

FRUITS
Nutritious, Colourful, Yet Fragile
Gifts of Nature



PROFESSOR DR. AZIZAH OSMAN

FRUITS

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Contents

Abstract	1
Introduction	3
Definition of Fruit	6
Cellular Components	7
Chemical Composition and Nutritional Values	9
Classification	12
Fruit Industry in Malaysia	17
Tropical Fruits (Area under Cultivation and Production)	21
Fruit Quality	25
Changes Occurring During Growth, Maturation and Ripening of Fruit	26
Preharvest Factors	32
Maturity Stage at Harvest	41
Postharvest Factors	52
Minimally Processed Fruits	84
Enzyme Infusion Technology: The Alternative to Conventional Peeling.	94
FAMA-UPM Collaborative Research	99
Current Trend of Fruit Consumption	104
Example of A Holistic Study of New Emerging Fruit - Pitaya	105
The Way Forward	111
References	112
Biography	141
Acknowledgement	149
List of Inaugural Lectures	151

ABSTRACT

Fruits, which are consumed because of their excellent taste and health benefits, mainly contribute carbohydrate, dietary fibre, vitamins and minerals to balance the human diet. Fruits have been a part of the human diet since the dawn of history but their nutritional importance has only been recognised in recent times. Commerce in fruits began in the 1980's when awareness on their nutritional importance has risen. Since then, its demand in the international markets has also increased tremendously. Hence, many tropical countries have moved from small, scattered farms to large commercial fruit plantations. Malaysia went through a series of phases since the inception of the National Agricultural Policy in 1984 to develop its fruit industry to reach its present status- able to be a leading exporter of some tropical fruits.

It is not possible to improve the quality of fruits once the fruits harvested but they can be preserved by slowing down the rate of undesirable changes, which leads to a reduction in their quality. Postharvest qualities of fruits are affected by pre-harvest factors, stage of maturity at harvest and postharvest factors. This is due to the fact that there are many physico-chemical changes taking place during growth, maturation, ripening and senescence stages in the life span of the fruit. A range of environmental conditions such as temperature, relative humidity, atmospheric compositions and mechanical injury can influence the rate at which these changes occur in harvested fruits. All these can be manipulated by careful management of the postharvest handling system for maintenance of quality and extension of shelf life of the fruits.

Proper postharvest handling practices are essential to reduce postharvest losses and maintain overall quality of fruits after harvest. Human factors such as handling practices and attitudes,

and technical aspects such as improper infrastructure and handling techniques could contribute to these losses.

Due to change in the life style especially in urban areas, convenient and ready-to-eat fresh-cut fruits, which is also referred to as minimally processed fruits are becoming more popular in the last two decades. However, there are problems associated to it. Hence, studies were conducted to overcome these problems. Apart from the increasing demands for fresh-cut fruits, there is also a trend during the same period of time, where consumers consume fruits not only for its nutritional contents but emphasis is also given to its functional properties.

The way forward for the fruit industry globally, including Malaysia, is to develop technology both for whole, intact and minimally processed fruits for shelf-life extension and quality maintenance not only from the perspective of nutritional aspects but also to give emphasis on the stability of the functional properties when they are being subjected to the different postharvest technologies at different stages of the distribution chains (whole, intact fruits) and preparation (minimally processed fruits).

INTRODUCTION

Fruits, which could provide variety, taste, aesthetic appeal and at the same time able to meet certain essential nutritional requirements have been a part of the human diet since the dawn of history (Wills *et al.*, 1998). Nevertheless, their entire or detailed nutritional importance has only been recognised in recent times. The nutritional value of fruit like citrus was recognised in the early 17th century in England where they discovered that citrus fruit could cure the disease scurvy which was widespread among navy personnel. Hence, captains took advantage of this to maintain the health of the crews on long voyages. Only in the 1930s, ascorbic acid (vitamin C) was discovered as the bioactive components responsible for the prevention of scurvy and later reported to have a range of beneficial effects related to many degenerative diseases. Dietary sources of vitamin C are essential as human are not able to synthesize it. All fruits contain vitamin C and they are the major dietary source supplying about 95% of the body's requirements. Due to this awareness on the importance of fruits in human diets, commerce in this commodity began since the 1980's. The demand for tropical fruits in the international markets increased tremendously in the last three to four decades. In many countries in the tropics, small, individual scattered farms or orchards were being taken over by large commercial plantations. In the past, cultivation of fruit trees was being practised using traditional techniques where the yield was low. In the present scenario, these large fruit plantations are adopting new cultivation techniques and modern systematic management technology where the yield is much higher. The clones of fruits cultivated are also of better quality in terms of many aspects such as yield or production /hectare, fruit quality and many others.

Malaysia is one of the countries in the region, which is blessed with many different types of fruits. It is estimated that there

are about 370 edible fruit species found in Peninsular Malaysia (Rukayah, 1999). Most of these species originated from this country and are still found in the jungle, while the rest are fruit species which were introduced from other countries and could adapt well with the climate here. In general, according to Rukayah (1999), fruit species that are found in Malaysia can be classified into two classes, namely;

- Fruits species which are being grown/cultivated
 - Fruits in this class can further be categorised as major and rare fruit types
- Fruit species which are growing wild
 - Fruits in this class can further be categorised into species which exist naturally wild (fruit species found in the jungle) and those wild species found growing in open areas

Major cultivated fruit species are usually widely grown and are of commercial importance both for fresh consumption and for further processing. There are 16 species (banana, papaya, pineapple, carambola/starfruit, watermelon, mango, durian, jackfruit, rambutan, citrus, guava, duku/langsat/duku langsung, ciku/sapodilla, cempedak, mangosteen and sour-sop) in this class (Rukayah, 1999), which can further be divided into two categories (Rukayah, 1999; Abdul Aziz, 1992), namely;

- Non-seasonal fruits which have potential to be exported
- Seasonal fruits which have potential both for domestic consumption and export

On the other hand, rare cultivated fruits, according to Rukayah (1999), refer to fruit species which are not grown on a commercial scale. They are usually grown with other fruit trees and there are 70 fruit species in this category. Some of the examples are breadfruit,

pulasan (*Nephelium mutabile* Blume.), *bacang* (*Mangnifera foetida* Lour.), *binjai* (*Mangnifera caesia* Jack), *kedondong* (*Spondias cytherea* Sonn.), *kuini* (*Mangnifera odorata* Griff.), *kundang* (*Bouea macrophylla* Driff.), *cermai* [*Phyllanthus acidus* (L.) Skeels], *jambu air mawar* [*Syzygium samarangense* (Blume Merr. & Perry)], *rambai* (*Baccaurea motleyana* Muell.-Agr.), *asam gelugor* (*Garcinia atroviridis* Griff.), tamarind, nutmeg, salak, *bidara* (*Ziziphus mauritiana* Lam.), pomegranate and figs. Lately, a few of these rare fruit species such as breadfruit, salak, *jambu air mawar*/*jambu semarang* [*Syzygium samarangense* (Blume Merr. & Perry)] and *pulasan* have been identified to be potential fruits of commercial importance. Hence, they were given attention by farmers and can be found quite widely in the markets.

The potential of most of the wild fruit species that are found in the jungle has not been identified (Rukayah, 1999). Apart from being source of food for birds and other animals, some are edible to man. These include wild fruits such as *buah tampoi* [*Baccaurea macrocarpa* (Miq.) Muell. Arg.], *petai* (*Parkia speciosa*), *kerdas* (*Pithecellobium globosum*) and *durian hutan* (*Durio oxleyanus* Griff.). Those wild fruits that are found in the open areas are usually not large trees but are shrubs and the fruits are usually harvested and enjoyed by children (play with these fruits), insects and birds.

Generally, the scenario of fruit industry in Sabah and Sarawak is quite different to that of Peninsular Malaysia (Rukayah, 1999). Most of the fruits are grown on a small scale or orchards. Apart from the major fruit species that are available in the markets, wild rare fruits such as *buah keranji* (*Dialium indum* L.) and *buah dabai* (*Canarium odotophyllum*) that are growing wild in the jungle can also be purchased from the markets. There are many wild rare fruits such as *durian hutan* (*Durio oxleyanus* Griff.), *belimbing merah* (*Baccaurea angulata*), *isau/kakus* (*Dimocarpus longan* ssp.

malesianus var.malesianus), and many different species of *terap* (*Artocarpus odoratissimus* Blanco) that are available in Sabah and Sarawak cannot be found in Peninsular Malaysia. Nevertheless, since several years ago, Sabah and Sarawak has started cultivation of several major fruits such as carambola, dragon fruit (pitaya), pineapple, jackfruit, cempedak, langsung, citrus and guava on a large scale. For example, in 2004, areas under cultivation of these major fruits in Sabah and Sarawak were 15,606 and 33,579 hectares respectively, while their productions were then 126,535 and 199,392 metric tonnes respectively (DOA, 2009).

DEFINITION OF FRUIT

According to Coombe (1976), fruit is the product of determinate growth from an angiospermous flower or inflorescence. This definition encompasses fleshy fruits that arise from the expansion of the ovary of the flower, and does not include fleshy fruits that arise from the growth of structures other than the ovary, such as the receptacle (apple, strawberry), bract and peduncle (pineapple). However, this botanical definition of a fruit does include dry fruits such as nuts, grains, legumes that are not commercially considered as fruits. The Oxford English Dictionary defines fruit as the edible product of a plant or tree, consisting of the seed and its envelope, especially the latter when juicy and pulpy. Nevertheless, to the layman or consumer, fruit is defined as plant products with aromatic flavours, which are either naturally sweet or normally sweetened before eating, implying that there are usually eaten as dessert foods. Thus, these definitions are more appropriate to the common usage of the term fruit. Figure 1 demonstrates the deviation of some common fruits from an ovary and the surrounding tissues.

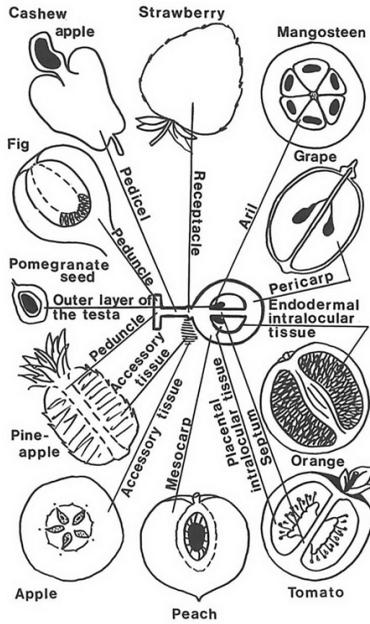


Figure 1 Deviation of some fruits from plant tissue.
(Source: Coombe, 1976)

CELLULAR COMPONENTS

The cells of fruits and vegetables are typical plant cells and the principal components are as in Figure 2 (Wills *et al.*, 1981). Nevertheless, more detailed explanations are available in Brouk (1975) and Esau (1964). Plant cells are bounded by a rigid cell wall which is composed of cellulose fibres and other polymers such as pectin substances, hemicelluloses, lignin and proteins. The middle lamella which is a layer of pectic substances acts to bind adjacent cells together. Adjacent cells often have small communication channels called plasmadesmata linking their cytoplasmic masses. The cell wall is permeable to water and solutes and its main functions are to:

- i. contain the cell contents by supporting the outer cell membrane, the plasmalemma, against the hydrostatic pressures of the cell contents, which otherwise burst the membrane; and
- ii. give structural support to the cell and the plant tissue.

Within the plasmalemma, the cell contents comprise of the cytoplasm and usually one or more vacuoles. These vacuoles are fluid reservoir containing various solutes such as sugars, amino and organic acids and salts, and are surrounded by a semipermeable membrane, the tonoplast. Together with the semipermeable plasmalemma, the tonoplast is responsible for maintaining the hydrostatic pressure of the cell, allowing the passage of water but selectively restricting the movement of solutes or macromolecules such as proteins and nucleic acids. The resulting turgidity of the cell is responsible for the crisp nature of fruits and vegetables.

The cytoplasm comprises of a fluid matrix of proteins and other macromolecules and various solutes. Important processes that occur in this fluid part of the cytoplasm include the breakdown of storage reserves of carbohydrates by glycolysis and protein synthesis. The cytoplasm also contains several important organelles which are membrane-bound bodies with specialised functions. These organelles include the nucleus, mitochondria, chloroplast, chromoplast, amyloplast, golgi complex and endoplasmic reticulum.

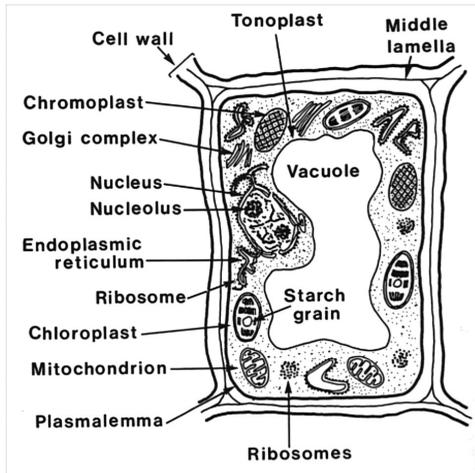


Figure 2 Diagrammatic representation of a plant cell and its constituent organelles
(Source: Wills *et al.*, 1981)

CHEMICAL COMPOSITION AND NUTRITIONAL VALUES

Wills *et al.* (1981) and Wills *et al.* (1998) described the chemical composition and nutritional values of fruits as listed below:

Water

Most fruits contain more than 80 % water, with some such as melons containing about 95 % and those high in starch content containing about 50 % water. The actual water content depends on the availability of the water to the tissue at the time of harvest. Thus, it is desirable to harvest fruits when the maximum possible water content is present, as this result in a crisp texture.

Carbohydrates

Generally, carbohydrates are the most abundant constituents in fruit after water. They are present across a wide range of molecular weights from simple sugars to complex polymers. Carbohydrates can account for 2-40 % of the fruit's tissue. The main sugars present in fruits are sucrose, glucose and fructose, with the predominant sugar varying in different fruits. Tropical and sub-tropical fruits have high sugar contents. Sugars and starch can be digested and utilised by human as energy sources. Carbohydrates are also present as dietary fibre which comprise cellulose, pectic substances, hemicelluloses and lignin.

Proteins

Fresh fruits are not important source of protein in the diet. Generally, fresh fruits contain about 1 % protein, and are mostly functional such as in the form of enzymes rather than acting as a storage pool as in grains and nuts.

Lipids

Lipids comprise less than 1 % in most fruits and are associated with protective cuticle layers on the surface of fruits and with cell membranes. Avocado and olive (used as a fresh fruit) are exceptions as they have 20 and 15 % lipid respectively as oil droplets in the cell.

Organic Acids

Most fruits contain organic acids at levels in excess of what is being required for the operation of TCA cycle and other metabolic pathways. Usually, the excess is stored in the vacuole away from other cellular components. The dominant acids in fruits are usually

citric (found in berries, citrus, guava, pineapple, pear, plum and tomatoes) and malic acids (found in apple, banana, cherry and melon). Other organic acids such as tartaric acid is dominant in grapes and isocitric acid is dominant in blackberries. Organic acids, apart from their biochemical importance, contribute greatly to the taste of fruits as balance between sugar and acid gives rise to the desirable taste of specific fruits.

Vitamins and Minerals

Although vitamin C (ascorbic acid) is only a minor constituent of fruit but it is of major importance in human nutrition for the prevention of scurvy. Virtually, all human dietary vitamin C is obtained from fresh fruits and vegetables. The daily requirement for vitamin C which is 50 mg can be obtained in less than 100g tissue in most fruits. Fruits may also be important nutritional sources of vitamin A and folic acid, usually supplying about 40 % of daily requirements. Potassium, iron and calcium are among the minerals found in fruits.

Volatiles

All fruits produce a range of small molecular weight compounds (molecular weight less than 250) that possess some volatility at ambient temperatures. These compounds are not important quantitatively (normally less than 10 mg/100g are present), but they are important in producing the characteristic flavour and aroma of fruits. Most fruits contain in excess of 100 different volatiles. They are mainly esters, alcohols, acids and carbonyl compounds (aldehydes and ketones). Ethanol and esters are common constituents of most ripe fruits. In most fruits, the characteristic aroma is due to the presence of one or two compounds,

CLASSIFICATION

Fruits, like other horticultural commodities, can be classified according to many factors such as its growing regions and environmental conditions (Kader and Barrett, 2004), respiration rates, ethylene production rates and their respiratory behaviour during ripening (Kader, 1992a).

Fruits that are classified according to their growing regions and environmental conditions (Kader and Barrett, 2004) can be further sub-divided into 3 categories, namely; temperate-zone fruits, subtropical fruits and tropical fruits.

- a) Temperate fruits
 - i) Pome fruits such as apple, pear, quince
 - ii) Stone fruits such as apricot, cherry, nectarine, peach, plum
 - iii) Small fruits and berries such as grape, strawberry, raspberry, blueberry, blackberry, cranberry

- b) Subtropical fruits
 - i) Citrus fruits such as grapefruit, lemon, lime, orange, pummelo tangerine , mandarin
 - ii) Non citrus fruits such as avocado, cherimoya, fig, kiwifruit, olive, pomegranate

- c) Tropical fruits
 - i) Major tropical fruits such as banana, mango, papaya, pineapple
 - ii) Minor tropical fruits such as carambola, cashew apple, durian, guava, longan, lychee, mangosteen, passionfruit, rambutan, sapota(*ciku*), tamarind

Fruits classified according to their respiration rates (Kader, 1992a) include various categories:

- a) Very low respiration rate - such as dates, dried fruits
- b) Low respiration rate - such as apple, citrus, cranberry, grape, honeydew melon, kiwifruit, papaya, persimmon, pineapple, watermelon
- c) Moderate respiration rate - such as apricot, banana, blueberry, cantaloupe, mango, nectarine, olive, peach, pear, plum, tomato
- d) High respiration rate - such as avocado, blackberry, raspberry

Fruits classified according to their ethylene production rates (Kader, 1992a) include the various categories:

- a) Very low rate of ethylene production - such as cherry, citrus, grape, strawberry, pomegranate
- b) Low rate of ethylene production - such as blackberry, blueberry, cranberry, persimmon, pineapple, raspberry, watermelon
- c) Moderate rate of ethylene production - such as banana, fig, guava, honeydew melon, lychee, mango, plantain, tomato
- d) High rate of ethylene production - such as apple, apricot, avocado, cantaloupe, nectarine, papaya, peach, pear, plum
- e) Very high rate of ethylene production - such as cherimoya, passionfruit, sapote(*ciku*)

McGlasson *et al.*, (1978) and Kader (1992a) classified fruits according to their respiratory behaviours during ripening. This class of fruits can be further categorised as climacteric and non-climacteric fruits. Climacteric fruits is characterised by a pronounced increase in respiration coincident with ripening. This increase in respiration is known as respiratory climacteric and it

coincides approximately with the attainment of maximum fruit size. It is during this respiratory climacteric that all the other changes characteristic of ripening occurs, which will be discussed later. Fruits that do not exhibit such a respiratory peak during their ripening and senescence phases are called non-climacteric fruits. Examples of fruits in each category are shown in Table 1. A typical respiratory pattern of fruit during growth, maturation, ripening and senescence phases are shown in Figure 3

The life of fruits (following germination), as can be seen in Figure 3 can be divided into three main physiological phases, namely; growth, maturation and senescence (Wills *et al.* 1981; Salunkhe and Desai, 1984a; Wills *et al.*, 1998). Fruit growth begins with cell division, and cell enlargement accounts for its final size (Salunkhe and Desai, 1984a). Maturation usually commences before growth ceases. Growth and maturation are often collectively referred to as the development phase, and cannot be distinguished very clearly. Wills *et al.* (1981) defined senescence as the period when anabolic (synthetic) biochemical processes give way to catabolic processes which in turn will lead to ageing and final death of the tissues. Ripening, a terminology reserved for fruit, usually starts during the later stages of maturation and it is generally considered as the beginning of senescence. In fact, Biale (1950) referred senescence as 'beginning of an end'. Development and maturation of fruits are completed when it is attached to the plant while ripening and senescence may proceed on or off the plant. Ripening fruit undergoes many postharvest physico-chemical changes that determine the quality of fruit purchased by the consumer (Wills *et al.*, 1981; Wills *et al.*, 1998).

An important characteristic of harvested fruits, like other harvested plant produce is that they are still living organs (Wills *et al.* 1981; Salunkhe and Desai, 1984a; Burdon, 1997; Wills *et al.*, 1998)

as they continue to perform most of the metabolic reactions and maintain the physiological systems that were present when they were still attached to the plant. They still respire, by taking up oxygen and giving off carbon dioxide and heat, and transpire (lose water). While still attached to the plant, the losses due to respiration and transpiration are replaced from the flow of sap which contains water, photosynthates (which are principally sucrose and amino acids) and minerals (Wills *et al.*, 1981; Salunkhe and Desai, 1984a; Wills *et al.*, 1998). Once harvested, fruits are perishable entity because they have to depend entirely on they own food reserves and water as the losses of respirable substrates and moisture are not replenished (Wills *et al.*, 1981; Salunkhe and Desai, 1984a; Wills *et al.*, 1998). They therefore suffer detrimental changes after harvest (Burdon, 1997). These changes include the utilisation of energy reserves through respiration, changes in biochemical composition, changes in texture associated with both water loss and biochemical change and the increased ethylene production associated with ripening of climacteric fruits.

Table 1 Classification of edible fruits according to their respiratory behaviour during ripening.

