dessert, made into candied jackfruit or jackfruit leather. The seeds are also eaten. In India, the seeds are boiled in sugar and eaten as dessert (Roy and Joshi, 1995). In Malaysia, the seeds are boiled with a little salt. Dried seeds were also used to make flour for value-added products. The unfertilised fruits can also be used with/or to replace fruit pulps.

Recently, more products based on jackfruit have been developed (Anon, 2004). There is an increase in demand for minimally processed jackfruit in Singapore and European markets. This is obvious since minimal processing offers some advantages such as the ease in serving portions of an otherwise large and difficult-to-peel jackfruit, reduces packaging and transportation costs, is more convenient as a ready-to eat produce, maintains quality and freshness, extends shelf life and could minimizes quarantine barriers in some importing countries.

Jackfruit is also used for further processing. For instance, jackfruit leather and jackfruit chips, made from dried jackfruit pulps (Nakasone and Paull, 1998). Pureed jackfruit is also developed into baby food, juice, jam, jellies and base for cordials

(Roy and Joshi, 1995). Jackfruits are made into candies, fruit-roll, marmalades and ice cream. Other than canning, advances in processing technologies too, have pushed towards more new products (Narasimham, 1990). Freeze-dried, vacuum-fried and cryogenic freezing has advent preservation method for new jackfruit-based products.

The rest of the fruits are also valuable (Roy and Joshi, 1995). The leaves become animal feeds. The latex is used as adhesives to mend broken chinaware. In India, the leaves were shaped and used as plates.

Jackfruit wood is an important source of timber in India and Sri Lanka (Roy and Joshi, 1995). The wood is resistant to termite infection and fungal decay. The sawdust yields yellow dye when boiled. The Chinese consider jackfruit pulp and seeds as cooling and a nutritious tonic. Various parts of the jackfruit were used as medicine to relieve ulcer, heal abscesses, snakebite and glandular swelling. Extract of jackfruit root is a remedy for skin disease, asthma and is reduce fever and diarrhea.

Table 2.4 listed the major export destinations for Malaysian jackfruit (Anon, 2004). The export of jackfruit registered an increase of 360%; from RM2.1 million in 1994 to RM9.5 million in 2003 (http://agrolink.moa.gov.my). Major importers for jackfruit are Singapore (23.5%), Hong Kong (10%) and Brunei (1.4%). Locally, jackfruits are generally retailed to direct sales to retailers, exporters, wholesale markets, hypermarkets/supermarkets or to the household consumers through Federal Agricultural Marketing Authority (FAMA)-sponsored Pasar Tani or Pasar Malam.

Table 2.4: Major Export Destinations of Fresh Jackfruit

Source: Department of Statistics, Malaysia (2004)

Year	Brunei		Hong Kong		Singapore		Others		Total	
	MT	RM ('000s)	MT	RM ('000s)	MT	RM ('000s)	MT	RM ('000s)	MT	RM ('000s)
1994	64	70	164	276	2,774	1,617	79	104	3,081	2,067
1995	51	53	394	590	2,733	1,413	162	212	3,340	2,268
1996	38	53	610	1,326	3,128	1,786	129	190	3,905	3,355
1997	43	51	582	1,326	2,746	1,371	1,535	1,067	4,906	3,815
1998	19	26	270	486	3,141	1,850	3,569	2,231	7,000	4,593
1999	24	28	372	887	3,172	3,171	2,752	1,943	6,320	6,030
2000	63	120	380	1,121	3,028	3,473	401	331	3,872	5,045
2001	207	350	466	1,264	2,493	2,632	100	199	3,265	4,445
2002	133	182	501	1,249	2,397	2,436	668	1,599	3,699	5,467
2003	111	130	562	938	2,073	2,221	8,666	6,177	11,412	9,466

Jackfruits for export market are usually in "whole-fruit" forms (Anon, 2008). The high freight cost of bulk fruits of which only about 40% of the fruits are edible are not cost-effective for local farmers. Hence, new developments in processing of jackfruit, especially to ensure suitable shelf life for export purposes are very important.