Climacteric fruits		Non-climacteric fruits	
Apple	Papaya	Blackberry	Pineapple
Apricot	Passionfruit	Blueberry	pomegranate
Avocado	Peach	Cherry	Raspberry
Banana	Pear	Cacao	Strawberry
Bluberry	Persimmon	Carambola	Tangerine
Breadfruit	Plantain	Cashew apple	Mandarin
Cherimoya	Plum	Date	Sweet orange

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

Climacteric fruits		Non-climacteric fruits	
Durian	Quince	Grape	Tamarillo (tree tomato)
Feijoa	Rambutan	Grapefruit	
Fig	Sapodilla	Lemon	
Guava	Sapote	Lime	
Jackfruit	Soursop	Longan	
Kiwifruit	Tomato	Loquat	
Mango		Lychee	
Muskmelon		Olive	
Nectarine		Orange	

(Source: McGlasson, *et al.*, 1978; Kader, 1992a)

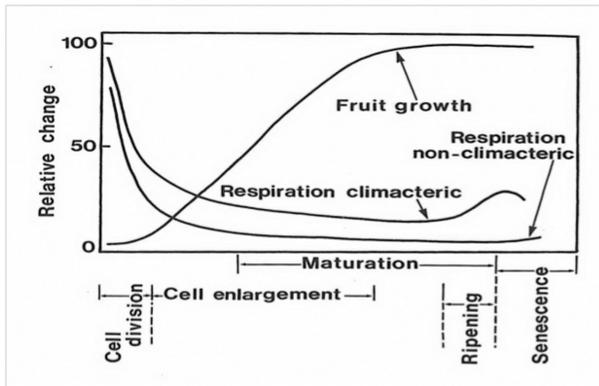


Figure 3 Growth and respiration patterns of fruits during development
(Source: Biale, 1964)

The major metabolic process taking place in harvested fruits is respiration (Wills *et al.*, 1981). Respiration can be defined as the oxidative breakdown of a more complex materials normally present in cells, such as starch, sugars and organic acids, into simpler

molecules such as carbon dioxide and water with the concurrent production of energy and other molecules that can be used by the cells for other reactions.

The respiration rate of fruits is an excellent indicator of metabolic activity of the tissue and thus is a useful guide to the potential storage life of the fruits (Wills *et al.* 1981; Salunkhe and Desai, 1984a; Wills *et al.*, 1998). If the respiration rate of fruit is measured during its development, maturation, ripening and senescence, a characteristic respiratory pattern is obtained (Figure 3). Respiration rate per unit weight is highest for the immature fruit and then steadily decline with age.

FRUIT INDUSTRY IN MALAYSIA

In Malaysia, since the inception of National Agriculture Policy (NAP) in 1984, fruits have been identified as a commodity in which the industry needs to be developed since it has high value adding and export potentials (MARDI, 1992). Since then, significant emphasis and support are given by the government to agriculture including developing the fruit industry. In the NAP, 15 fruits are identified for the development of the fruit industry on a commercial scale. These fruits include banana, papaya, pineapple, watermelon, carambola (starfruit), mango, durian, jackfruit, citrus, duku langsung/dokong, guava, ciku, cempedak, rambutan and mangosteen. One of the main objectives of NAP for developing the fruit industry is to ensure production of local fruits of high quality so that it can meet both local and export demands (MARDI 1992). At the same time, production of these selected fruits on a commercial scale should be increased to ensure fruit growers will have continuous high returns, which in turn could contribute to the economy of the country.

In 1987, Malaysian Fruit Industry Council was established , aiming at encouraging close cooperations between the public and

private sectors in developing the Malaysian fruit industry(MARDI, 1992). In view of its potential, the government has given significant emphasis including giving incentives to ensure the fruit industry could be developed rapidly.

In the early years of the last decade, the country's R&D has focussed on the '8+2' fruit types which include pineapple, papaya, mango, citrus, watermelon, guava, carambola, durian, rambutan and jackfruit, while the remaining fruit types such as banana, mangosteen, ciku, duku, dokong and others were still given due attention by the researchers for future needs (Siti Hawa, 2003). Even though the fruit industry has increased with respect to both demands and production, there are many constraints. These include:

- i) High production cost
- ii) Insufficient promotion and marketing, and
- iii) Lack of new improved varieties to meet changing consumers' and growers' demands and with good post harvest characteristics, resistance to pests and diseases, high yield, short juvenile period, consistent flowering and fruiting, and others.

Malaysian Farm Accreditation Scheme (SALM) was launched in January 2002 by DOA (Department of Agriculture) under the Ministry of Agriculture (Abdullah, 2003), with the objective of giving recognition to farms which adopt good agricultural practices (GAP) in producing fruits and vegetables of high quality and safe to consumers. The GAP incorporates other highly recognised guidelines such as those of EUREPGAP [(Euro retailer Produce Working Group-Good Agricultural Practices), now referred as GLOBALGAP] and other international codes of practices. In addition, it is also guided by NAP 3 which stresses on the need to

further develop the horticultural industry to meet the expanding demand for fresh and processed fruit products in both domestic and foreign markets (MOA, 1999).

In June 2003, FAMA (Federal Agricultural Marketing Authority) launched the Malaysia's best branding programme for five priority fruits, namely; carambola, mango, pineapple, papaya and watermelon. These five fruits were selected because Malaysia has the comparative advantage in producing them (Wan Ibrahim, 2003). According to him, during that time, Malaysia was the biggest exporter of papaya and watermelon to Hong Kong and Taiwan. In addition, Malaysia was also the major exporter of carambola to Europe. Plates 1 and 2 show the Malaysia's best logo and the five priority fruits with the logo on it respectively. This programme is targeted towards promoting production and marketing of high quality produce sealed with a stamp of approval, Malaysia's Best. This programme is not only intended for the application of a common brand for Malaysian fresh produce (fruit), but also an assurance of delivering the quality exceeding the minimum level requirements as determined by the Ministry of Agriculture, to the consumers (Abdullah, 2003). Two basic components of Malaysia's Best are safety and quality (Wan Ibrahim, 2003). The safety component is implemented through the certification of farms to ensure Malaysian agricultural produce, such as fruits, are produced according to good agricultural practices (GAP). This is to ensure that heavy metals, pesticides and microorganisms present in farm produce are at an acceptable and safe level. On the other hand, the quality component encompasses the aspects of grading, packing and labelling of agricultural produce regulations, which are drawn by FAMA and the accredited farms have to comply to this before they are allowed to use the Malaysia's Best logo on their fruit. The Malaysia's Best programme is the continuity of SALM

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

where the fruits are subjected to stringent quality control processes which begin at the farm level and continues at every step of the handling chain until it reaches the consumer by emphasizing on good handling practices incorporating national and international standards especially Codex (Abdullah, 2003). In other words, SALM emphasizes on good agricultural practices, while Malaysia's Best is mainly focussing on quality at post harvest.

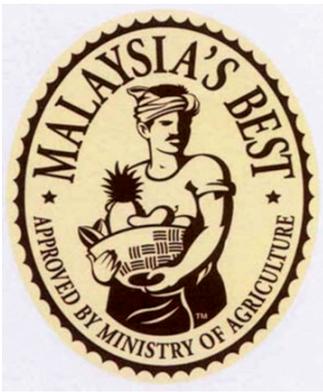


Plate 1 Malaysia's Best logo
(Source: FAMA, 2005)



Plate 2 Watermelon, papaya, mango, carambola and pineapple with Malaysia's Best logo
(Source: FAMA 2005)

Later, in August 2008, 3P Regulations 2008, which was FAMA Act 1965 (Revised) 2004 (Act 141) was gazetted. This is a programme launched by FAMA to improve the quality of agricultural produce, including fruits, through grading, packing and labelling. The regulations require that all agricultural produce are graded, packed and labelled before they are marketed (domestic, export or import). The objectives of these regulations are:

- i) to enhance the efficiency and effectiveness of the marketing of local produce in order to retain their competitiveness

- ii) to maintain current market share or to expand both domestic and overseas market access in line with the changes in the global trade

The 3P Regulations 2008 was run by FAMA and was originally set to be made compulsory by April 2009 (Anon., 2011). However, the deadline for full implementation has been postponed to a later date. There are reports indicating that the 3P Regulations are made effective starting 1 July 2011 and to be fully enforced by end of 2013 (Bernama, 2011).

TROPICAL FRUITS (AREA UNDER CULTIVATION AND PRODUCTION)

Global

The amount of production and area harvested with tropical fruits in the world in 2009 are shown in **Table 2**, while that of the major South-Eastern Asian countries are as in **Table 3**. **Table 4** lists down the world top tropical fruits producing countries.

Table 2 World Tropical Fruits - Production (tonnes) and area harvested (hectare) 2009

Area (Continent)	Production (tonnes)	Area harvested (Ha)
Africa	721499	177328
Americas	1797805	160786
Asia	15283360	2112403
Europe	38000	3200
Oceania	34903	7999
Total	17875567	2461716

(Source: FAO, 2011)

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

Table 3 Major South-Eastern Asian Countries Tropical Fruits - Production (tonnes) and area harvested (hectare) 2009

Country	Production (tonnes)	Area harvested (Ha)
Philippines	3300000	370000
Indonesia	2550000	210000
Thailand	838106	187991
Malaysia	206472	24445
Timor-Leste	866	190

(Source: FAO, 2011)

Table 4 World top tropical fruits producing countries (2008)

Rank	Country	Production (MT)	Value (1000\$)
1	India	3657000	418580
2	Philippines	3200000	366272
3	China	2579095	300578
4	Indonesia	2450000	280427
5	Bangladesh	974760	103014
6	Thailand	877316	88134
7	Brazil	684376	78333
8	Pakistan	547400	64097
9	Colombia	475000	54368
10	Mexico	357130	40061
11	Madagascar	219669	25181
12	Malaysia	201966	26325
13	Peru	175879	18313
14	Turkey	127760	9156
15	Tunisia	86865	8813

(Source: FAO, 2011)

Major and Minor Tropical Fruits in the World Markets

The major tropical fruits in the world markets are mango, pineapple, papaya and avocado while the minor tropical fruits are lychee, durian, rambutan, guava and passion fruit (FAO 2010).

Malaysia (Peninsular Malaysia, Sabah, Sarawak and Labuan)

Table 5 shows the area (hectares) under fruit cultivation and the amount produced (metric tonnes) in Peninsular Malaysia, Sabah, Sarawak and Labuan from 2004-2009 (DOA, 2009). Peninsular Malaysia includes the states of Johore, Kedah, Kelantan, Melaka, Negeri Sembilan, Pahang, Perak, Perlis, Penang, Selangor and Terengganu. The cultivated fruits encompass carambola, papaya, *cempedak*, ciku, dokong, duku, duku langsung, durian, guava, langsung, *limau manis*, *limau besar*, mango, mangosteen, pitaya (dragon fruit), jackfruit, pineapple, banana, *pulasan*, rambutan, *salak* and watermelon.

Table 5 Areas (hectares) under fruit cultivation and amount produced (metric tonnes)

Year	Area(hectare)/ Production (metric tonnes)	Peninsular Malaysia	Sabah	Sarawak	Labuan (Federal Territory)
2004	Area(Hectares) Production (metric tonnes)	245,267 1,204,512	15,606 126,535	33,579 199,392	501 1,132
2005	Area(Hectares) Production (metric tonnes)	242,457 1,296,926	15,640 130,067	34,209 199,485	527 1,631
2006	Area(Hectares) Production (metric tonnes)	230,668 1,094,548	15,904 132,700	34,403 200,316	248 1,589
2007	Area(Hectares) Production (metric tonnes)	227,977 1,100,087	17,001 141,683	34,695 191,452	248 1,589
2008	Area(Hectares) Production (metric tonnes)	212,479 1,260,934	17,412 148,904	34,663 186,184	259 2,064
2009 ^p	Area(Hectares) Production (metric tonnes)	221,100 1,341,190	18,150 158,380	36,100 198,030	300 2,200

^pTemporary Figure
(Source: DOA, 2009)

FRUIT QUALITY

Quality is defined as any of the features that make something what it is, or the degree of excellence or superiority (Kader, 1992b). Quality criteria can be divided into external and internal factors. External factor can be considered as of primary importance for marketing purposes (Wills *et al.*, 2007). Although consumers buy on the basis of appearance and feel, their satisfaction and repeat purchases are dependent upon good edible or organoleptic properties (Kader, 1992b).

Some important quality criteria are listed in Table 6 below. These quality attributes are closely affected by pre-harvest factors, stage at harvest and also postharvest factors.

Table 6 Quality components of fresh fruits and vegetables

Main Factors	Components
Appearance (visual)	Size: dimensions, weight, volume Shape and form: diameter/ depth ratio, smoothness, compactness, uniformity Colour: uniformity, intensity Gloss: nature of surface wax Defects: external, internal Morphological Physical and mechanical Physiological Pathological Entomological
Texture (feel)	Firmness, hardness, softness Crispness Succulence, juiciness Mealiness, grittiness Toughness, fibrousness

Flavour (taste and smell)	Sweetness Sourness (acidity) Astringency Bitterness Aroma (volatile compounds) Off-flavours and off-odours
Nutritive value	Carbohydrates (including dietary fiber) Proteins Lipids Vitamins Minerals
Safety	Naturally occurring toxicants Contaminants (chemical residues, heavy metals) Mycotoxins Microbial contamination

(Source: Kader, 1992b)

CHANGES OCCURRING DURING GROWTH, MATURATION AND RIPENING OF FRUIT

Fruit Growth, Development and Ripening

Fruit enlargement throughout the growing season is the result of cell division before and after flowering (anthesis), cell enlargement after anthesis, or both (Jackson, 1999a). The relative importance of these processes varies from one species to another. Generally, cell division predominates in the first few weeks after blossoming, but overlaps the cell enlargement phase which lasts until fruit maturity. If the cumulative increases in volume, weight, or diameter of a fruit is plotted against time after anthesis, the resulting curve may be either sigmoid or double-sigmoid in character.

Ripening of fruits involves a series of physiological, biochemical and organoleptic changes that transforms an inedible fruit into an

edible fruit with optimal quality features (Sharma *et al.*, 2008). Some of these changes include synthesis of secondary metabolites associated with flavour and aroma, synthesis of pigments, degradation of chlorophyll, alteration in organic acids and cell wall metabolism and softening of the fruit tissue (Giovannoni, 2004). Some of the changes that take place during fruit ripening are detailed out below.

i) Colour

The most obvious signal that occurs in many fruits is colour change, that is the loss of green colour with exceptions of avocado, kiwifruit and a few others (Wills *et al.*, 2007). The loss of green colour is because of degradation of chlorophyll pigments and is often associated with the synthesis of other pigments such as carotenoid and anthocyanins. Although carotenoid is only expressed when chlorophyll degrades, carotenoid is already synthesis during the fruit development. It is just masked by the presence of chlorophyll pigments. Up till now, colour change has been used by consumer to determine the ripeness of fruits and quality acceptability. An example of this is shown in Figure 4 (Osman *et al.*, 1998a; Wan Mustapha, 1998)

ii) Carbohydrates

The largest quantitative change associated with ripening is the breakdown of carbohydrate polymers (Wills *et al.*, 2007). Carbohydrates are organic compounds containing carbon, hydrogen and oxygen. Photosynthesis reduction of CO₂, and the hexoses (glucose, fructose) and pentoses (ribose, ribulose) produces carbohydrates. Polymerisation of several sugar derivatives leads to various storage (starch) and

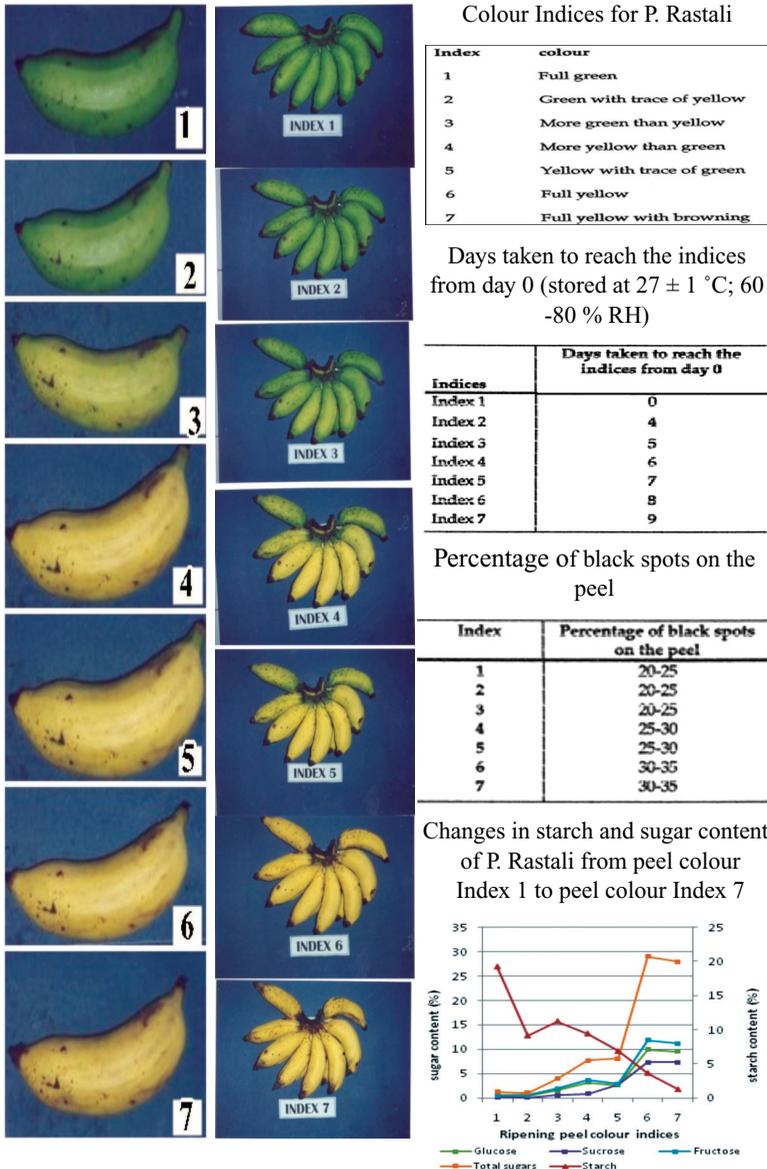


Figure 4 Colour Indices of P. Rastali
 [Source: Osman, *et al.* (1998a); Wan Mustapha, (1998)]

structural components (cellulose, pectin) (Paliyath and Murr, 2008). Changes in carbohydrates include (1) Starch to sugar conversion, (2) sugar to starch conversion and (3) conversion of starch and sugars to CO₂ and water through respiration (Kader, 1992b). These affect both the taste and the texture of produce. Increase in sugar content contributes much sweeter fruits and thus, more acceptable (Wills *et al.*, 2007).

The breakdown of polymeric carbohydrates, especially pectic substances and hemicelluloses, weakens cell walls and the cohesive forces binding cells together. In the initial stages, the texture becomes more palatable, but eventually the plant structures disintegrate (Wills *et al.*, 2007). Cell wall degradation is the major factor that causes softening of several fruits (Paliyath and Murr, 2008). This involves the degradation of cellulose and pectin components and also breakdown of starch (Sharma *et al.*, 2008 and Paliyath and Murr, 2008). Breakdown of pectics and other polysaccharides results in softening of fruits which increase in susceptibility to mechanical injuries (Kader, 1992b). Degradation of cellulose and pectin is mainly caused by enzyme activity. The activities of both cellulase and pectinase have been observed to increase during ripening of avocado fruits and result in their softening (Bennet and Christofferson, 1986).

iii) Organic acids

Organic acids are major components of fruits. The acidity of fruits arises from the organic acids that are stored in the vacuole (Paliyath and Murr, 2008). Different fruits have different composition of organic acids. Generally, young fruits contain more acids, that declines during maturation and ripening as they are respired or converted to sugars (gluconeogenesis) (Paliyath and Murr, 2008; Wills *et al.*, 2007).

In general, citric and malic acids are the major organic acids of fruits (Paliyath and Murr, 2008). Acids can be considered as a reserve source of energy to the fruit and would, therefore, be expected to decline during the greater metabolic activity that occurs on ripening (Wills *et al.*, 2007).

iv) Aroma

One of the factors that contribute to the acceptance of optimal eating quality is aroma. Aroma of a fruit is due to the synthesis of many volatile organic compounds during fruit ripening (Wills *et al.*, 2007). The compounds are mainly esters, alcohols, acids, and carbonyl (aldehydes and ketones). Although ethylene contribute to the major volatile formed with 50-75 % of the total carbon, it does not contribute to the fruit aroma. The number of volatile compounds was reported to increase throughout the ripening of jackfruit (Ong *et al.*, 2006). Voon *et al.*, (2007) detected 22 esters, 14 sulphur compounds, 7 alcohols, 3 aldehydes and 1 ketone in the pulp of five different durian cultivars using solid-phase micro-extraction coupled to gas chromatography-time of flight mass spectrometry (GC-TOFMS).

v) Tannins

The term ‘tannin’ refers to a complex range of phenolic compounds which give the fruit a bitter or astringent taste (Jackson and Looney, 1999a). This taste is often confused with sourness as it tends to leave a furry sensation in the mouth after swallowing. Tannins are important in the overall taste of the fruit: too much of this flavour principle is unpleasant, but too little can result in the fruit tasting flat. People vary in their

ability to tolerate bitterness in fruit. Tannins will often change in form as fruits mature and become less astringent to the taste.

vi) Respiration

The respiration rate indicates the degree of metabolic activity taking place in the fruit. In general, when this rate is high, ripening and senescence will proceed rapidly (Jackson and Looney, 1999a). It thus indicates the potential storage life and relative perishability of fresh fruit and it is a guide to the storage conditions that should be employed after harvest. In general, the higher the respiration rate (example banana, and avocado), the shorter is postharvest life (Kader, 2002).

vii) Ethylene

Ethylene production increases during ripening of climacteric fruits and it is believed that this gaseous plant hormone is the initiator of the ripening process in these fruits (Jackson and Looney, 1999a). One unique characteristic of climacteric fruits is that the presence of small amount of ethylene, either applied or produced by the fruit, stimulates the fruit to produce more ethylene which further accelerates the ripening process. With non-climacteric fruits, applied ethylene will stimulate some aspects of fruit ripening, such as chlorophyll breakdown in citrus rind, but the fruit do not respond by producing more ethylene. Clearly, the effects of ethylene on fruit ripening profoundly affect the approach to fruit storage.

There are many factors which can affect the post harvest quality of fruits. These include:

- i. preharvest factors
- ii. maturity stage at harvest
- iii. postharvest factors

Preharvest conditions and the degree of harvest maturity significantly affect the fruit quality after harvest. Harvesting the fruit at the correct time physiologically can influence its performance at postharvest (Burdon, 1997). The postharvest handling system should focus at ensuring the harvested fruit reaches the market in the exact conditions required by the end user.

PREHARVEST FACTORS

a) Light

Appropriate light intensity and quality do influence postharvest eating quality of fruits. Insufficient or excessive light striking the plant can cause alteration in product appearance (Kays, 1999). Excessive sunlight exposure causes sunscald or sunburn which is a common problem for a wide range of crops (Sams, 1999 and Kays, 1999). Pineapple (Lutchmeah, 1992) and banana (Wade *et al.*, 1993) are some examples of crops with significant sunscald problem. Initially, pigmentation of the affected area is degraded by the excess solar energy. This is followed by cellular death and collapse of the tissue if the duration or intensity of exposure is high enough (Kays, 1999). Insufficient light typically results in smaller fruit.

b) Pruning

Pruning is an operation of removal of part of plant in order to maintain and manipulate crop canopy and bearing (Shukla *et al.*, 2007). The greater the light interception by an individual fruit and its surrounding leaves the better is its quality [including fruit colour, size, soluble solids concentration (SSC), and flavour] (Crisosto *et al.*, 1995).

Some of the importances of pruning operation are listed below:
Encourages the initiation of multiple shoots which bears flowers and fruits

- Removal of diseased, dried and broken non-reproductive branches
- To increase better light interception for better photosynthesis
- To encourage new shoots for flower initiation
- To restrict vegetative growth for better fruit growth and development
- Rejuvenation of old fruit tree

c) Temperature

Temperature does not only affect growth but also development and in some cases, it interacts with photoperiodism to affect growth and development (Madakadze, 2004). Photoperiodism is the response of an organism to the length of a light period (Prasad, 2003). Temperature plays a key role in germination of seeds, growth of seedlings, flowering, fruit set, fruit and tuber development, incidence of pests and diseases, quality of produce, storage and etc. (Peter, 2007).

Temperature increases as latitude and altitude decrease, and extremes are moderated in sites close to a large volume of water. Temperature is modified by geographic features such as slopes and wind currents (Jackson and Looney 1999b). Tropical fruits usually grow in areas within the latitudes 23.5 °N – 23.5 °S where there is little temperature difference throughout the year and they need substantial amounts of heat to ripen. Few types of tropical fruits tolerate frosts at any time during the year (Jackson, 1999b).

d) Rainfall

Rainfall affects the crop growth and incidence of pests and diseases by altering relative humidity of atmosphere and by altering the atmospheric and soil temperature. Under high rain fall areas, crops grow vigorously and occupy large area (Peter, 2007). Both excessive water and drought can affect the quality. Too much water leads to water-logging of which many fruit crop are susceptible. Lack of sufficient water however will affect taste, appearance and increase incidences of certain pests.

Peel-pulp Splitting Disorder (PPSD)

Peel- pulp splitting disorder (PPSD) is one of the physiological disorders observed in Mas banana (Plate 3), where the peel of the fruit cracks and the underlying pulp splits while fruit is still attached to the plant. This is not observed in the other local dessert bananas such as ‘Berangan’ banana and Rastali banana. Usually, this disorder is caused by environmental or cultural conditions such as humidity, rainfall or weather fluctuations. PPSD and fruit cracking are also a major commercial problems in other crops such as tomatoes (Peet, 1992; Whaley and Scott, 1997; Emmons and Scott, 1998), citrus

(Almela *et al.*, 1994), pomegranate (Kumar 1990; Roy and Waskar, 1997), apple (Opara, 1996a; Opara 1996b), atemoya (Paull, 1996a) and many others. Higher occurrence of PPSD in Mas banana are found in areas with relatively higher (>2000 mm total rainfall) rainfall distribution (Wo *et al.*, 2003a). From their study, they also observed that over-ripe fruit and/or rainy weather in the last few days before harvesting could result in more fruit fingers with this disorder. PPSD Mas banana fruits are seen to ripe more rapidly than the non-split ones.

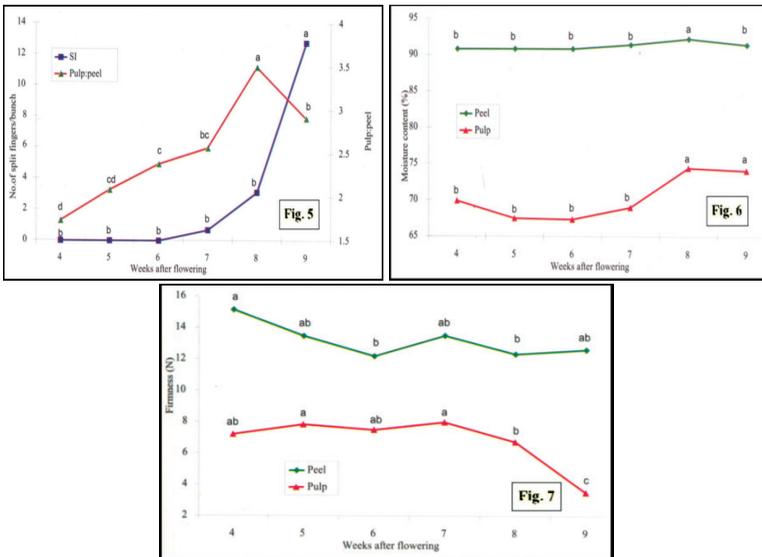


Plate 3 Peel-pulp Splitting disorder in Mas banana

The fact that the PPSD fruits having higher concentrations of soluble solids and pulp moisture suggested that excess nutrients and moisture may be the causal factors of PPSD in Mas banana (Wo *et al.*, 2003b). Later, it was found that sudden changes in the pulp to peel ratio (Figure 5), moisture content (Figure 6) and firmness (Figure 7) at the later stage of maturity [7 weeks after flower emergence (WAFE)] gave significant positive correlations with PPSD incidence (Wo *et al.*, 2005). They found that incidence of PPSD occurred from 6 to 9 WAFE and there was higher incidence of PPSD in fruit bunch with delayed harvesting (Figure 5). High incidence of PPSD was found at rainy season due to high water

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

uptake by the pulp. This increase in pulp size when the peel of fruit was not able to accommodate the sudden increase in fruit size causes the peel to split. Their results indicating positive correlations between the incidence of PPSD and fruit circumference, fruit weight and pulp to peel ratio also suggested that the increase in PPSD was also related to a rapid increase in fruit size especially at the late harvesting stage and at rainy season.



Figures 5, 6 & 7 Changes in splitting incidence (SI) and pulp ratio (Figure 5), moisture content (Figure 6), and pulp and peel firmness (N) of Mas Banana (*Musa cv Mas*) during maturation. Means with same letter are not significantly ($p \leq 0.05$) different.

Wo (2007) further reported that the soluble solids concentration, titratable acidity and pH of of Mas banana indicated that the fruit had reached harvest maturity at 6 to 7 WAFE. She further found that peel calcium content of PPSD fruits was significantly lower than the normal fruits, suggesting that the incidence of PPSD could be

attributed to the lower intercellular strength as a result of low peel calcium (Wo *et al.*, 2007)

From scanning electron microscope (SEM) micrographs of PPSD fruit (Figures 8-12), there was no intercellular space observed within pulp region as compared to the apparent intercellular space in the normal fruit pulp (Wo, 2007; Wo, *et al.*, 2007). Pulp cells of PPSD fruit had enlarge and expanded rapidly during the later stage of fruit development. Hence, incidence of PPSD occurred in some of the fruits harvested at 6 to 9 WAFE when the space provided by the peel had been fully occupied and the continually expanding pulp put stress towards the peel causing the peel to split. When this occurred, the splitting force would be driven to the pulp. This happens because of the longitudinal peel strain structure as well as the high cell-adhesion strength between the peel-pulp transition layer and the mesocarp at the green mature stage. The vascular bundles in PPSD banana fruit peel were observed to be relatively smaller as compared to the normal fruit peel, suggesting that the normal fruits had better transpiration and respiration routes for water and nutrient balance within the fruit.

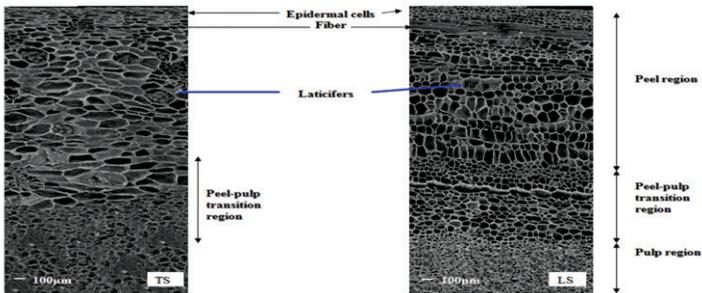


Figure 8 Transverse section (TS) and longitudinal section (LS) of Mas banana when viewed by scanning electron microscopy (SEM). The epidermal cells on the surfaces of the banana fruit sections are readily distinguished; three major parts are peel, peel-pulp transition and pulp
 TS = x 33; LS = x 32

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

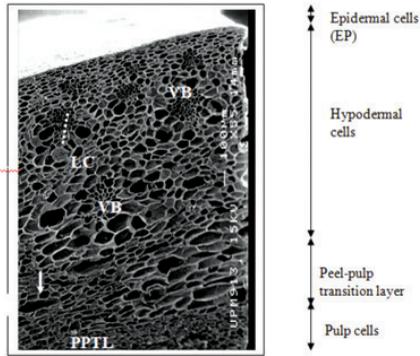


Figure 9 SEM micrograph of Mas banana peel transverse section with PPSD. Vascular bundles (VB) and lactifers (LC) with coagulated latex intersperse within the hypodermal cells. Arrows show the intercellular spaces at the peel-pulp transition layer (PPTL). A dotted line measures the size of a VB. x55

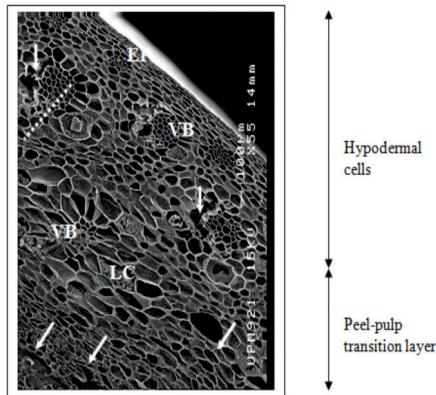


Figure 10 SEM micrograph of normal Mas banana peel transverse section (control) obtained from the same bunch as the PPSD fruit. Arrows show the intercellular spaces at the PPTL, hypodermal cells and VB. x55

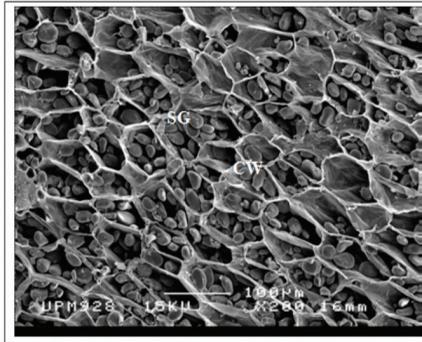


Figure 11 SEM micrograph of Mas banana pulp transverse section with PPSD fruit from a fruit bunch harvested at 7 weeks after flower emergence. Starch granules (SG) seem heavily deposited the pulp cells. The pulp cell walls (CW) are turgid at mature green stage. x200

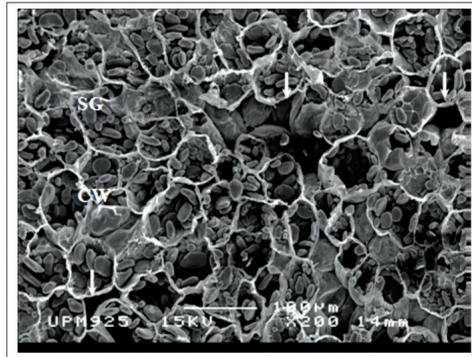


Figure 12 SEM micrograph of a normal Mas banana peel transverse section (control) from the same brunch with the PPSD fruit harvested at 7 weeks after flower emergence. Starch granules (SG) seem heavily deposited the pulp cells. The pulp cell walls (CW) are turgid at mature green stage, arrows show the intercellular spaces at the peel region x200

From the results of studies obtained by these researchers, it could be suggested that incidence of PPSD could be reduced by harvesting the fruit bunches once it has reach the maturity stage at 6 to 7 WAFE. It should also be noted that delay harvesting to obtain more mature fruits will increase incidence of PPSD which in turn will result in reduction in market quality and loss of yield.

e) Soil, fertiliser, irrigation

Soil fertility refers to the ability of a soil to supply the nutrient elements in the amounts, forms and proportions required for maximum plant growth. It is measured in terms of the amount of the available forms of the essential nutrient elements in the soil at any given time (Jones, 1982). When nitrogen, phosphorus, potassium and sulphur are artificially supplied to the soil, they are often added as multi-nutrient fertilisers. Sulfur is not usually guaranteed as an ingredient of fertilisers but is an incidental ingredient of some multi-nutrient fertilisers (Jones, 1982). Sandy soils are not good as they contain very little nutrients and have poor water holding capacity. Heavy clay soils are very difficult to work but suitable for palm tree crops. The acidity and/or alkalinity of the soils are also very important (Peter, 2007).

Irrigation is an increasingly important practice in fruit production. It is even being used in regions with 900-1400mm of rain; a rate of precipitation long considered adequate for commercial production. The justification is that even a 1 or 2-week period of water stress can seriously reduce crop yields or fruit quality (Jackson, 1999c).

MATURITY STAGE AT HARVEST

It has been observed that the quality of harvested fruits is also affected by their stage of maturity at harvest. Fruits with good quality are obtained when harvesting are done at the proper stage of maturity. Immature fruits when harvested will give poor quality and erratic ripening while delayed harvesting may increase their susceptibility to decay, resulting in poor quality and hence low market value.

The maturity stage at harvest for harvesting the fruit depends on the market for which it is intended and it is determined in terms of the marketable life required. In commercial terms, this often equates to whether it will be air-or sea-freighted (Burdon, 1997). Fruits to be air-freighted will have a shorter journey time and may therefore be harvested slightly more mature than that going by sea; in all cases, the maturity at arrival should match that required by the importer. In this discussion, examples of fruits that are used to illustrate the above are passion fruit, breadfruit and local dessert bananas (Berangan, Rastali and Mas bananas).

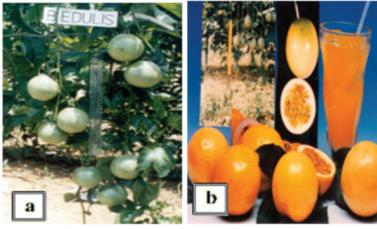
Passion Fruit

Passion fruit belongs to the family Passifloraceae which is represented by 14 genera, of which the genus *Passiflora* is the principle representative (Bora and Narain, 1997). According to them, the important commercial varieties are the yellow (hard, thick yellow rind with brown seeds) and purple (purple skin with black seeds). Both varieties contain pulp which varies from yellow to orange in colour. Purple passion fruit juice, because of its pleasant flavour is usually consumed as fresh juice while the juice of yellow passion fruit is considered suitable for processing. Due to its high acidity and strong aroma, fresh passion fruit juice is considered

as concentrate and is mainly used in the production of diluted sweetened beverages, and processed as jam, jelly and marmalades. According to Morton (1987), passion fruit juice can be boiled down to a syrup which can be used in the preparation of ice cream, candy, cake icing and filling, sauce and cold fruit cocktail.

A study was carried out to determine changes in the physico-chemical characteristics of three yellow passion fruit accessions, namely, Yellow Hybrid (YH-1), Brazilian Edulis (BE-1) and Sabah Yellow (SY-1) during fruit maturation (Ramli, 1995). Results obtained will indicate the optimum harvest time for good juice yield and other associated characteristics. As can be seen in the figures (Figures 13a-g), there are changes in the physico-chemical characteristics of these three yellow passion fruit accessions as the fruit matures (Ramli, 1995). Pulp weight and juice volume followed a single and double sigmoid pattern respectively (Ramli, 1995; Osman, *et al.*, 1996a).

The intensity of the juice colour (yellowish) increased progressive until 9th and 8th weeks after fruit set for both YH-1 and BE-1, and SY-1 respectively. TSS, pH and ascorbic acid content increased until the 9th week for BE-1 and YH-1 and until the 8th week for SY-1. While total sugars increased until the 8th week for SY-1 and the 9th week for BE-1 and YH-1, tannin content was the lowest at the 8th week for SY-1 and the 9th week for BE-1 and YH-1. From the changes observed in this study, it can be recommended that accessions BE-1 and YH-1 could be harvested between the 8th and 9th week while accession SY-1 could be harvested between 7th and 8th week as the sugars and ascorbic acid contents are at their optimum.



a) *B.edulis* fruit ripe fruit; juice b) *B.edulis* fruit;

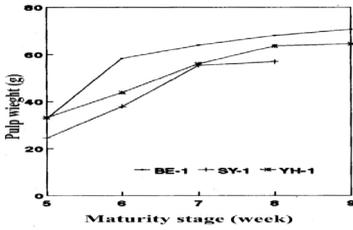


Figure 13a Changes in fruit pulp weight during fruit development

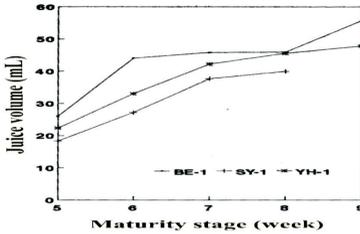


Figure 13b Changes in juice volume during fruit development

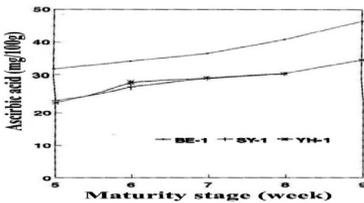


Figure 13c Changes in ascorbic acid during fruit development

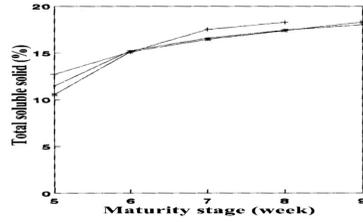


Figure 13d Changes in total soluble solid during fruit development

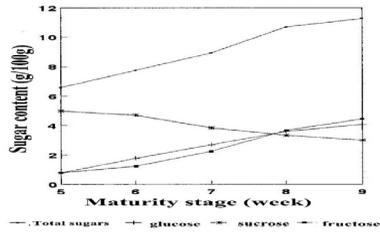


Figure 13e Changes in sugar content in YH-1 during fruit development

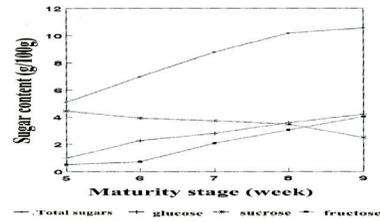


Figure 13f Changes in sugar content in BE-1 during fruit development

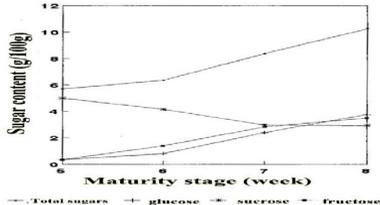


Figure 13g Changes in sugar content in SY-1 during fruit development

(Source: Ramli, 1995; Osman, *et al.*, 1996a)

Breadfruit

Breadfruit, a tropical fruit which originated in the Indo-Malayan archipelago (Popenoe, 1920) is borne on a large tree, usually found in the lowlands of the tropics. It is a dense, spherical to avoid fruit weighing 0.2-3 kg. The fruit is a starchy staple and the mature, unripe fruits are eaten in much the same way as tubers and root crops (Worrel and Sean Carrington, 1997). In comparison to these, breadfruit is as good nutritionally, and in some cases superior, especially in terms of mineral and vitamin content (Graham and de Bravo, 1981). Although, in most of the tropical countries, breadfruit is consumed locally, there are export trade from the Caribbean to Europe and North America, serving the ethnic markets (Roberts Nkrumah, 1993).