2.3 Fruit Ripening

The lives of fruit can be divided into 3 main physiological stages; namely growth, maturation and senescence (Wills *et al.*, 1989). In the growth phase, cells divide and enlarge. This explains the increase in produce size. Maturation can commence before growth is complete. Senescence begins when synthetic reactions (anabolic) gave way to degradative (catabolic) reactions. Growth and maturation must take place with fruit still attach to the plant, whereas ripening and senescence can occur on or off the plant.

Ripening in the fruits involved changes in the sensory factors of colour, texture and taste which render the fruits acceptable for consumption (Biale, 1975). These changes can be observed by analysing the change in pigments, pectin, carbohydrate and acids. Although the rate of these changes differ in different fruits, the respiratory patterns in these fruits were something these fruits have in common.

Respiration is a major metabolic process that takes place in living plant (Rhodes, 1986). It is an oxidative breakdown of complex compound such as starch, sugars and organic acids, which accumulate during photosynthesis; into simpler products that can be utilized by the plant. Some fruits exhibit an increase in respiratory rate corresponding to the onset of ripening. It also coincides with the attainment of maximum fruit size. Fruits that show this trend are termed “climacteric”. In tropical fruits, the increase in climacteric peak is rapid and corresponds to the achievement of eating ripeness.

Kidd and West (1924) found that during storage, apples showed a drop in the rate of respiration before the rate increase again, depending on the storage temperature. These researchers named this changes “climacteric” indicating the change of fruit development phase to the senescence phase. The upsurge in respiratory rate occurred at the end of maturation process (Rhodes, 1970). The characteristic features of the climacteric are the decline in the rate of oxygen uptake and carbon dioxide evolution after harvesting to a low value referred to as the “preclimacteric minimum” followed by a sharp rise to a peak and terminating in the postclimacteric stage (Biale, 1975).

Figure 2.2 showed the fruit attains the eating ripe stage at the climacteric peak or some time after the peak, depending on the species and to some extent, temperature and composition of the atmosphere at which the commodity is kept. The change in the rate of respiration is actually a secondary factor brought about by the presence of ethylene, an increase in RNA and protein synthesis and the change in cell permeability. Therefore the term climacteric can be defined as the time at which several chemical changes are initiated by the autocatalytic production of ethylene, which signify the change from development phase to senescence phase. This involves an increase in the rate of respiration and fruit ripening (Rhodes, 1986).