Breadfruit appears to be underexploited as a food principally because of its poor postharvest storage behaviour, Nevertheless, converting the fruit pulp to dry flour which is more stable offers solution to the storage stability problems (Wootton and Tumaalii, 1984). In the South Pacific Islands, breadfruit flour is prepared by grinding sun-dried pulp slices. It has been used in Hawaii as a replacement for taro in 'poi' (Reeves, 1973) and can also be used in other recipes.

In Malaysia, breadfruit is consumed as vegetables and also made into snacks such as chips and fritters (dipped in batter and deep fried). In some places, breadfruit cubes together with cubes of other root crops or tubers are the main ingredients in the making of "pengat" or "bubur caca". Therefore, information on the changes in the physico-chemical characteristics are useful in determining the stage for harvesting the fruit for the related end use. There are changes in the physico-chemical characteristics during fruit development (Bassin, 1993; Osman, *et al.*, 1994). The fruit length, width and weight exhibited a double sigmoid pattern and the

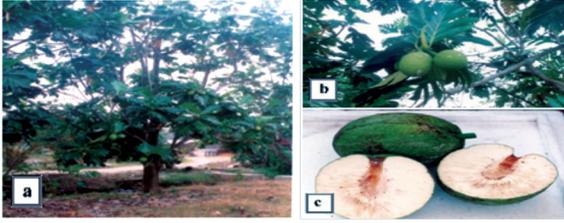
physiological maturity was attained at week 8 after fruit set (Figures 14a-b), while fruit firmness and the number of polyhexagonal segments on the skin decreased with maturity (Figures 14c-d).

Apart from the pH and total soluble solids (TSS) content, tannin, moisture, protein, crude fibre and titratable acidity increase as the fruit matured. On the other hand, the starch content exhibited a gradual increase followed by a rapid production period reaching a peak at week 12 after fruit set and this was followed by decreasing trend thereafter (Figure 14e). In Figure 14e, it could also be seen that the changes in starch content was reflected in the increase in sugar content, suggesting that the starch was converted into glucose, fructose and sucrose especially in the later part of the fruit development.

Banana

Bananas are members of the *Musaceae* family which act as a dessert fruit to millions of people in the world and rank amongst other fruits as a major international trading commodity (Turner, 1997). Nevertheless, the international banana trade represents only 15-20% of the total world banana production. Apart from the high nutritional value, they have a delightful flavour and are available in all seasons of the year. In the commercial production of bananas, the fruit is harvested while green and transported to market where in some cases, it is ripened under controlled conditions with the aid of exogenous ethylene in ripening rooms or chambers. In most cases, there is always a need to transport the banana fruit in a green state. Hence, harvest time represents a compromise between leaving the fruit on the plant long enough to maximise yield or harvesting it soon enough so that there is sufficient greenlife to market the fruit in the manner expected by the end user (Turner, 1997).

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature



a) breadfruit tree
b) breadfruit
c) LS of mature breadfruit

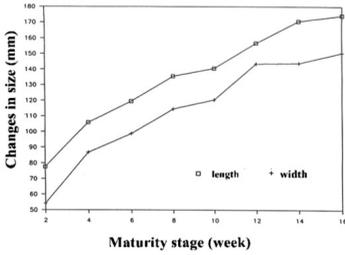


Figure 14a Changes in fruit length and width during fruit development

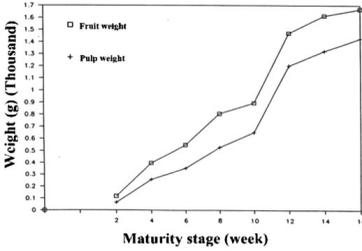


Figure 14b Changes in fruit and pulp weight during fruit development

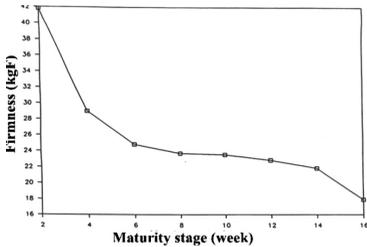


Figure 14c Changes in fruit firmness during fruit development

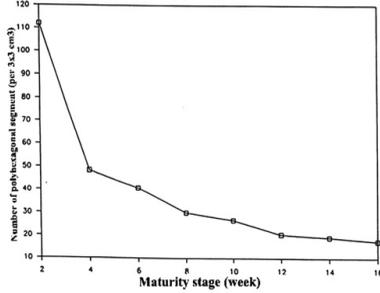


Figure 14d Changes in number of polyhexagonal segments on skin during fruit development

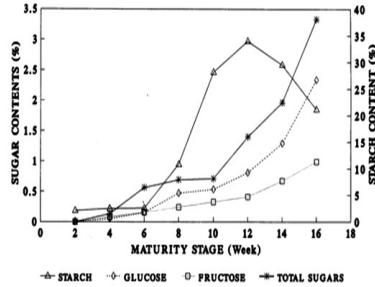


Figure 14e Changes in fruit starch and sugar contents during fruit development

(Source: Bassin, 1993; Osman, *et al.*, 1994)

Peacock (1995) reported that for every week that the fruit is harvested earlier than normal, greenlife increases by three to five days but bunch weight falls by almost 10%. Nevertheless, in order to ensure that dessert banana will undergo through the ripening process satisfactorily, it should be harvested at maturity, which is defined by Peacock and Blake (1970) as ‘the stage of biochemical development that a fruit has reached when the climacteric rise begins’.

In Malaysia, banana is one of the non seasonal fruits mentioned earlier. Among the dessert bananas which are of economic importance include ‘Berangan’ banana, Mas banana, Rastali banana, Embun banana and the Cavendish banana. Studies are conducted to determine the changes in the physico-chemical characteristics of ‘Berangan’ banana, Mas banana, Rastali banana, (Mohd Hidzir, 1998; Osman, *et al.* 1998b; Abdul Rahman, *et al.* 1998; Nik Saad, 1996) and Cavendish banana (Mustaffa, *et al.*, 1997; Mustaffa, *et al.*, 1998). Some of these changes during fruit development of Mas banana, Rastali banana and ‘Berangan’ banana are shown in Figures 15a-g.

Changes in sugar content during fruit development of ‘Berangan’ banana and Rastali banana follows a similar trend as exhibited by Mas banana, where sugar content tends to increase with fruit maturity.

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

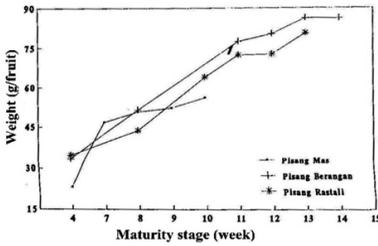


Figure 15a Changes in fruit weight during fruit development

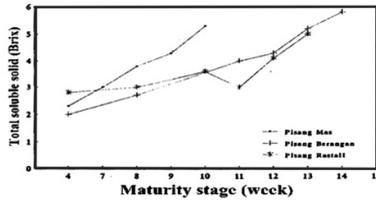


Figure 15d Changes in total soluble solid during fruit development

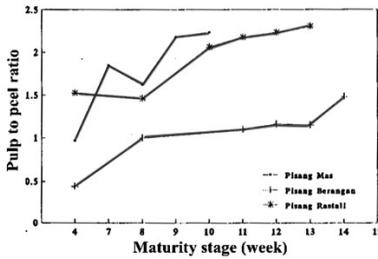


Figure 15b Changes in pulp to peel ratio during fruit development

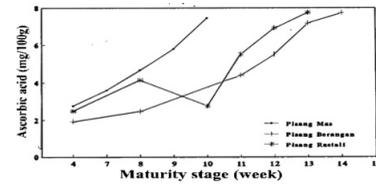


Figure 15e changes in ascorbic acid during fruit development

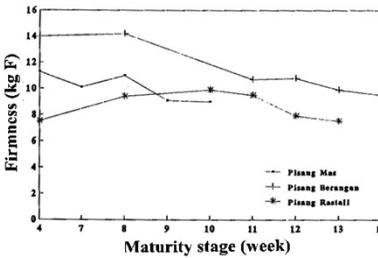


Figure 15c Changes in texture during fruit development

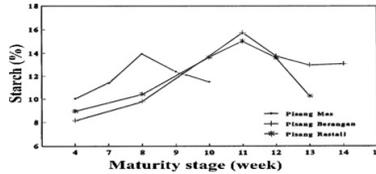


Figure 15f Changes in starch during fruit development

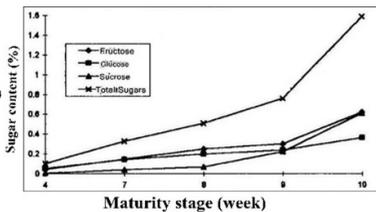


Figure 15g Changes in sugars of P.Mas during fruit development

(Source: Mohd Hidzir, 1998)

The study which was carried out to observe the changes in the physico-chemical characteristics of Cavendish bananas included observations to determine whether the positions of the hands within a bunch and fingers within a hand do affect these changes (Mustaffa *et al.*, 1998). They found that there were significant differences in the physico-chemical characteristics of fruits from different positions (hand and fingers within a hand) of the bunch at different maturity stages (Figures 16a-f). The results they obtained indicated rapid changes in the physical characteristics such as weight, volume and length of fruits. The total soluble solids, ascorbic acid and sugar contents increased slowly during development, then rapidly during ripening. Changes in both pH and titratable acidity values were found to be irregular in all fruits in all positions during the maturity stage.

Their results also showed that there were significant differences between the different positions of hand in a bunch and between different positions (upper and lower) of finger in a hand during the maturity stage. They found that the top hand (1st hand from the top) and upper fingers were bigger in size, mature and ripens earlier compared to the middle (5th hand from the top) and bottom (2nd hand from the bottom) hands within a bunch and lower fingers within a hand respectively.

These researchers also reported that the results of their work in determining changes in tannin and pectic substances at different positions within a bunch of Cavendish banana showed the same trend (Mustaffa, *et al.*, 1997). The top hands and upper fingers were higher in tannin, AIS (alcohol insoluble solids) and pectic substances than the middle and bottom hands within a bunch and lower fingers within a hand respectively. The positional effects seen in these studies could possibly be due to difference in the physiological maturity of the fruit. Results obtained from these

studies by these researches (Mustaffa, *et al.*, 1997; Mustaffa, *et al.*, 1998) are important for researchers working on bananas in assisting them to select and categorise bananas of similar physico-chemical characteristic to ensure getting reproducible results. For those involved in the commercial post harvest handling of bananas, the results obtained in these studies provide a useful guide for the post harvest handling of bananas of similar maturity and characteristics.

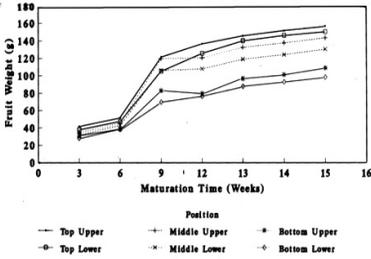


Figure16a Changes in weight during fruit development

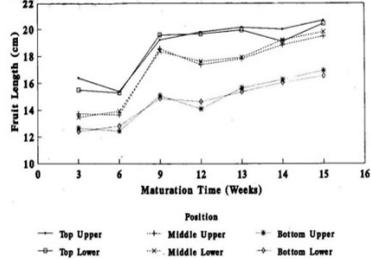


Figure16b Changes in length during fruit development

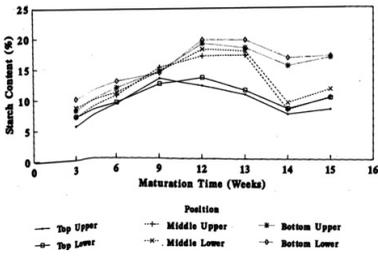


Figure16c Changes in starch content during fruit development

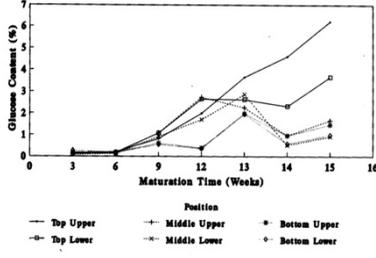


Figure16d Changes in glucose during fruit development

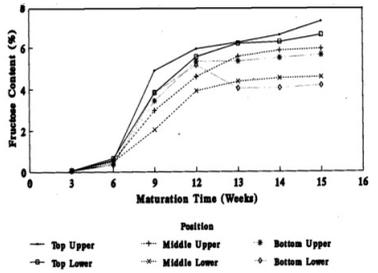


Figure16e Changes in fructose during fruit development

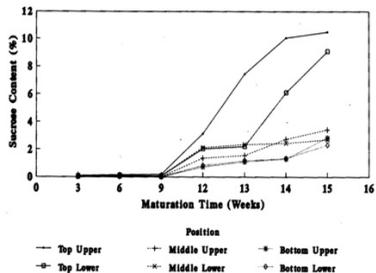


Figure16f Changes in sucrose during fruit development

(Source: Mustafa, *et al.*, 1998)

POSTHARVEST FACTORS

Postharvest Factors Affecting Fruit Quality

Harvesting the fruit moves it to the postharvest handling system. The way in which it is handled thereafter determines the condition in which it will reach the market. A number of studies on the effect of different postharvest treatment on changes in physico-chemical characteristics are carried out on fruits such as carambola (Osman *et al.*, 1996b), guava (Osman *et al.*, 1996c), sapota (ciku) (Osman *et al.*, 1998c), papaya (Osman *et al.*, 1999a) and honeydew (Osman *et al.*, 2000a). In all these studies, it was found that the mechanical injured fruits contributed towards a more rapid physico-chemical changes that led to fruit deterioration, thus a shorter shelf life as compared to fruits subjected to other treatments such as hydrocooling and chilling injury. The physico-chemical characteristics studied include the polygalacturonase (PG) activity, texture, pH, titratable acidity and total soluble solids content.

The postharvest factors, which affect the quality of fruits are discussed below.

a) Temperature

Temperature affects most of the physiological processes of the harvested fruits. Respiration, transpiration and ethylene production rates are the main naturally occurring physiological processes, which affect the quality of harvested fruits (Ben-Yehoshua, 1987). Temperature effectively affects activity of enzymes in fruits. Generally, activity of enzymes in fruits declines at temperature above 30°C. Many enzymes are still active at 35° C, but most of them are inactivated at 40° C. Therefore, normal ripening occurs only within a particular range of temperature from 10-30° C (Wills *et al.*, 1998). The main physiological disorders of fruits related to

temperature are chilling injury, heat injury, green ripening, loss of texture (softening) and browning of peel and pulp of fruits (Smith *et al.*, 1989; Pantastico *et al.*, 1990; Dadzie and Orchard, 1997).

i) Chilling injury (CI)

Chilling injury refers to fruit disorder induced by exposure to low temperatures below the optimum level for storage. Below a particular critical temperature, usually between 0 to 10 ° C, chilling injury occurs in many tropical and subtropical fruits (Wills *et al.*, 1998). The primary cause of chilling injury is thought to be damage to plant cell membranes (Skog, 1998). The membrane damage sets off a cascade of secondary reactions, which may include ethylene production, increased respiration, reduced photosynthesis, interference with energy production, accumulation of toxic compounds such as ethanol and acetaldehyde and altered cellular structure. Skog (1998) further stated that as plant structures differ in both susceptibility to damage and ability to repair these membranes, symptoms vary greatly between commodities. CI is a time by temperature problem. If the produce is stored below the critical temperature for short periods, the plant can repair the damage. If exposure is prolonged, irreversible damage occurs and visible symptoms often can be seen. Injury occurs sooner and is more severe, the lower the temperature is below the threshold temperature. Detection and diagnosis of CI is often difficult, as products often look sound when removed from the chilling temperature, but symptoms may occur when the produce is placed at higher temperatures. Symptoms which appear at higher temperatures may appear almost immediately, or may take several days to develop. Symptoms also may not be visible externally (Skog, 1998).

There are several symptoms that commonly result from CI. These include surface lesions, water soaking of tissues, internal

discolouration, breakdown of tissues, failure to ripen and increased susceptibility to decay (Morris, 1982). Banana is extremely sensitive to CI and the optimum range of storage temperature is between 14-16 °C (Nguyen *et al.*, 2003) and can occur during harvesting, distribution and storage, resulting in loss of quality and consumer acceptability as the banana fails to ripen and begins to develop off-flavour. The most common visual symptoms of CI in banana are dull yellow skin, browning of the skin, hardening of the central placenta and increased susceptibility to mechanical injury (Couey, 1982). However, Pantastico *et al.* (1967) reported that symptoms in banana are mainly apparent on the peel. An early or mild symptoms of CI are indicated by browning throughout the peel vascular tissues, while a severe symptom is indicated by browning throughout the peel surface.

CI leads to disruption of normal physiological functions, thereby causing metabolic imbalances, which are often used to quantify and characterise the CI development (Walker *et al.*, 1991). Membrane lipid phase transitions have been proposed to lead to the development of CI (Lyons, 1973). The event caused the damage of the cell membrane resulting in electrolyte leakage. The leakage is generally considered as an indirect measure of plant cell damage (Wang, 1989) and has been used to determine the extent of CI (Murata and Tatsumi, 1979). Apparently, peel discolouration and electrolyte leakage are potential symptoms of CI when banana are exposed to chilling temperatures. Ratule *et al.* (2004) assessed the effects of chilling temperature on the changes in peel electrolyte (PEL), peel discolouration [peel browning index (PBI) and degree of browning (DOB)] of 'Berangan' banana. The results obtained in their study indicated that the increase in DOB which could be due to the increase in phenolic compounds was more rapid in bananas stored at 5°C as compared to 10°C. At 15°C, the significant linear

relationship found between DOB and storage duration could probably be due to the senescence process. CI of bananas stored at 5°C was due to the linear increase in PEL and PBI and the quadratic increase of DOB while chilling injury of bananas stored at 10 °C was due to linear and quadratic increases of PBI and DOB respectively.

Ratule *et al.* (2006) characterised CI development in 'Berangan' banana [*Musa cv Berangan (AAA)*] during storage at 5 and 10 °C. The results of their study showed that degree of browning (DOB), peel electrolyte (PEL), soluble solids concentration (SSC) and weight loss (WL) increased significantly ($p < 0.01$), while peel colour (L^* , C^* and h°) decreased significantly ($p < 0.01$) when 'Berangan' bananas were exposed to 5 °C. The significant ($p < 0.01$) increase in DOB and SSC, and the significant decrease of peel colour were not followed by increase of PEL and weight loss (WL) when banana fruits were exposed to 10 °C. Therefore, they suggested that DOB, PEL, SSC, WL and peel colour (L^* , C^* and h°) were considered to be reliable quantitative measures of chilling damage of 'Berangan' banana during storage at 5 °C. On the other hand, changes in the value of DOB, peel colour (L^* , C^* and h°) and SSC could be used as indicators of chilling injury of 'Berangan' banana stored at 10 °C.

ii) Green ripening

Green ripening is an impairment of the ripening process in both the peel and the pulp of banana due to prolonged exposure to an abnormally high temperature or under inappropriate gas composition during MA storage (Pantastico, *et al.*, 1990). It is characterised by pulp softening and eventual rotting while the peel remains green. Beside high temperature, green ripening is also a common problem for banana stored under MA which involves

the use of sealed polyethylene bags. This problem arises when the ethylene concentration inside the bag increases to a level high enough to trigger off ripening.

iii) Loss of texture

After harvesting of fruits, their firmness (texture) decreases during storage and ripening. Loss of firmness or softening during ripening has been associated with two or three processes (Smith *et al.*, 1989). The first process is the breakdown of starch to form sugar. The second process is the breakdown of the cell walls or reduction in the middle lamella cohesion due to solubilisation of pectic substances. The third process is the movement of water from the peel to the pulp during ripening due to the process of osmosis.

iv) Browning of peel and pulp

Oxidation of phenolic substrates by polyphenol oxidase (PPO) is the main factor of the brown discolouration of many fruits. Dopamine, DOPA, catechol, chlorogenic acid, and arterenol are common phenolic components of fruits peel and pulp (Nguyen *et al.*, 2003). The degree of browning in banana, after cutting, was correlated with PPO activity and the concentration of free phenolic substrates (Weaver and Charley, 1974; Jayaraman *et al.*, 1982)

b) Relative Humidity

Relative humidity affects transpiration of fruits. Transpiration is the movement of water through the cellular tissue of a plant, and eventual evaporation of this water from plant surfaces. Most of the fresh fruits contain about 80 percent water, with some such as watermelon and cucumber containing more than 95% and others which are high in their starch content having around 50% when

harvested (Wills *et al.*, 1998) The main problems of fruits related to low relative humidity are loss of weight (weight loss) and shrinkage of fruit peel. A physiological disorder, peeling difficulty which is specific to Mas banana can be observed when the fruits are ripened at low relative humidity (Tung *et al.*, 1987; Wo *et al.*, 2004).

i) Loss of weight

Fruits continue to lose water after harvest and it cannot be replaced and causes loss of weight. The main mechanism contributing to weight loss is the evaporation of water activated by a gradient of water vapour pressure at different locations of fruit (Zhou *et al.*, 2008). Gradient of water vapour pressure increases by decreasing the relative humidity of fruits storage atmosphere.

ii) Shrinkage of fruit peel

Shrinkage of fruit peel is the natural result of water loss from the surface of fruits to the storage environment with low relative humidity (Smith *et al.*, 1989). Loss in weight of only 5% will cause many perishables including bulky fruits with a low surface area to volume ratio, to appear wilted or shriveled. Even in the absence of visible wilting, water loss can result in reduced crispness and/or early ripening of some fruits (Wills *et al.*, 1998).

iii) Peeling difficulty disorder (PDD)

This disorder is specific to one of the local dessert bananas, Mas banana. Peeling difficulty disorder (PDD) is manifested when the peel is not readily peeled off although the fruit is already at the fully ripe stage (Plate 4). When this occurs, only the yellow- waxy layer of the peel is removed while the inner tissues of the peel strips which are comprised of vesicle are still adhered to the pulp (Wo, 2007).