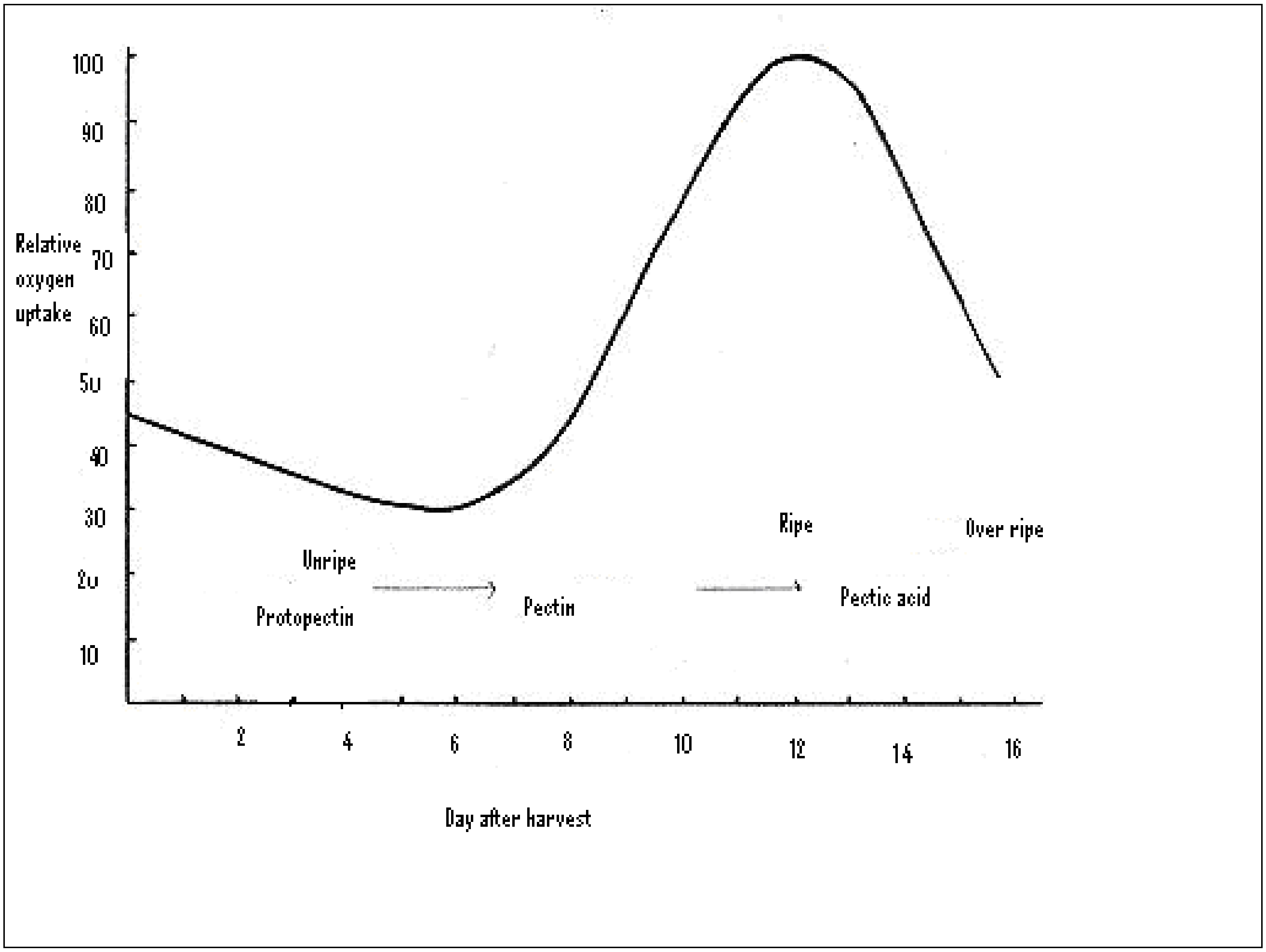

Figure 2.2: The climacteric pattern of respiration and associated changes in fruit ripening. (Biale, 1975)

Fruit ripening occur as a result of a series of biochemical and physical changes in fruits until it is deem suitable to be eaten. In fact, it is a transformation of a physiologically mature but inedible plant organ into a visually olfactory and taste sensation (Wills *et al.*, 1989). The attainment of maximum eating quality of a fruit necessitates completion of these chemical changes. Ripening process is often associated with the decline or total lost of chlorophyll content and pigment synthesis that brought about the change in colour. pH is mainly responsible for the degradation of chlorophyll. As fruits mature and started to ripen, organic acids leached from the vacuole and effectively reduce the pH environment of the fruit.

Carotenoid is more stable and usually remains intact even after extensive ripening (Darby *et al.*, 1977). Carotenoid may already be present, and become more apparent as the chlorophyll breaks down; or it is synthesized as chlorophyll gradually disappears. In oranges, for instance, the change is a consequence of chlorophyll breakdown and formation of carotenoid pigment. In bananas, the chlorophyll disappears with little or no formation of carotenoids. Tomatoes with impaired chlorophyll degradation mechanism but normal carotenoid biosynthesis, end up with a dirty brown colour when ripen (Darby *et al.*, 1977).

Changes in term of acid content, sugar and volatiles will affect the taste, flavour and aroma of the fruits (Mattoo, 1969). Organic acids most frequently found in fruits are malate and citrate. These acids are assumed to be stored in the vacuole. As fruit ripening advanced, the membrane permeability of the cell walls changes, resulting leakage of cell content (Rhodes, 1986).

Many fruits show a fluctuation in acids content during development: usually with a low initial level, that increase steadily with growth and reaching a maximum sometime in mid season. The acids levels then decline as maturity commence. As the fruits mature, the levels of organic acids and phenolics decrease which will minimize the astringency and acidity. Acid level influences the fruit flavours. Sour lemon (*Citrus limon*) contains 4.9% organic acid, while sweet lemon (*Citrus limettiodies*) contains less than 1% (Bogin and Wallace, 1966).