The failure of the peel to separate readily from the pulp can affect the eating quality of the banana as the adhering peel could result in an astringent aftertaste and masking the aroma and sweetness of the pulp. Studies carried out by Tung *et al.* (1987) and Wo *et al.* (2004) indicated that Mas banana ripened in low relative humidity had poor peeling problems.



Plate 4 Mas banana with PDD
(Source: Wo, 2007)

c) Gases composition of Storage Atmosphere

Under ideal conditions, most plants, including their fruits, respire aerobically. Aerobic respiration in plants involves the breakdown of sugars and other energy sources made during photosynthesis. The overall reaction of respiration of fruits is:



These energy sources are broken down by the well known metabolic pathways (glycolysis, the Krebs's cycle and oxidative phosphorylation) and are used to form adenosine triphosphate (ATP). During this normal respiratory process, the plant and all of its

tissues use O₂ from the atmosphere as a terminal electron acceptor in oxidative phosphorylation, and release the aerobic by-product CO₂ (Kader, 1987). Storage atmosphere including low O₂ and high CO₂ concentrations effectively reduces the respiration rate of fruits. As a result of reduced respiratory activity, the degradative processes associated with ripening and ageing decline (Spencer, 1966). This addition or removal of gases resulting in an atmospheric condition different from that of normal air is called controlled atmosphere (CA) and modified atmosphere (MA) storage. CA storage generally refers to decreased O₂ and increased CO₂ concentrations, and implies precise control of these gases, whereas the MA storage is used when the composition of the storage atmosphere is not closely controlled, such as in plastic film packages where the change in the composition of the atmosphere occurs intentionally or unintentionally (Wills *et al.*, 1981). MA storage can be used in conjunction with refrigeration to extend storage life of some fruits and vegetables (Kader *et al.*, 1989).

CO₂ injury and off-flavours are the main physiological disorders of fruits related to gases composition of storage atmosphere of fruits. CO₂ injury is caused by prolonged exposure of fruits to excessively high concentration of CO₂ and/ or low concentration of O₂ during storage (Wills *et al.*, 1998). Off-flavours are related to the accumulation of the products of anaerobic respiration, i.e., ethanol and acetaldehyde. To reduce or remove the undesirable effects of anaerobic respiration, it would be desirable to transfer the fruits to air at a low, but non-chilling, temperature following low-O₂ treatment so that ethanol and acetaldehyde contents may be decreased to below threshold levels that cause off-flavour (Dangyang and Kader, 1990).

d) Exogenous Ethylene

Ethylene (C_2H_4), a plant hormone, directly and indirectly regulates metabolism of fruits. Increased levels of ethylene increase respiratory and enzymatic activities, decrease cell compartmentalization, alter auxin (other plant hormone) transport and metabolic processes. The rise in the rate of ethylene production indicates the beginning of the ripening process of fruits (Saltveit, 1999). The rate of ripening of climacteric and non climacteric fruits increases by subjecting them to exogenous ethylene (Abdul Shukor *et al.*, 1990). The difference in the response between these two classes of fruit is that the magnitude in the climacteric rise is relatively independent of the concentration of exogenous ethylene, while that of non climacteric fruits, the magnitude of increase is dependent on the concentration of exogenous ethylene.

This can be observed when apples are put together with mature green banana in a closed plastic bag or any other form of packaging, the banana will ripen much earlier than the ones without apples (author's personal observation). The reason for this is that the ethylene which is produced by the apple (exogenous ethylene), triggers the ripening of the banana. Potassium permanganate ($KMnO_4$) is quite effective in reducing ethylene levels. To ensure efficient destruction of C_2H_4 , it is necessary to expose the storage atmosphere to a large surface area of $KMnO_4$ (Wills *et al.*, 1981). This can be achieved by coating or impregnating an inert inorganic porous support such as alumina or expanded mica with saturated solution of $KMnO_4$. Potassium permanganate in this manner had been used to retard ripening of many fruits.

e) Mechanical Damage

Mechanical damage is one of the major factors leading to postharvest deterioration of fruits (Thompson and Burden, 1995). It can occur

at any time from the point of harvest to the point of consumption. Mechanical damage can detract from the product's appearance and increase potential for infection by diseases. It can also result in lower market quality and price. Impact, pressure (compression) and vibrations are the main sources of fruits mechanical damage. Mechanical damage of fruits can also develop browning reaction in the peel and pulp of the fruits (Ben-Yehoshua, 1987).

i) Impact damage

Impact damage can result in bruising with or without skin rupture. Impact bruises are caused by a sharp blow such as an object falling onto the fruit or fruit falling against another fruit or onto a hard surface with sufficient force to damage or even separate the cells. Impact damage can occur throughout the entire marketing process from harvesting to the consumer. Injury is sometimes not immediately apparent but may show later (Dadzie and Orchard 1997).

The response of Rastali banana to simulation of transportation, including vibration and impact was studied in relation to the incident of physiological and pathological disorder (Abdul Rahman *et al.*, 2000a). Fungal infections, blemishes, peel colour and other damage characteristics were evaluated. Result of this study found that the blemished area, peel colour index and mould growth index of Rastali banana increased during the 30 days storage period for both vibration and impact simulation tests. At day 15, Rastali banana with combination test (vibration test combined with impact test) showed higher blemished area and peel colour index as compared to vibration test or impact test alone. The results of their study also indicated that the damage to packaged fruits from handling drops is cumulative and the severity of damage increases as the number of drops increases.

ii) Pressure (or compression) damage

Pressure (or compression) damage results from excessive pressure on the fruit. Pressure damage can occur in fruit even without physical movement. Pressure damage can be caused by other fruits and occurs primarily during and after packing as a result of forcing too many fruits into too small a container (Dadzie and Orchard 1997).

iii) Vibration damage

Vibration damage is mainly associated with transportation and results from repeated and prolonged vibration of the fruit. This damage is greatest in the top layers of fruit, particularly where there is a loose pack, since in this situation there is little to restrain fruit vibration during transportation and distribution (Dadzie and Orchard 1997).

Osman *et al.* (2000b) conducted a study to determine the damage criteria and physical changes of 'Berangan' banana caused by vibration during the simulation of truck transportation. 'Berangan' banana hands packed in standard corrugated fibreboard boxes were subjected to the vibration simulation test using Lansmont Touch Test Electrohydraulic system vibrator with demand level of 0.73 Grms (ASTM Standard). Their result indicated that there was significant ($p < 0.05$) increase in percentage of blemished area, peel colour index and mould growth score with increasing storage time. Skin blemishes caused by vibration established marks on the banana skins and mould growth was primarily observed on the blemished area. From this study, it can be concluded that minimising the occurrence of vibration would be an appropriate preventive measure to maintain the quality and extending the shelf life of 'Berangan' banana

f) Pathogen

Postharvest diseases can cause serious losses of fruits both in terms of quantity and quality. Fruits infected with disease have no market value. Some diseases may affect the skin of the fruits but may leave the underlying flesh intact, while others affect only certain areas of the flesh or the cortical region (Maneenuam *et al.*, 2007). Most of the diseases of fruits are caused by several fungi, sometimes in association with other microorganisms such as bacteria (Maftoonazad *et al.*, 2007). For example, anthracnose is one of the important post-harvest diseases of banana. It is caused by the fungus, *Colletotrichum musae*. Anthracnose is common on wounds, but it is capable of attacking sound fruit as well. Occasionally it invades the necks of banana fingers when they are damaged (Maqbool *et al.*, 2010).

Postharvest Treatments to Overcome Problems Associated with Postharvest Factors Affecting Fruit Quality

Many techniques have been used to overcome some of the problems mentioned above. These techniques are employed to extend the post harvest life and maintain quality of the fruits.

Table 7 Postharvest treatments to overcome problems associated with postharvest factors affecting fruit quality

Problem	Treatment	Reference
Chilling injury	i) Hot water treatment	i) Ratule <i>et al.</i> , 2006 Zaulia, 2008
	ii) Exposure to high temperature prior to low temperature	ii) Ketsa <i>et al.</i> , 2000 Ratule, 2006 Zaulia <i>et al.</i> , 2000
Green ripening	Avoid exposure of fruit to high temperature after harvesting	Pantastico <i>et al.</i> , 1990
Loss of texture	Chemical treatment (dipping in calcium chloride/lactate)	Conway and Sams, 1984 Bico <i>et al.</i> , 2010
Loss of weight	Low temperate and high relative humidity storage,	Trakulnaleumsai <i>et al.</i> , 2006
	Coating treatment	Jafarizadeh Malmiri <i>et al.</i> , 2011a Jafarizadeh Malmiri <i>et al.</i> , 2011b
Shrinkage of fruit peel	Low temperature and high relative humidity storage	Smith <i>et al.</i> , 1989
CO ₂ injury	Controlled atmosphere (CA)	Tariq <i>et al.</i> , 2001 Pantastico <i>et al.</i> , 1990
Off-flavours	Low temperature	Marcilla, <i>et al.</i> , 2006

Mechanical damage	Use of top cushioning materials for all of the packaging methods	Vursavus and Ozguven, 2004
Pathogen	Fungicidal treatment, coating treatment and Irradiation	Zhang and Quantick, 1998 Jafarizadeh Malmiri <i>et al.</i> , 2011a Jafarizadeh Malmiri <i>et al.</i> , 2011b Thomas, 1986
Peeling difficulty disorder	High relative humidity storage	Wo <i>et al.</i> , 2004 Wo, 2007

In this discussion, only the use of surface coating, manifestation of chilling injury (CI), modified atmosphere (MA) packaging and peeling difficulty disorder (PDD) will be discussed.

Surface Coating

Zaulia *et al.* (2007) conducted a study on the effect of various coatings on the chemical changes of different pineapple cultivars (N36 and Gandul) at low temperature storage (10 ± 1 °C; 85-88 % RH). Results obtained in their study showed that emulsion containing 20% v/v palm oil was the most suitable for N36 pineapples as it was found to be effective in reducing the loss in ascorbic acid content, reducing titratable acidity and increasing total soluble solid and sugar-acid ratio of N36 pineapples, without chilling injury during storage. In the case of Gandul pineapple, 20% v/v liquid paraffin was found to be the most suitable coating emulsion for maintaining fruit quality since it has the ability to increase fructose content, reduce titratable acidity and retain ascorbic acid content.

Jafarizadeh *et al.* (2011a) developed an edible coating based on chitosan-glycerol to delay ripening of 'Berangan' banana. Their results showed that edible coating formulation comprising of chitosan (2.02 % w/v)-glycerol (0.18 % w/v) was effective in extending the shelf life and delaying ripening of 'Berangan' banana stored at ambient condition (26 ± 2 °C; 40-50 % RH) . In another study, Jafarizadeh *et al.* (2011b) found that high concentration [(1.5 % w/v) Na-CMC (sodium carboxymethyl cellulose)] in combination with glycerol (1 % w/v) had a stronger effect in retarding the ripening of banana at ambient temperature as compared to other edible coating based on cellulose derivatives [MC (methyl cellulose), HPMC (hydroxypropylmethyl cellulose)] studied.

Chilling Injury (CI)

Ratule (2006) reported that the development of surface browning was the most obvious CI symptom developed in 'Berangan' banana when subjected to chilling temperature:

- 5 °C - increases in peel browning (decreased in peel colour and increased in degree of browning), peel firmness, weight loss, peel electrolyte leakage and soluble solid concentration.
- 10 °C - developed browning (decrease in peel colour and increased in degree of browning) and increase in solid concentration.

There are reports indicating that heat treatments of varying durations appear promising for insect disinfection and as means of delaying ripening and alleviating storage disorders in some commodities (Mitcham and McDonald, 1992). Therefore, the CI development in 'Berangan' banana that was generally indicated by peel browning could also be reduced by application of heat treatment. Postharvest heat treatment have been reported to have

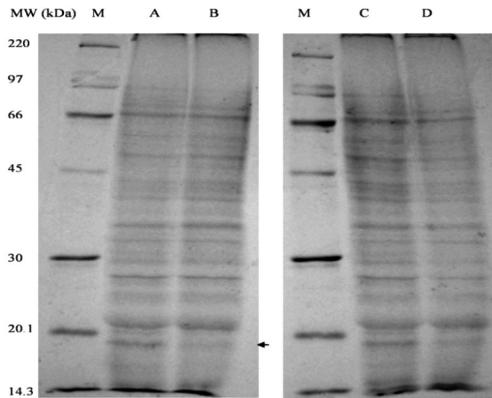
benefits against CI symptoms such as skin pitting, water soaking and skin and flesh browning (Ferguson *et al.*, 2000; Woolf *et al.*, 1995).

There are also several reports indicating that CI could be reduced by heat treatment prior to exposure to low temperature (Klein and Lurie, 1990; McColum *et al.*, 1993; Saad, 1999, Osman *et al.*, 1999b; Osman *et al.*, 2002). A short application of hot water dip (HWD) (53 °C, 2 min) significantly reduced sensitivity of oranges (Wild and Hood, 1989); grapefruit (Wild, 1990; Rodov *et al.*, 1995), lemon and kumquat (Rodov *et al.*, 1995) to CI.

Ratule (2006) conducted a study to determine the effect of HWD in reducing CI development in 'Berangan' banana during storage at chilling temperature (10 °C), so as to obtain the optimum temperature-time response of HWD in reducing development of CI without a significant reduction in fruit quality. The result of his study indicated that conditioning the 'Berangan' banana by HWD at 48 °C for 8 min was the most effective treatment in reducing CI development in 'Berangan' banana during storage at chilling temperature (10 °C).

The protective effect of heat treatments against CI correlated with several biochemical components including accumulation of heat shock proteins (HSP) (Sabehat *et al.*, 1996) and polyamines (PA) such as spermidine (SPD) and spermine (SPM) (Wang 1994). Ratule (2006) conducted a study to determine whether the reduction of CI development in HWD-treated banana was due to the expression of HSP and/or the increase in PA content [putrescine (PUT), spermidine (SPD) and spermine (SPM)]. Result of his study indicated that HWD at 48 °C for 8 min did not show any expression of HSP in 'Berangan' banana. On the contrary, HWD-0D banana exhibited the disappearance of polypeptide with molecular weight 19.13 kDa. (Figure 17). After 8 days of storage, there were more

faint polypeptides (28.07, 35.66 and 51.90 kDa) that were expressed in HWD-treated fruits (HWD-8D). This poor incorporation of amino acid to protein indicated that there was a change of native protein conformation in the peel of banana due to the heat treatment.



The equal of radioactivity at 13,500 counts per min (CPM) were loaded in each lane:

- (A) exposed to control condition (27 ± 2 °C) at day 0 (CON-0D)
- (B) dipped in 48 °C water for 8 min at day 0 (HWD-0D)
- (C) exposed to control condition (27 ± 2 °C) at day 8 of storage (CON-8D), and
- (D) dipped in 48 °C water for 8 min at day 8 of storage (HWD-8D).

Proteins are separated on 12.5% SDS page and visualised by autoradiography. The [¹⁴C] maker proteins (M) are expressed at the left of each lanes A and C. The prominent changes in protein expressions are marked with arrows.

Figure 17 SDS-polyacrylamide gel patterns of [³⁵S]-methionine-labelled proteins in the peel disks of 'Berangan' banana.

However, Ratule (2006) found that HWD at 48 °C for 8 min induced the increase of PA especially putrescine (PUT) (Figure 18a) and spermidine (SPD) (Figure 18b) after 8 days storage at 10 °C (HWD-8D). However, in this study, there was no significant change in the spermine (SPM) content in both control and HWD-treated banana during the 8 days storage. (Figure 18c). This indicated that there was no response of heat stress to increase the SPM content

in HWD-treated ‘Berangan’ banana stored at chilling temperature. This is in contrast to results of other researchers in HWD-treated ‘Fortune’ mandarin where the level of SPM was higher than PUT and SPD (Gonzalez-Aguilar *et al.*, 1997). In this study, banana contained less SPM (Figure18c) than PUT and SPD (Figures18a and 18b). The result obtained in this study is supported by the chromatogram as shown in Figure19. However, Wang and Qi (1997) also reported that SPM contents were relatively low as compared to PUT and SPD in cucumber.

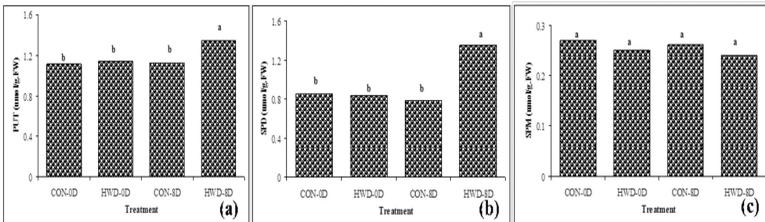


Figure 18 Effect of hot water dip (HWD) on the (a) putrescine (PUT) content, (b) spermidine (SPD) content, and (c) spermine (SPM) content

- (1) exposed to control condition (27 ± 2 °C) at day 0 (CON-0D)
- (2) dipped in 48 °C water for 8 min at day 0 (HWD-0D)
- (3) exposed to control condition (27 ± 2 °C) at day 8 of storage at 10 °C (CON-8D), and
- (4) dipped in 48 °C water for 8 min at day 8 of storage at 10 °C (HWD-8D).

Treatment means followed by the same letter are not significantly different by DMRT, $P \leq 0.05$. FW = Fresh weight.

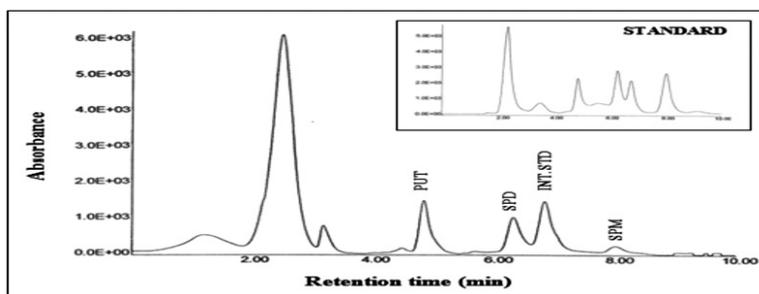


Figure 19 Separation of polyamines (putrescine = PUT, spermidine = SPD, internal standard (INT.STD) and spermine = SPM) in ‘Berangan’ banana peel using high performance liquid chromatography (HPLC). Inside, a reference chromatogram of standard.

Thus, result obtained by Ratule (2006) indicated that the increase in CI tolerance in banana was more likely related to the increase of PUT and SPD which protect the fruits against the chilling temperature. Results obtained were supported by the significant correlation found between PUT and peel L^* ($r = 0.66^*$) and C^* ($r = 0.75^*$) and also significant correlation between SPD and peel L^* ($r = 0.83^{**}$) and C^* ($r = 0.80^{**}$) after storage at 10°C . Ratule (2006) then stated that this increased tolerance against CI development by PUT and SPD could be due to their ability to preserve membrane integrity by retarding lipid peroxidation.

It was reported that PA especially PUT and SPD were able to protect plant cell from oxidative damage (Bors *et al.*, 1989). PA reduced the oxidative damage by stabilising molecular complexes in membranes (Besford *et al.*, 1993), and reducing membrane damage from lipoxygenase activity (Tiburcio *et al.*, 1997). Borrell *et al.* (1997) also suggested that inhibition of lipid peroxidation might be one of the mechanisms responsible for anti-senescence effects of PA. Therefore it was hypothesized that the reduction of CI in

HWD-treated banana by the increase in PUT and SPD could be related to the reduction of lipid peroxidation.

Lipid peroxidation refers to oxidative degradation of lipids resulting in cell damage (Anon, 2006), and may occur either in biologically mediated reaction catalysed by lipoxygenase (LOX) or through direct chemical or photochemical reactions (Kays, 1991). Lipid peroxidation in the membrane would appear during chilling storage and could be responsible for the formation of irreversible liquid gel-phase (Sharom *et al.*, 1994). Lyons (1973) stated that the formation of lipid gel-phase would bring about a contraction that causes crack leading to increased permeability.

In plant, lipid peroxidation occurred by degradation of fatty acids in cell membrane (Kendall and Mckersie, 1989). Gaillard (1968) pointed out that fatty acids are essential components of membranes and are important for the compartmental and orderly function of most physical and chemical reactions taking place in a functional fruit cell. It was also reported that there was a high correlation between chilling sensitivity and the sum of fatty acids in fruits (Matsuo *et al.*, 1992). Fatty acid composition could affect membrane fluidity, stability and functions (Liang *et al.*, 2005).

The decrease of fatty acid unsaturation mostly is contributed by the peroxidation of polyunsaturated fatty acids (PUFA) in the membrane tissues. According to Yamauchi *et al.* (1986), the peroxidation of PUFA was caused enzymatically by LOX or non-enzymatically by reactive oxygen species to form lipid hydroperoxides. However, Zhuang *et al.* (2002) reported that lipid peroxidation had been thought to be predominantly due to enzymatic processes in plant tissues. They further reported that LOX pathway was the only enzymatic pathway of fatty acids peroxidation known to be operative in plants.

Enhanced lipid peroxidation could also be responsible for the increase in malonaldehyde (MDA) content in membrane tissues. Ali *et al.* (2004) reported that MDA was often considered as a reflection of membrane dysfunction and LOX was considered to be partly responsible for the formation of this lipid peroxidation products. MDA was also often used as an index of cell oxidative damage under environmental stress (Shen and Wang, 1997). Determination of MDA provides an indirect estimate of stress induced membrane damage (Teklemariam and Blake, 2003). Based on the discussion above, Ratule (2006) conducted a study to determine fatty acid composition, LOX activity and MDA content in HWD-treated 'Berangan' banana in order to demonstrate the occurrence of lipid peroxidation. The relationship between these lipid peroxidation characteristics were then determined.

From chromatogram of FAME standards (Figure 20A), there were several major fatty acids found in the peel of 'Berangan' banana during storage for 8 days at chilling temperature (10 °C) (Figure 20B). These fatty acids were palmitic (C16:0), stearic (C 18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidonic (C20:4) and nervonic (C24:1) acids. However, only the content of oleic (C18:1), linolenic (C18:3) and arachidonic (C20:4) showed significant ($p < 0.05$) difference between the HWD-treated and control peel. Result of this study also indicated that linolenic acid (C18:3) was the predominant fatty acids (Table 8). Wang and Hildebrand (1988) also reported that linolenic acid was the most abundant fatty acids in most of the plant tissues.

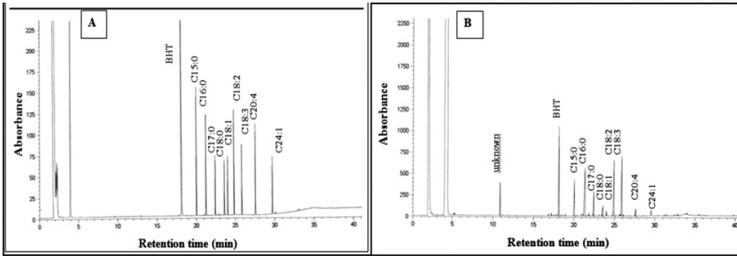


Figure 20 A & B Separation of fatty acids methyl ester (FAME) using gas chromatography. (A) a chromatogram standard of FAME; (B) a chromatogram sample of ‘Berangan’ banana peel.

In this study by Ratule (2006), ‘Berangan’ banana exposed to HWD treatment at 48 °C for 8 min showed no significant decrease of fatty acids (linolenic and arachidonic acids) and U/S (unsaturated to saturated fatty acids) ratio after 8 days storage at 10 °C, while there was a significant ($p < 0.05$) decrease in fatty acids and U/S ratio of CON-8D banana after storage at 10 °C. There was also no significant increase in lipoxygenase (LOX) activity (which was reported to be responsible for the fatty acids degradation) (Figure 21) in HWD-8D banana. This might contribute to the retaining of the U/S ratio of fatty acids in HWD-treated ‘Berangan’ banana. In this study, it was also found that there was a significant ($p < 0.05$) increase observed in the malonaldehyde (MDA) content in both HWD-treated and control bananas (Figure 22). However, the increase was found to be significantly ($p < 0.05$) higher in control banana (CON-8D) as compared to HWD-8D treated banana after storage at 10 °C.

Table 8 Effect of hot water dip (HWD) on fatty acids content: palmitic (C16:0), stearic (C18:0), oleic (18:1), linoleic (C18:2), linolenic (C18:3), arachidonic (C20:4) and nervonic (C24:1) acids of ‘Berangan’ banana peel stored for 8 days at 10 °C

HWD Treatment	Fatty acids (g/100g TFR)								
	C16:0	C18:0	C18:1	C18:2	C18:3	C20:4	C24:1	U/S	
CON-0D	9.84 a	5.57 a	1.59 c	19.51 a	30.57 a	2.46 a	3.17 a	1.63 a	
CON-8D	12.42 a	3.88 a	2.74 ab	18.46 a	20.45 b	1.22 b	3.18 a	0.90 b	
HWD-0D	8.11 a	5.70 a	1.98 bc	18.26 a	28.97 a	2.29 ab	3.71 a	1.61 a	
HWD-8D	10.40 a	4.16 a	3.01 a	19.03 a	26.73 a	1.89 ab	3.30 a	1.59 a	

Mean separations followed by different letters within column denote significant differences by using DMRT at $P \leq 0.05$.

CON-0D = Banana exposed to $27 \pm 2^\circ\text{C}$ and fatty acids were measured at day 0 of storage;

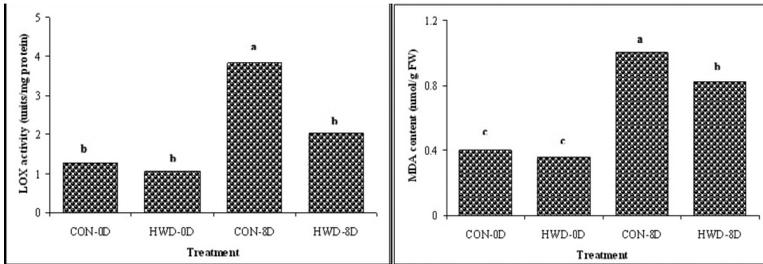
CON-8D = Banana exposed to $27 \pm 2^\circ\text{C}$ and fatty acids were measured at day 8 of storage;

HWD-0D = Banana dipped at 48°C for 8 min and fatty acids were measured at day 0 of storage;

HWD-8D = Banana dipped at 48°C for 8 min and fatty acids were measured at day 8 of storage.

TFR = Total fat residue

U/S = Unsaturated to saturated fatty acids



Figures 21 & 22 Effect of hot water dip (HWD) on the lipoxigenase (LOX) activity and malonaldehyde (MDA) content in 'Berangan' banana peel. Treatment means followed by the same letter are not significantly different by DMRT, $P \leq 0.05$. FW = Fresh weight

1. exposed to control condition (27 ± 2 °C) at day 0 (CON-0D)
2. dipped in 48 °C water for 8 min at day 0 (HWD-0D)
3. exposed to control condition (27 ± 2 °C) at day 8 of storage at 10 °C (CON-8D), and
4. dipped in 48 °C water for 8 min at day 8 of storage at 10 °C (HWD-8D).

The result obtained in this study suggested that lipid peroxidation was less in HWD-treated banana as compared to control banana. It was also found that there were increases in both PUT and SPD contents in HWD-treated fruits but not in control fruits after storage at 10 °C (Figure 23). Therefore, the minimal occurrence of lipid peroxidation in HWD-treated banana could be due to the increase in PUT and SPD after storage at 10 °C. The results obtained also showed significant correlation between both PUT and SPD and lipid peroxidation characteristics (Table 9). These significant correlations indicated the effect of PUT and SPD in retarding lipid peroxidation in HWD-treated banana after storage at 10 °C.

The significant ($p < 0.05$) decrease in fatty acids (linolenic and arachidonic) and the significant increase in both LOX activity and MDA content in control fruits (CON-8D) suggested higher lipid

peroxidation in control fruit as compared to that of HWD-treated fruits. Thus, the reduction of CI development in HWD-treated banana could be related to the increase in PUT and SPD in fruits, which then contributed to the reduction of lipid peroxidation.

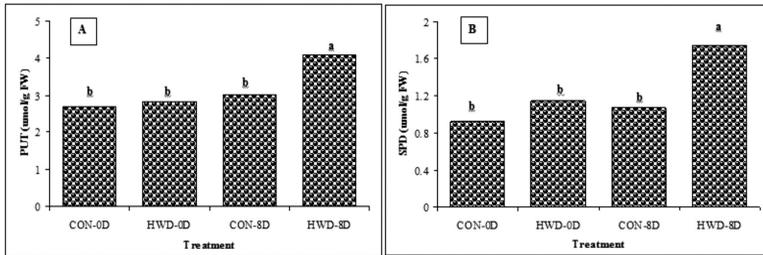


Figure 23 Effect of hot water dip (HWD) on (A) putrescine (PUT) and (B) spermidine (SPD) in 'Berangan' banana peel. Treatment means followed by the same letter are not significantly different by DMRT, $P \leq 0.05$. FW = Fresh weight.

1. exposed to control condition (27 ± 2 °C) at day 0 (CON-0D)
2. dipped in 48 °C water for 8 min at day 0 (HWD-0D)
3. exposed to control condition (27 ± 2 °C) at day 8 of storage at 10 °C (CON-8D), and
4. dipped in 48 °C water for 8 min at day 8 of storage at 10 °C (HWD-8D).

Table 9 Correlation coefficients between polyamines (PA) content (putrescine = PUT and spermidine = SPD) and lipid peroxidation characteristics (linolenic and arachidonic acids, U/S = unsaturated to saturated fatty acids, lipoxygenase = LOX and malonaldehyde = MDA) of 'Berangan' banana

	PUT	SPD	Linolenic acid	Arachidonic acid	U/S	LOX	MDA
PUT	--						
SPD	0.67*	--					
Linolenic acid	0.72*	0.83**	--				
Arachidonic acid	0.59 ns	0.49 ns	0.44 ns	--			
U/S	0.73*	0.69*	0.65*	0.89**	--		
LOX	-0.69*	-0.65*	-0.73*	-0.69*	-0.76*	--	
MDA	-0.64*	-0.87**	-0.68*	-0.25 ns	-0.63*	0.62*	--

For correlation coefficients, n = 10

** , ns , Significant at $P \leq 0.01$ and $P \leq 0.05$, or non significant, respectively

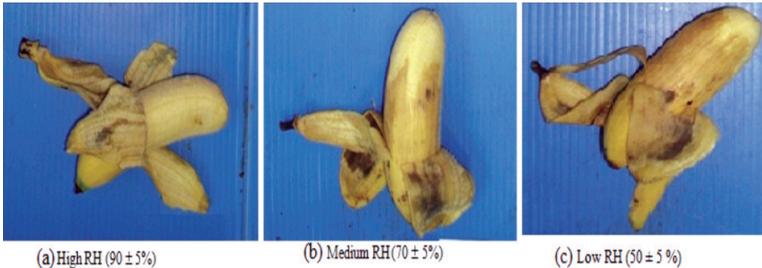
Modified Atmosphere (MA) Packaging

In this discussion, banana will be used as an example to demonstrate the effect of MA storage in extending the shelf life of the fruit. Storage of dessert bananas at temperatures below 13 °C resulted in chilling injury symptoms such as retarded development of yellow colour (Kim and Lee, 1992; Olorunda *et al.*, 1978) and failure to ripen (Haard and Timbie, 1976) while storage at 13 °C limits the shelf life to only two weeks (Salunkhe and Desai, 1984a). Bananas stored in sealed polyethylene (PE) bags were reported to have a longer storage life than those without bags (Scott and Roberts, 1966; Chiang, 1967; Smock, 1967; Woodruff, 1969; Liu, 1970). Scott *et al.* (1970) found that shelf life of banana sealed in PE bags stored at 20 °C was two weeks. Nevertheless, by adding potassium permanganate, the shelf life was further extended by another week. A study was conducted to determine the effect of waxing with paraffin and modified atmosphere on the quality of 'Montel' banana during storage (Mustaffa *et al.*, 2000). All the treated and control banana hands except for the control at ambient temperature were stored at 15 °C. They found that banana packed in low density polyethylene (LDPE) bags with KMnO_4 ripened within 60 days after harvesting at week 12 after flower emergence. This was followed by treatment in LPPE bags without KMnO_4 (54 days), clingwrap (42 days), liquid paraffin (36 days) and control at 15 °C (24 days) and control at ambient (18 days). Their results indicated that fruit packed in LDPE with KMnO_4 was the best treatment as compared to waxing with paraffin and other MA packaging to extend the shelf life of 'Montel' bananas.

Peeling Difficulty Disorder (PDD)

A study was conducted to identify the causal factors of PDD by determining the effects of three RH levels, namely high (90 ± 5

% RH), medium (70 ± 5 % RH) and low (50 ± 5 % RH) on the occurrence of PDD and ripening quality characteristics (Wo *et al.*, 2004; Wo, 2007). The peel anatomical structure of Mas banana fruits in relation to occurrence of PDD was also determined. Results obtained by Wo (2007) indicated that at fully ripe stage, Mas banana ripened at low and medium RH conditions manifested PDD (Plates 5b and c) and the occurrence was found to be closely related to the significant ($P < 0.005$) increased moisture lost, decreased peel moisture content and peel thickness of the fruit during ripening. Significantly ($P < 0.005$), linear and quadratic increase in sugar to acid ratio, peel L* and C* values of fruits ripened at low RH indicated that fruits ripened at low RH had an advanced ripening as compared to fruit ripened at medium and high RH.



Plates 5 a-c Ripened Mas banana [(a) without PDD]
[(b &c) with PDD]
(Source: Wo, 2007)

In addition to higher occurrence of PDD in fruits ripened at low RH, it was also observed that these fruits have a dull-yellow peel, suggesting that the respiratory climacteric had been disturbed by the water stress. The peel of the fruit also developed black patches as a result of the severe water loss.

From the anatomical study, increase in PDD in banana ripened at low RH was a characteristic of the thin peel. The tissues that were proposed to be responsible to separate readily when being peeled were examined (Figure 24). Ideally, it is at the peel-pulp transition layer which was expected to give way when banana fruit was peeled. However, when this PDD fruit is peeled, the peel was broken at epidermal and hypodermal layers above the vascular bundle (Figures 25 -26) and was not separated readily at the peel-pulp transition layer despite the fully ripened stage. There was a continuous break at a horizontal level immediately above the vascular bundles (Figure 27). The removable outermost layer of the peel broke at the level above the tracheary elements of vascular bundles. Fruits with manifestation of PDD had collapsed cell wall resulting in reduced intercellular spaces at peel-pulp transition layer. Without sufficient intercellular spaces to facilitate peeling, peel was not readily separated from the outer most layer of pulp. The subsequent higher intra-cellular strength between tissues from peel-pulp transition layer and outer most pulp tissues than that between hypodermal and vessel tissues below the epidermis attributed to the PDD.

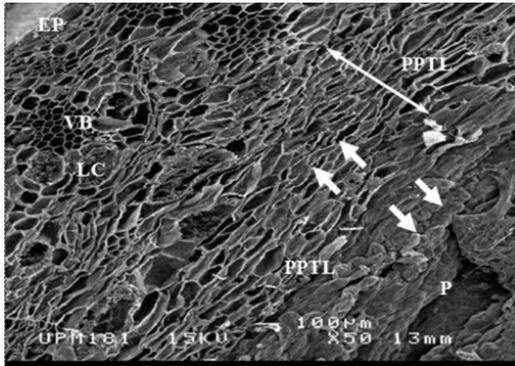


Figure 24 Peel transverse section of a Mas banana at an edible stage, ripened at $50 \pm 5\%$ RH, 25°C . Single-ended arrows indicated the direction of the peel and pulp tissues at the region of peel-pulp transition layer (PPTL) when the fruit was peeled. EP, epidermis; VB, vascular bundle; LC, laticifer; P, pulp. x 50.

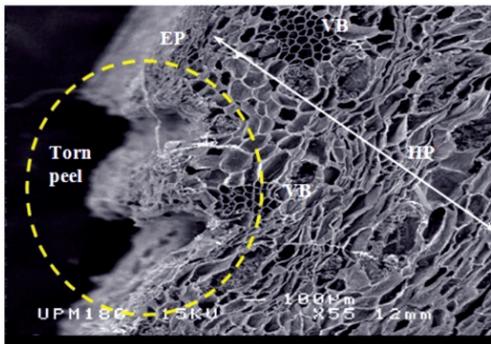


Figure 25 Peel transverse section of a Mas banana at an edible stage ripened at $50 \pm 5\%$ RH, 25°C . Dotted circle indicated the epidermal (EP) and hypodermal (HP) cells torn above the vascular bundles (VB) manifested peeling difficulty disorder. x55

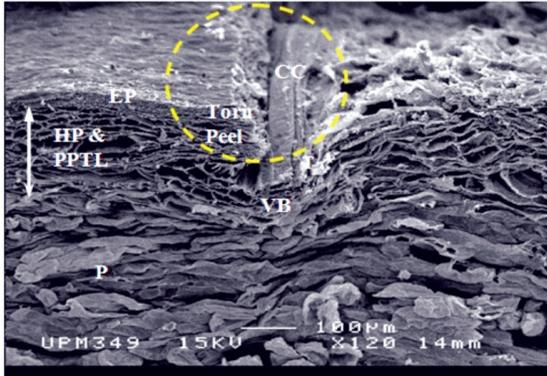


Figure 26 Peel transverse section of Mas banana at fully ripened stage, ripened at 50 ± 5 % RH, 25 °C. The fruit manifested PDD, where the irremovable peel broke at the vascular bundle (VB) area. The break exposed the continuous conducting cell (CC) of tracheary elements of vascular bundles. Note the contracted peel layer: epidermis (EP), hypodermis (HP) and peel-pulp transition layer (PPTL). P, pulp. x120

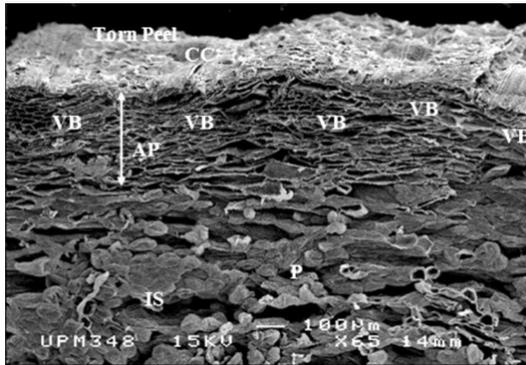


Figure 27 Peel transverse section of Mas banana at fully ripened stage, ripened at 50 ± 5 % RH, 25 °C. adhered peel (AP) on the pulp (P) was torn above a layer of vascular bundle (VB), exposing the conducting cells (CC) of the VB. Note the intercellular space (IS) at the pulp region. x65

Figure 28 shows part of the adhering peel on the outermost layer of the over-ripe fruit pulp. Both adhering peel and peel-pulp transition tissues seem to be similar in size, shape and morphology. However, the adhering peel cells are found to shrink (area X- Figure 28) due to hydration and loss of cell wall integrity, resulting in loss of intercellular adhesiveness with the upper part of the peel.

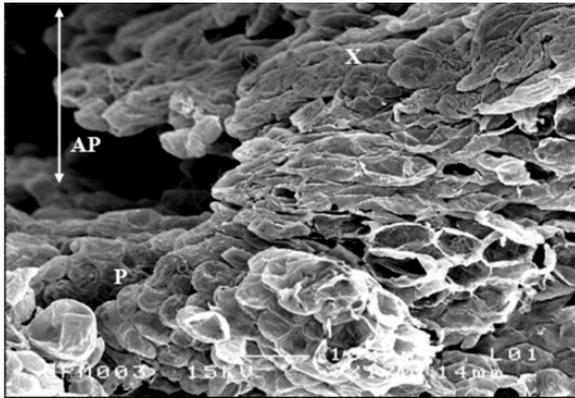


Figure 28 Top view of adhered peel (AP) cells from the peel-pulp transition layer on a fully ripe Mas banana ripened at $50 \pm 5\%$ RH, 25°C . The peel adhered on the outermost layer of the pulp (P). Note that the adhering peel cells at the area X are shrunken. x 170.

To reduce PDD during fruit development, Mas banana fruit bunches should be harvested at 6 to 7 WAFE and not to delay harvesting for optimum yield. The good quality fruit bunches without PPSD should be ripened at RH higher than 70 % to prevent occurrence of PDD. This optimal level of RH was in line with the findings of Paul (1996b) and Lizada *et al.* (1990).

MINIMALLY PROCESSED FRUITS

The term “minimally processed fruit” refers to any type of fruits that has been physically altered (trimmed, peeled, washed, and/or cut) from its original state, but remains in a fresh, “unprocessed” state (Olivas and Barbosa-Canovas, 2005). The International Fresh-cut Produce Association (IFPA) defines fresh-cut products as fruits or vegetables that have been trimmed and/or peeled and/or cut into 100% usable product that is bagged or prepackaged to offer consumers high nutrition, convenience and flavour while still maintaining freshness (Rico *et al.*, 2007).

Consumers are increasingly aware of the importance of healthy eating habits, but have less time available for food preparation especially consumers in the urban areas who are mostly career couples, non-family households, single parent families, women in the labour force, small families (3-4 family members) and etc. Due to the busy lifestyle, ready-to-eat (minimally processed) fruits have gained emphasis as it is more convenient and possess fresh like quality. Furthermore, besides convenience, they are more economical to buy minimally processed fruits as compared to the bulky and expensive whole fruits and consumers could also buy more varieties of minimally processed fruits at any single purchase. Therefore, the importance of fresh-cut fruit industry is becoming progressively more significant (Olivas and Barbosa-Canovas, 2005). Minimal processing of fruits has two main purposes: (1) Keeping the produce fresh, without losing its nutritional quality and (2) ensuring a sufficient shelf-life to make distribution feasible within a region of consumption (Laurila and Ahvenainen, 2002).