In ripening fruits, the organic acids usually decrease as can be seen in mangoes, simultaneous with a pH change from 2.0 to 5.5. The levels of citric, malic and ascorbic acids had also been reported to decrease by 10, 40 and 2.5 folds respectively during fruit ripening (Modi and Reddy, 1967).

Ripening also brings about an increase in simple sugars, which contributed to sweetness (Bollard, 1970). The increase in sugar content is most rapid during ripening. The increase in fruit sugar content may be brought about by the breakdown of carbohydrate, which breaks into glucose. In fruits with low or no carbohydrate, such as melon, the increase in sugar during ripening on vine is due to transport from leaves. The ratio of sugar to acid plays an important role in the determination of fruit ripeness and also will influence the taste of ripe fruit. In most fruits, the most common sugars are glucose and fructose. However, sucrose may also be present at similar level.

The cell walls of fruits become more permeable and the change in cell walls composition resulted in the lost of firmness (Willats *et al.*, 2001). Softening of fruits is caused either by the breakdown of insoluble protopectin into soluble pectins or by starch hydrolysis. Softening associated with ripening make fruits susceptible to bruising and mechanical injury. Fruits are often harvested when they are still in mature green stage to prevent mechanical damage.

Apple softening can be retarded by 2,5-norbornadiene (2,5-NBD), which acts by competing with ethylene for binding sites and inhibits its action in plant tissues (Blakenship and Sisler, 1989). When applied to "Delicious" apples as a gas in either closed or flowing system, 2,5-NBD prevented the softening of apples stored for 30 days at 25^{o}C with either 2000 or 4000 μL 2,5-NBD/L of air. The firmness of fruits was comparable for fruits held for 30 days at 5^{o}C and loss of soluble solids and starch was similar to that for the refrigerated apples. The synthesis of lignin also affects the texture in some vegetables. Wax is also produced in some fruits.

Many fruits become soft as the pectic material in the interlamellar degraded and lose their strength and cementing power (Bourne, 1976). As ripening advances, a decrease in the esterification of pectic constituent was observed (Shewfelt *et al.,* 1971). These researchers also stated that a reduction in shear press firmness of the tissue occurred.

The lost of textural quality in fruits is closely related to the change in the pectic substances. The amount and quality of pectic substance will determine the cohesiveness of the fruit. The pectic substances are the major constituents of the middle lamella as well as structural elements in the primary cell wall (Talmadge *et al.*, 1973). They comprise a substantial portion of the cell walls of soft fruits and fleshy roots.

During ripening, the water-soluble pectins increase and the insoluble fractions decrease, resulting in texture of “mealy”, “buttery” or “custard-like” of the ripe fruits. The predominant polysaccharide of the pectic substances is rhamnogalacturonan, a high molecular weight polymer composed of α-1,4-linked D-galacturonopyranose residues backbone, interspersed with α-1,2-linked rhamnopyranose. As many as 65% of the carboxyl groups of poly-D-galacturonic acid are esterified by methyl groups, whereas positions 2 and 3 might be acylated. Knee *et al.* (1975), used fungal glycosidases to study the structure of apple fruit cell walls found that pectic polysaccharides in the middle lamella are simply substituted methyl esterified galacturonan; and the primary wall are made up of branched methyl esterified rhamnogalacturonan

The texture of fruits also depends upon turgidity, size and shape of the cells, presence of supporting tissues and composition of the plant (Knee *et al.* 1975). Turgidity is brought about by the osmotic pressure of the cells. A firm texture is maintained with rigid and strong cell walls. Supporting tissues, such as parenchyma, sclerenchyma or collenchyma, will also influence the texture of fruits.

In young plants, where parenchyma is predominant, the texture is more succulent polysaccharides (Knee *et al.*, 1975). On the other hand, sclerenchyma and collenchyma will give a tough, fibrous or stringy texture. The fleshy parts of fruits are mostly unlignified and contain low proportion of hydroxyproline-rich proteins, a