Problems Associated with Minimally Processed Fruits

Minimally processed fruits are more perishable than whole fruits due to damaged tissues and lack of protective skin (Watada and Qi,

1999). Mechanical operations such as peeling and cutting increase metabolic activities such as respiration rate and delocalization of enzymes and substrates. This may lead to deterioration such as browning, softening, decay and off-flavour (Montero-Calderon *et al.* 2008; Di Egidio *et al.*, 2009). Also, the high humidity condition and a large area of cut surfaces, which provide a rich source of nutrients, create a good environment to growth of microorganisms (Oms-Oliu *et al.*, 2010).

Ways to Overcome Related Problems

Some of the key requirements in the minimal processing of fruits are summarized as below (Laurila and Ahvenainen, 2002):

- Raw material of good quality (correct cultivar. variety, correct cultivation, harvesting and storage conditions)
- Strict hygiene and good manufacturing practices, HACCP
- Low temperature during working
- Careful cleaning and/or washing before and after peeling
- Water of good quality (sensory, microbiology, pH) used in washing
- Mild additives in washing for disinfection or browning prevention
- Gentle spin drying after washing
- Gentle cutting/slicing/shredding
- Correct packaging materials and packaging methods
- Correct temperature and humidity during distribution and retailing

Teh (1999) conducted a survey on minimally processed refrigerated local fruits practices in Malaysia. However, this study only covers street stalls, stalls at shopping centres, chilled cabinets at supermarkets and hypermarkets located at Seri Kembangan, Subang

Jaya, Kuala Lumpur and several street stalls in Penang. Results of her study showed that the types of fruits being sold as minimally processed fruits are papaya, watermelon, pineapple, jackfruit, honeydew, mango, carambola, guava, *jambu air*, ciku, young tender coconut and water chestnut. Minimally processed activities carried out include halving, deseeding, slicing or segmentation, coarsely chopped or diced, peeling of skin, partial removal of husk (for young tender coconut) and pulping.

Temperature is the most important factor governing the storage life of minimally processed fruits (Jingtair, 1993), although storage conditions of minimally processed fruits are sometimes similar to those of whole fruits (Floros, 1993). Teh (1999) reported that the storage temperature of minimally processed fruits in street stalls, stalls at shopping centres and cabinets at supermarkets and hypermarkets were between 25-27 °C, 24-26 °C and 7-24 °C respectively. The approximate shelf life of the minimally processed fruits were found to be 1 day at both street stalls and stalls at shopping centres and 1-3 days in chilled cabinets in supermarkets and hypermarkets.

Figures 29a-c show the modes of presentation of the minimally processed fruits at street stalls, iced-slush display cabinet at shopping centres, iced-slush display cabinet and chilled cabinet at supermarkets/hypermarkets. From her observation, Teh (1999) reported that minimally processed tropical fruits will be an important sector in the fruit industry (it is already now – 2011). However, appropriate preparatory techniques are essential for further improvement of the sector by avoiding contamination. In addition, packaging and storage conditions need to be determined for each fruit type in order to obtain high quality minimally processed fruits with reasonable shelf life.



Figure 29(a) Modes of presentation of the minimally processed fruits at street stalls



Figure 29(b) Iced-slush display cabinet at shopping centre



Figure 29(c) Iced-slush display cabinet and chilled cabinet at supermarket/hypermarket.

There are several techniques for increasing the shelf-life and maintaining the quality of minimally processed fruits:

i) Low temperature storage

Minimally processed durian (*Durio zibethinus*)

Durian is one of the most important seasonal climacteric fruits (Tongdee *et al.*, 1990; Booncherm and Siriphanich, 1991) in tropical Asia. Unlike in Thailand, where durians are detached from tree at the mature stage and then allowed to ripen, in Malaysia, Indonesia and the Philippines, the fruits are collected after they fall naturally from the tree upon ripening. Pauziah *et al.* (1992) and Nantachai (1994) reported that ripened durian that are allowed to drop naturally have a better aroma and taste compared to those that are plucked from the tree and ripened, and are preferred by the local and foreign markets in Hong Kong and Singapore. However, they have a limited shelf life of 3-4 days (Pauziah *et al.*, 1992).

It has been reported that durian pulp which has lower metabolic activity and less susceptible to chilling injury compared to the husk, can be stored for a longer period at low temperature than the whole fruit (Booncherm and Siriphanich, 1991). Due to these reasons and a high husk to pulp ratio of 2:1, storage of durian pulp is more promising than the whole fruit. Earlier studies reported that mature, unripened whole durian fruit could be stored at 4 °C for 20 days (Praditdoug, 1986) while the pulp could be stored at 5 °C for up to 8 weeks with slight chilling injury observed after 4 weeks of storage (Booncherm and Siriphanich, 1991). Other previous findings showed that durian pulp could be stored at 4 °C up to 30 days, with the main problems observed being chilling injury and contamination by fungi at the base of the seed (Salunkhe and Desai, 1984b; Praditdoug, 1986).

All the results of earlier findings mentioned above indicate that durian pulp has a longer shelf life than the whole, intact fruit, contrary to most other fruits where minimally processed fruits

have a shorter shelf life. The reason for this is that for most fruits, the outer layer of peel, skin or rind and waxy material at the outer surface, which protects the soft inner cells from damage, are usually removed in minimal processing, exposing the fleshy cells (King and Bolin, 1989) and rendering it highly perishable (Watada and Qi, 1999). However, durian fruit possess an additional layer covering the pulp, as well as the husk. The surface of the pulp is covered with epidermal cells and cuticle which is not easily broken and forms a barrier to microorganisms (Siriphanich, 1994).

Voon *et al.* (2006) conducted a study to determine the effect of storage temperature (4 ± 2 °C; 90-95 % RH and 28 ± 1 °C; 70-85 % RH) on the physico-chemical, microbial and sensory changes of minimally processed durian (*Durio zibethinus* cv. D24). The results obtained in the study indicated that spoilage of minimally processed durian stored at 28 ± 1 °C; 70-85 % RH was characterised by the pulp acidification due to the production of acetic, succinic, citric and lactic acids accompanied with a loss in texture, increase in fructose and glucose and a decrease in sucrose contents.

Storage of durian pulp at 4 ± 2 °C; 90-95 % RH effectively retained fruit firmness and organic acid contents, maintained the pH at neutral level and increased sugar content of the pulp. Chilling also slowed down the growth of microorganisms but fruit underwent losses in aroma and off-odours developed on day 14 and increased thereafter rendering the pulp unacceptable in terms of overall aroma on day 21 of storage. The minimally processed durian pulp could be held at 4 ± 2 °C; 90-95 % RH for 14 days with acceptable microbiological count and without off-odour development. At ambient temperature (28 ± 1 °C; 70-85 % RH), minimally processed durian pulp could only be stored for 1 day after which the pulp became acidified.

ii) Dipping treatments

Dipping treatments can be used to delay physiological decay and maintain the quality of minimally processed fruits (Soliva-Fortuny and Martin-Belloso, 2003). Browning is one of the major concerns in fresh-cut fruits and directly affects the consumer's purchase decision (Oms-Oliu *et al.*, 2010). Traditionally, dipping in sulfites solution has been used for browning prevention. However, their use on fresh-cut fruits was banned in 1986 by FDA due to their potential hazards to health (Oms-Oliu *et al.*, 2010). The most common alternative for sulfites is ascorbic acid (Laurila and Ahvenainen, 2002). Other example for dipping treatment is calcium solution which is used to maintain or improve tissue firmness of fresh-cut fruits (Oms-Oliu *et al.*, 2010). Calcium chloride has been one of the most frequently used salts of calcium for minimally processed fruits (Oms-Oliu *et al.*, 2010).

Minimally processed guava (*Psidium Guajava* L.)

Peeled and cut guava wedges undergo certain physical, chemical and biological changes which shortened the shelf life of the product. These changes may be induced by minimal processing due to exposure of injured tissues as a result of the mechanical process of peeling, slicing or cutting (Izumi and Watada, 1994). Effect of vacuum infusion of calcium on the quality of minimally processed guavas (*Psidium Guajava* L.) during storage was evaluated (Osman *et al.*, 1999c). An optimum concentration and pressure for vacuum infusion of calcium lactate solution were determined in this study. The quality of the minimally-processed guava was assessed by physico-chemical analyses and sensory evaluation. From this study, it can be concluded that minimally processed guava wedges dipped in 1.5 % calcium lactate solution under 410 mm Hg for 1 min at

ambient temperature and wrapped in cling wrap could prolong the shelf life of the product by 7 days besides maintaining its quality when stored at 7 ± 1 °C: 75-92 % RH.

Another study was conducted to evaluate the effect of vacuum infusion of pectinase and calcium on the texture and colour of minimally processed guava (*Psidium Guajava* L.) (Osman *et al.*, 2001). This study determined the effect of using pectinase, calcium lactate and reduced pressure to retain the texture and colour of minimally processed guava during storage at 7 ± 1 °C: 75-92 % RH. Reduced pressure of 35 cm Hg was found to be the optimum pressure and infusion with 1 % pectinase also gave a positive effect on physical changes of the fruit. However, result of this study revealed that combination treatment of enzyme infusion at reduced pressure followed by calcium dipping (1.5%) and cling wrapping caused the fruits to lose its firmness and colour during storage.

Thus, from these two studies, it can be suggested that shelf life of minimally processed guava wedges could be prolonged for 7 days besides maintaining their quality by dipping in 1.5% calcium lactate solution under reduced pressure (350-410 mm Hg) followed by wrapping in cling wrap and storing at 7 ± 1 °C: 75-92 % RH.

Minimally processed honeydew melons (*Cucumis melo* var *reticulatus*)

Mohd Yusof (1997) conducted a study to determine the effect of vacuum infusion of calcium on the quality of minimally processed honeydew melons (*Cucumis melo* var. *reticulatus*) during chilled storage (7 ± 1 °C; 75-92 % RH). Results of this study revealed that the honeydew melon wedges should be dipped in 1 % calcium lactate under 350 mm Hg pressure followed by cling wrapping. Fruit wedges treated in this way had a shelf life, with acceptable physico-chemical, microbial and sensory characteristics of 10 days. The

unwrapped calcium-infused fruit wedges had an acceptable shelf life of only 5 days. This was most probably due to the higher rate of respiration and ethylene production exhibited by the unwrapped fruit as compared to fruit wedges which was cling wrapped.

Abdul Rahman *et al.* (2000b) carried out a study to evaluate the effect of enzyme and calcium vacuum infusion on the quality of minimally processed honeydew melons (*Cucumis melo* var *reticulatus*) during chilled storage. Their results showed that infusion with different concentrations of calcium lactate solutions after infusing with selected concentration (0.5 %) and vacuum pressure (350 mm Hg) of pectinase gave a negative effect on the physical changes although the calcium content increased with increasing of calcium lactate concentration. Thus, from this study, it can be concluded that combination of pectinase (0.5 %) and calcium lactate at a selected pressure (350 mm Hg) was not able to maintain the quality of minimally processed honeydew melon.

iii) Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) reduced oxygen and increased carbon dioxide levels in package headspace therefore, can help to slow down ethylene production and respiration rate as well as changes in colour, texture and other quality factors of fresh-cut fruits (Montero-Calderon *et al.*, 2010). The mixture of gases in the package depends on different factors such as type of products, storage temperature and packaging material (Sandhya, 2010). In general, for most fruits, the gas composition can be 2-5 % CO₂, 2-5 % O₂ and the rest nitrogen (Laurila and Ahvenainen, 2002).

iv) UV Irradiation

Ultraviolet light is a type of non-ionising radiation with wavelengths from 100-400 nm and classified into three types: UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (100-280 nm) (Gonzalez-Aguilar *et al.*, 2010). UV-C especially at 254 nm has the highest germicidal action and usually is used to control microorganism growth in fresh-cut fruits (Gonzalez-Aguilar *et al.*, 2010). It does not leave any residue and is lethal to a wide range of microorganism. It is easy to use and does not have legal restrictions (Gonzalez-Aguilar *et al.*, 2010).

v) Edible Coating

Edible coating is defined as edible material (polysaccharide, protein or lipid) that is used as a thin layer on the surface of foods (Gonzalez-Aguilar *et al.*, 2010). It can be applied onto minimally processed fruits for providing a selective barrier to oxygen, carbon dioxide and moisture, improving textural and mechanical properties, preventing flavour loss and carrying food additives (Tapia *et al.*, 2008). The effectiveness of antimicrobial agents, calcium salts, antioxidants, and functional ingredients can be improved with their incorporation into edible coatings (Oms-Oliu *et al.*, 2010).

Mohd Aripin (2009) and Osman *et al.* (2009a) evaluated the effects of different concentrations of alginate-based edible coating on the storage quality of fresh-cut 'Chokanan' mango. The results obtained in this study indicated that the best concentration of alginate-based coating formulation to extend the shelf life of fresh-cut mango cubes was 0.75 % (w/v) since it was able to slow down the rate of weight loss, change in firmness, and increase in total soluble solid content.

Azarakhsh *et al.* (2010a and 2010b) evaluated the effects of alginate and gellan-based edible coatings on quality of fresh-cut pineapples during cold storage. The results obtained in these studies indicated that alginate- and gellan-based edible coatings could significantly reduced weight loss and respiration rate and maintained the colour and firmness of fresh-cut pineapples during low temperature storage as compared with control (uncoated sample). Later, Azarakhsh *et al.* (2011) optimised the alginate- and gellan-based edible coating formulations for fresh-cut pineapples by response surface methodology. They reported that the optimised alginate- and gellan-based coatings were composed of 1.29 % (w/v) sodium alginate, 1.16 % (w/v) glycerol; 0.56 % (w/v) gellan gum and 0.89 % (w/v) glycerol respectively.

ENZYME INFUSION TECHNOLOGY: THE ALTERNATIVE TO CONVENTIONAL PEELING

Traditional methods for peeling of generally all kind of citrus fruits include hand or mechanical peeling facilitated by steam treatment to loosen and digest the peel (Pao and Petracek, 1997). Hand peeling is labour intensive and generally for all citrus fruits, often results in losses of 30-40 % of the edible portion of the fruit as membrane and juice especially from broken segments while segmenting the sections (Baker and Grohmann, 1995). Steam and lye peeling are the most commonly used methods in the processing industry (Janser, 1996), but these methods often cause damage to the flesh and produces fruit that are unacceptable for the minimally processed, ready-to-eat market.

Enzyme peeling which is defined as the application of exogenous enzymes specifically for altering characteristics of intact tissues (Baker and Wicker, 1996) was developed and patented for citrus by Bruemmer (1981). According to McArdle and Culver (1994), the

exogenous enzyme particularly pectinase will selectively alter the structure without affecting the other characteristics such as segment integrity. Citrus fruits are generally relatively solid and free of voids, while the albedo and core of fruit are extremely porous. In this respect, citrus fruits are suitable for peeling by vacuum infusion. Thus, enzyme-aided peeling can be an alternative to conventional peeling. The general enzyme-aided peeling process for citrus fruits is shown in Figure 30.



Figure 30 The general enzyme-aided peeling process.

Mandarin Orange (*Citrus suluensis*)

Mandarin orange is suitable to be peeled enzymatically as it has a thin layer of peel and albedo. Liu *et al.* (1999; 2000a) conducted studies to determine the ease of peeling of Mandarin orange with the aid of pectinase by using 5 different enzyme concentrations ranging from 0 to 0.5 % v/w and 5 different vacuum infusion durations ranging from 5 to 15 minutes. The fruits were first scored with

eight radial lines from stem end to blossom end and followed by the immersion of the fruit in the enzyme solution at 700 mm Hg, pH 4.5 and at ambient temperature. The time taken for complete peel removal was observed for each different enzyme concentrations and vacuum durations. Peelzym® IV at 0.4 % v/w and vacuum duration of 13 minutes were found to be optimal for peeling, producing fruits that were relatively free of adhering albedo and firm. The quality of the enzyme-peeled mandarin orange segments was then evaluated by sensory evaluation (Liu *et al.*, 2004). The peeled fruit segments were judged by 30 panelists to ascertain their appeal to consumers. A significant ($P < 0.05$) difference between enzyme-peeled and hand-peeled segments was found, with the panelists preferring the enzyme-peeled segments. Plates 6a-b show the enzyme-peeled and hand-peeled whole fruit of *C. suhuiensis*

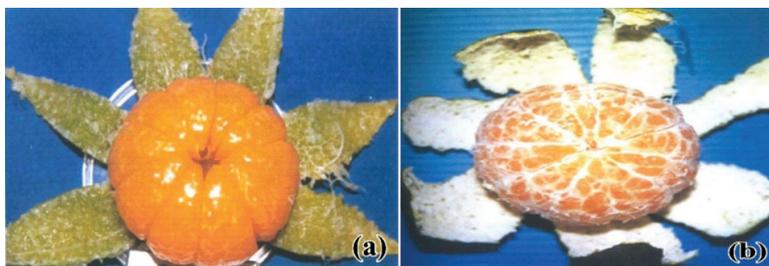


Plate 6 (a) Enzyme-peeled; (b) hand-peeled whole fruit of *C. suhuiensis*

Mandarin oranges that were enzymatically peeled (with pectinase) were subjected to removal of membranes (rag) from the segments of mandarin orange with the aid of cellulose enzyme, the Celluclast® (Liu *et al.*, 2000b). Results obtained indicate that 3 % v/w Celluclast® is optimum for membrane removal of mandarin segments producing segments that were firm, with less broken segments, had a better appearance and relatively free of

adhering membrane. Result of this study also suggested that the optimal conditions established for the Celluclast® concentration and incubation time (176.67 minutes) after infusion (700 mm Hg for 15 minutes) can also be used for other citrus fruits with some modifications. Plates 7a-b show the enzyme peeled and hand peeled local mandarin (*Citrus suhuiensis*) segments.

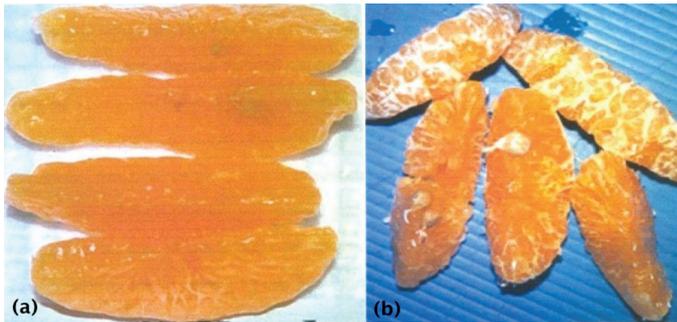


Plate 7 (a) Enzyme-peeled membraneless segments; (b) hand-peeled membraneless segments of *Citrus suhuiensis*

Musk Lime (*Citrus mitis* B.)

Musk lime or locally known as *limau kasturi* fruit is recognised by its smooth and very thin peel and small size that caused difficulty of hand peeling in industrial juice processing. Adnan *et al.* (2000) conducted a study to determine the optimum concentration of the pectolytic enzyme, Peelzym II required to loosen the peel of *limau kasturi*. Enzymatic peeling was performed by means of enzyme infusion under vacuum (500 mm Hg), followed by a period of incubation (15 min) in the enzyme solution. Result obtained indicated that a shorter time was required to loosen the peel of the *limau kasturi* with increasing Peelzym II concentration. Enzyme concentration of 1.0 % (v/w) was found to be the optimum concentration with an incubation time of 135 minutes.

Limau kasturi which has a very thin and having little or no spongy albedo requires a higher (1 %) enzyme concentration for the peeling process as compared to pomelo, (*C. grandis*) (Aziz *et al.*, 1999) which has a very thick albedo and mandarin orange (*C. suhuiensis*) (Liu *et al.*, 1999; 2000a) which has a moderately thick albedo; requiring optimum enzyme concentration of 0.45 % (v/w) and 0.4 % (v/w) respectively for complete peel removal. This phenomenon may be due to the physical strength of cell walls that varies considerably from fruit to fruit (Janser, 1997).

However, another study was carried out by Adnan *et al.* (2002) to further optimise the vacuum pressure of enzyme infusion. The time taken to loosen the peel significantly decrease (from 193 min to 98 min) with an increase in vacuum pressure from 0 to 700 mm Hg. Results obtained indicate that the optimum enzyme concentration required to loosen *limau kasturi* peel was 1.0 % (v/w) at pH 3.0, and the optimum vacuum pressure was found to be at 700 mm Hg. At this concentration, the peeled fruits were relatively free of adhering albedo, with fruit segments still intact and having a more attractive appearance. This study showed that enzymatic peeling under vacuum could be one of the most appropriate alternatives to conventional peeling of *limau kasturi*. The end product (clear peeled fruit) of the process is ready for further processing such as juice making without the interference of peel which may reduce the quality (bitter taste) of the juice produced.

Pomelo (*Citrus grandis*)

A study conducted to determine the optimum condition for the enzymatic peeling of pomelo which is also commonly known as *limau bali* (Aziz *et al.*, 1999). Results of their study showed that the optimum concentration of Pectinase ultra Sp1 was 0.45 % (v/w) at room temperature and pH 4.5. The incubation time required

for complete peeling of pomelo fruit was 66 minutes. The fruit obtained from enzymatic peeling was firm and had a very good shiny appearance and the individual fruit segments were easily separated from each other. In the study, it was found that lower enzyme concentration increased the process time while higher concentrations caused damage to the fruit (in terms of appearance).

There are reports stating that enzyme solution could be used for several consecutive peeling runs for grapefruits (Rouhana and Mannheim, 1994; Soffer and Mannheim, 1994). In a study conducted by Aziz *et al.* (2000), the effectiveness of recycling of the enzyme solution used for further peeling of Pomelo was evaluated. Results obtained indicated that the optimum incubation time needed for peeling process to be completed was 60 minutes for the first batch, and 85 and 115 minutes for the second and third batches, respectively. Although re-use of the enzyme resulted in an extended time for peeling, the fruit obtained for second and third peeling batches showed no significant difference to the fruits obtained from the first cycle, and had a very good shiny appearance. The results indicated that the enzyme solution could be used for three consecutive peeling batches and this finding was found to be beneficial in adopting this process in the industrial market.

FAMA-UPM COLLABORATIVE RESEARCH

Proper postharvest handling practices are important to reduce postharvest losses and improve overall harvest quality. A study was carried out to determine postharvest handling activities that were practiced, potential postharvest handling activities and the factors that contributed to postharvest losses of selected fruits (carambola, papaya, mango, guava, limau madu, pineapple, watermelon and pomelo (Osman *et al.*, 2009b). This study comprised a survey to investigate postharvest handling activities from farm gate to

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

consumers (farm, collecting centres/packing houses, wholesalers, retailers, transporters and consumers) at eight zones located in Peninsular Malaysia, Sabah and Sarawak. Figure 31 shows the potential postharvest handling activities that can be carried out and the response obtained from the survey while Figure 32 details out the reasons for not performing the potential postharvesting handling activities.

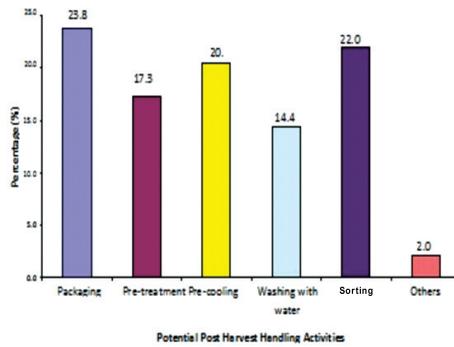


Figure 31 Potential Post Harvest Handling Activities

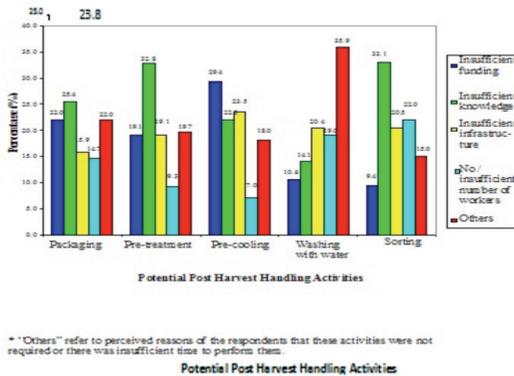


Figure 32 Reasons for Not Performing Potential Post Harvest Handling Activities

Results of this study indicated that insufficient knowledge, with respect to good handling practices is the major contributing factor to postharvest losses of fruits which were found to be the highest at the wholesaler and retailer levels as compared to other levels along the distribution chain. This is followed by insufficient knowledge on supply and demand, and insufficient knowledge regarding off-season/off-grade product diversifications (Figure 33). Results of the study also indicated that attitude of respondents and workers apathy, improper and insufficient infrastructure and availability of resources (insufficient funding, improper equipment and insufficient equipment) were the other factors contributing to the postharvest losses of fruits at the respective levels along the distribution chain.

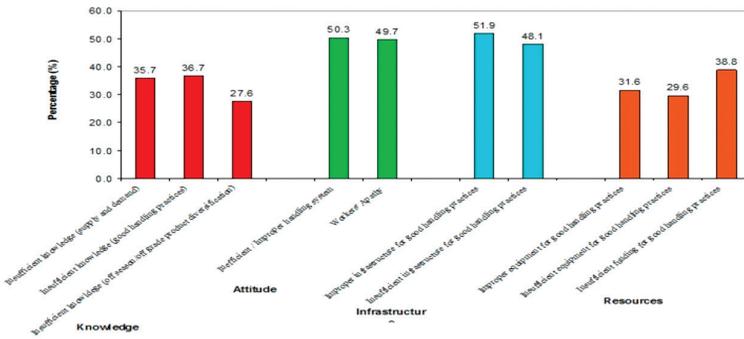


Figure 33 Breakdown of factors contributing to postharvest losses of fruits and vegetables

Osman *et al.* (2009c) conducted observation trips throughout Malaysia, some areas around Bangkok, Thailand and the oriental and open markets around the Hague, Rotterdam and Amsterdam in The Netherlands, to study the extend of postharvest losses and other value adding activities including trends in minimal processing activities for fruits and vegetables. From the observation trips, obvious practices found are as follows:

i) Thailand

- Most postharvest value adding activities (trimming, sorting, grading and packaging) are carried out in the farms.
- Apart from wet markets, their collection and distribution centres, wholesale and retail markets are more organised and systematic with well designed infrastructure for display and retailing activities.
- There is a trend of minimally processed fruits found in retail outlets. They have many creative presentations and the way these minimally processed fruits were displayed is very colourful and in an orderly manner as shown in the plates below.



Plate 8 Colourful display of packed minimally processed fruits (pineapple, papaya, cantaloupe, pomelo and watermelon)



Plate 9 Creative display of minimally processed wax apple



Plate 10 Creative presentation of minimally processed *ciku* (centre), papaya and pomelo

ii) Netherlands

- Similar packaging practices as observed in Thailand and Malaysia.

- One good practice which is observed in the open market in the Netherlands and not found in Malaysia and Thailand is the presence of cold rooms which served as storage area for respective lots in the open markets as shown in the plates below.
- There is also a trend of minimally processed fruits found in retail outlets



Plate 11 Cold room located behind vegetables stall



Plate 12 Cold room located behind vegetables stall

iii) Malaysia

- Presentation of minimally processed fruits available need to be improved in terms of attractiveness and creativity. Some of the minimally processed fruits available in the retail outlets are as in the plates below.



Plate 13 Ready-to-eat minimally processed fruits at a retail market in Sabah



Plate 14 Ready-to-eat minimally processed fruits at a retail market in Kota Bharu

CURRENT TREND OF FRUIT CONSUMPTION

In the last two decades, consumers consume fruits not only for their nutrients, but emphasize is also given on their other functional properties. Daily intake of fruits has been linked with lowering the cases of cardiovascular diseases, cancer, diabetes and all sort of other illnesses (Leather, 1995; Rice-Evans and Miller, 1995; Williamson, 1996). Hence, the capabilities of the fruits to act as natural antioxidants, antimicrobial, anticancer, anti-obesity and anti-inflammatory are parts of the research. Studies on the fruits' functional properties are not only limited on the consumable parts but also on their residues or wastes. Examples of such fruits that have been studied for their antioxidant activities are apple, guava and carambola (Hassimotto *et al.*, 2005; Leong and Shui, 2002; Wang *et al.*, 1996). On the other hand, besides being an antioxidant, apple (He and Liu, 2008; Wolfe *et al.*, 2003) and rambutan peels that are usually discarded are also showed to possess anti-proliferative (He and Liu, 2008; Reagan-Shaw *et al.*, 2010) and antibacterial (Thitilertdecha *et al.*, 2008) activity respectively. Another example is the well known grape seed. A potent antioxidant agent, the grape seed also possesses antimicrobial, anticancer and several other functions as being revised by Yilmaz and Toledo (2004).

Main reason for the fruit's beneficial effects is due to the presence of phytochemicals such as phenolics, anthocyanins, carotenoids, tocopherols and many more. Reviews done by several researchers (Craig, 1997; Leather, 1995; Rice-Evans and Miller, 1995; Williamson, 1996) have highlighted the importance of these phytochemicals in protecting human against preventable diseases and death. For instance, although phenolic compounds such as flavonoids can be found in most parts of the fruit, they are usually more abundant in the peel and seed. Taking the grape seed and skin as a reference, Yilmaz and Toledo (2004) have summarised the

functional values of this constituent in protecting our body against harm as below:

- cancer
- cardiovascular diseases
- ulcer

Nevertheless, a list of the fruit goodness on human health will go on and on as the research continues.

EXAMPLE OF A HOLISTIC STUDY OF NEW EMERGING FRUIT - PITAYA

Pitaya

A new emerging fruit, pitaya of the *Hylocereus* species, is currently receiving a lot of attention either from consumers or scientists. This climbing epiphytic plant is native to Mexico, Central and South America and more typical in tropical forest regions than semi-deserts (Mizrahi *et al.*, 1997). It belongs to the Cactaceae family and falls under the order Caryophyllales (Rowley, 1978) and there are about 24 species of pitaya fruit worldwide. *H. polyrhizus* (red peel, red flesh) and *H. undatus* (red peel, white flesh) are the most common pitaya species found in Malaysia. Pitaya plant does grow on the ground even though it is semi-epiphyte. However, strong support that is usually made from concrete or wood was used for cultivation. In the wild, they originally will hang from trees to form great canopies (Rowley, 1978). The red flesh pitaya fruit is round in shape weighing around 130-350 g whereas the white flesh pitaya is slightly oval and can weigh from 250 to 600 g (Le Bellec *et al.*, 2006). They both contained small black edible seeds.

Pitaya fruits are not only cultivated for fresh consumption but they are also cultivated for further processing. The emergence of pitaya-based products such as jellies, ice creams and jams has

become a promising business in food industries (Mizrahi *et al.*, 1997). On top of that, because of the presence of high glucose in its pulp, fermentation process can be carried out to produce wine (Mizrahi *et al.*, 1997). Furthermore, the red pigment from pitaya known as betacyanin is studied by many workers as a promising colouring agent with nutritional value (Moßhammer *et al.*, 2005; Stintzing *et al.*, 2002; Wu *et al.*, 2006; Wybraniec *et al.*, 2001).

Current research now has move on to determine functional value of this fruit either in its pulp, peel or seed. For instance, betacyanins that is abundant in pitaya peel and pulp is thought able to improve viral defense and build resistance mechanisms towards pathogens (Ulrichova and Sosnova, 1970), act as antioxidant (Escribano *et al.*, 1998; Cai *et al.*, 2003; Pavlov *et al.*, 2005), anticancer (Sreekanth *et al.*, 2007) and anti-inflammatory (Allegra *et al.*, 2005). Studies on pulp, peel and seed of either white or red flesh pitaya or both on hypocholesterolemic effect (Mohd Adzhim Khalili *et al.*, 2009), antioxidant (Adnan *et al.*, 2010a; Adnan *et al.*, 2010b; Mohd Adzhim Khalili *et al.*, 2009; Nurliyana *et al.*, 2010; Wu *et al.*, 2006), antiproliferative (Gutiérrez *et al.*, 2007; Wu *et al.*, 2006) and antimicrobial activities (Mohd Maidin *et al.*, 2009; Mohd Maidin *et al.*, 2010a; Mohd Maidin *et al.*, 2010b; Nurmahani *et al.*, 2011) have been evaluated. Physico-chemical properties of the red pitaya peel are studied by Jamilah *et al.*, 2011. On the other hand, the essential fatty acids of red and white flesh pitaya seeds (Ariffin *et al.*, 2009) as well as other chemical compositions of the seed (Lim *et al.*, 2010) have also been determined.

A holistic study of the above mentioned pitaya fruit was carried out at FSTM as listed below.

- A) Determination of the exact state of physiological maturity of red flesh pitaya (*Hylocereus polyrhizus*) that provides high yield of edible portion, juice and puree of high quality (Sew, 2009; Mohamad Basri, 2009)

Their results indicated that fruits harvested at 33 days after anthesis (DAA) had the best quality based on their high yield of edible portion (62.59%) and high sugar to acid (45.22) (Sew, 2009; Mohamad Basri, 2009). Both of these characteristics are important for fresh fruits. Nevertheless, juice yield was highest (22.6%) in fruits harvested at 35 DAA as compared to fruits harvested at 33 DAA (19.3%) and 30 DAA (7.7%). There was no juice yield from fruits harvested at 25 and 27 DAA (Sew, 2009); this could possibly be due to the fact that red flesh pitaya fruit is too pulpy and pectinaceous at this maturity stage to yield juice.

Results obtained in this study also indicated that there was a significant difference observed in the physico-chemical characteristics of the freshly prepared red flesh pitaya puree produced from fruits harvested at different stages of maturity. This could most probably be attributed to the difference in the physico-chemical characteristics of the fresh fruits from different maturity stages itself (Mohamad Basri, 2009).

- B) Effect of different postharvest storage conditions of red flesh pitaya (*Hylocereus polyrhizus*) fruits prior to juice production on the final juice quality (Tey, 2010).

In the fruit juice industry, juice yield, colour attributes and content of health beneficial compounds such betacyanin, total phenolic and ascorbic acid are the main concern of fruit

juice manufacturers in terms of cost, appearance and other added values. By taking these factors into consideration, results of this study indicated that 33 DAA fruits stored at ambient temperature ($26\pm 2^{\circ}\text{C}$; $60\pm 10\%\text{RH}$) up to 6 days, low temperature ($10\pm 0.5^{\circ}\text{C}$; $76\pm 9\%\text{RH}$) up to 21 days and frozen pulp stored at freezing temperature ($-20\pm 2^{\circ}\text{C}$) up to 36 days could produce juice with good quality comparable to juice produced by fruits or frozen pulps without storage (Day 0).

Observation of this study also indicated that the most suitable storage condition for fruits prior to juice production is $10\pm 0.5^{\circ}\text{C}$; $76\pm 9\%\text{RH}$, taking into consideration of the reasonable storage period (three weeks) and better retention of the required quality parameters mentioned earlier. Storage of frozen pulps at freezing conditions prior to juice production is not recommended due to low juice yield and betacyanin content.

C) Optimisation of processing conditions of red pitaya (*Hylocereus polyrhizus*) puree using response surface methodology (Karim *et al.*, 2010)

Results obtained indicated that generally, all response surface models were significantly ($p < 0.05$) fitted for describing the variation in colour, betanin content, enzymatic activity and microbiological count of pitaya puree as a nonlinear function. The total soluble solids of pitaya puree was found to exhibit a linear function of processing conditions. The overall optimal region for the production of a desirable red pitaya puree was achieved by heating at 79.36°C for 152.9 seconds at a pH of 4.16

- D) Physico-chemical properties of the red pitaya peel (Jamilah *et al.*, 2011)

The results obtained in their study indicated that the peel contained high total dietary fibre and betacyanin content. The study also included the proximate analysis, physico-chemical properties and carbohydrate components of the peel.

- E) The essential fatty acids of red and white flesh pitaya seed oils (Ariffin *et al.*, 2009)

Linoleic acid, a polyunsaturated fatty acid was the highest fatty acid in both types of pitaya seed oil as determined in the study.

- F) Chemical compositions of red and white flesh pitaya seed oils (Lim *et al.*, 2010)

Besides determining the fatty acids composition, their study also included determination of phenolic, sterol and tocopherol compounds in the seed oil. High amount of β -sitosterol was found in both pitaya seed oils as well as α -tocopherol was found to be the major tocopherol in the seeds.

- G) Antioxidant activity of different extracts of red pitaya (*H. polyrhizus*) seed (Adnan, *et al.*, 2010a)

Ethanol extract of the red pitaya seed gave the highest antioxidant activity in comparison to chloroform and hexane extracts.

- H) Antioxidant activity of white (*H. undatus*) and red flesh pitaya (*H. polyrhizus*) fruit pulp (Adnan *et al.*, 2010b; Mohd Maidin *et al.*, 2010b).

Red flesh pitaya pulp showed better antioxidant activity as compared to white flesh pitaya pulp as shown in Figure 34 a-b.

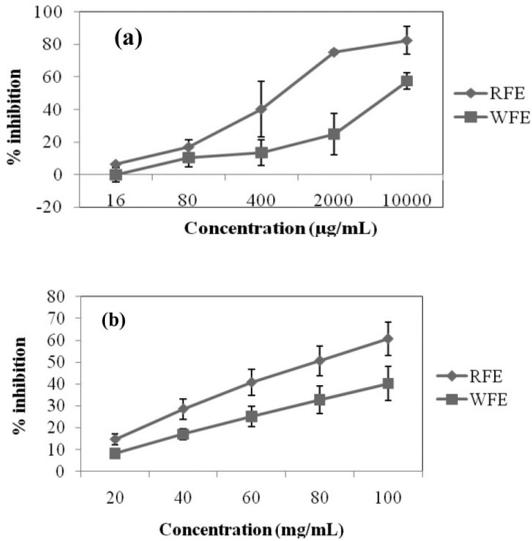


Figure 34 Antioxidant activity of extracts from white and red flesh pitaya pulp as determined using (a) conjugated diene and ; (b) DPPH[·] assay. RFE = red pulp; WFE = white pulp

- I) Antimicrobial activity of white (*H. undatus*) and red flesh pitaya (*H. polyrhizus*) fruit pulp (Mohd Maidin *et al.*, 2009; Mohd Maidin *et al.*, 2010a; Mohd Maidin *et al.*, 2010b)

The white and red flesh pitaya pulp showed inhibition against two types of bacteria namely *Salmonella typhimurium* and *Klebsiella pneumoniae* as seen in Table 10.

Table 10 The inhibition zone exhibited by red and white flesh pitaya peel, pulp and seed using disc diffusion method

Bacteria	Inhibition zone (mm)	
	RFE	WFE
Staphylococcus aureus	NI	NI
Bacillus cereus	NI	NI
Listeria monocytogenes	NI	NI
Enterococcus faecalis	NI	NI
Escherichia coli	NI	NI
Salmonella typhimurium	7.0±0.30	7.0±0.32
Campylobacter jejuni	NI	NI
Yersinia enterocolitica	NI	NI
Klebsiella pneumoniae	7.0±0.28	7.7±0.31

NI = No inhibition; RFE = red flesh pitaya; WFE = white flesh pitaya

J) Antibacterial property of *H. polyrhizus* and *H. undatus* peel extracts (Nurmahani *et al.*, 2011)

Their results indicated that peel of both types of fruit possessed antibacterial property. However, chloroform extracts exhibited a more potent antibacterial property as compared to both ethanol and hexane extracts.

THE WAY FORWARD

Due to change in the lifestyle and small family size, consumers are going for minimally processed fruits. This is already a trend in many other countries. Observations made by the author and co-researchers in The Netherlands, Thailand and Malaysia revealed that there is already an existing trend towards minimally processed fruits.

In the past, researchers gave attention on finding ways and technologies for shelf life extension and quality maintenance of fruits at different stages (harvesting, packaging, storage, transportation) of the distribution chain from the aspect of nutritional properties. However, currently, research should be focussed not only on these mentioned properties but should also include maintenance of the functional properties (antioxidant, antidiabetic, antibacterial, anticancer, anti-inflammatory, anti-obesity) of the fruits when subjected to the selected (ability to prolong shelf life and maintain quality) post harvest treatments or technology.

From the discussions made, it is obvious that fruits that are nutritious and colourful are very essential in the human diet. However, it is fragile to abuse of the surrounding environmental factors such as temperature, relative humidity, atmospheric gas compositions and mechanical injury. Hence, it has to be handled with tender loving care; otherwise, all efforts given for its production (high yield) will be lost at postharvest.

REFERENCES

- Abdul Aziz, M.Y. (1992). The potential for Malaysian fruits in overseas markets. *Food Technology in Malaysia*. 13: 25-33.
- Abdul Rahman, R., Osman, A. and Mohd Hidzir, M.F. (1998). Physico-chemical changes of three local dessert bananas (P. Mas, P. Rastali and P. Berangan) during fruit growth and maturation. *Proceedings of the First National Banana Seminar*. pp. 290-296.
- Abdul Rahman, R., Osman, A. and Teng, J.J. (2000a). Effect of impact and vibration on the quality and storage life of Pisang Rastali (*Musa sapientum* cv. Rastali) during transportation simulation. *Proceedings of the Malaysian Science and Technology Congress*. pp. 354-362.

- Abdul Rahman, R., Osman, A., Mohamad, N.E. and Ghazali, H.M. (2000b). Effect of enzyme and calcium vacuum infusion on the quality of minimally processed honeydew melon (*Cucumis melo* var *reticulatus*) during storage. *Proceeding of the 12th National 3Biotechnology Seminar*, 12-15 November 2000, Lumut Perak. pp. 375-378.
- Abdul Shukor, A.R., Yulianingsih, Nair, H., Acedo, A.L. and Teng, C.K. (1990). Regulation of ripening in banana. In: Abdullah, H. and Er.B. Pantastico (Eds.). *Banana: Fruit Development, Postharvest Physiology, Handling and Marketing in ASEAN*. ASEAN Food Handling Bureau, Kuala Lumpur, Malaysia. pp. 72-84.
- Abdullah, H. (2003). Current postharvest issues associated with Malaysia's Best. *Proceeding of National Horticultural Conference 2003*, Equatorial Hotel, Bangi, Malaysia, 20-22 October 2003. pp. 64-72.
- Adnan, H., Osman, A., Ghazali, H.M. and Abdul Rahman, R. (2000). Peeling of Limau kasturi (*Citrus mitis* Blanco) by enzyme infusion. *Proceedings of the 12th National Biotechnology Seminar*, 12-15 November 2000, Lumut, Perak. pp 392-394.
- Adnan, H., Osman, A. Ghazali, H.M. and Abdul Rahman, R. (2002). Peeling of musk lime (*Citrus mitis* B.) using pectolytic enzymes. *Asia-pacific Journal of Molecular Biology and Biotechnology*. 10(1): 11-15.
- Adnan, L., Osman, A. and Abdul Hamid, A. (2010a). Available online: 10 Nov 2010. Antioxidant activity of different extracts of red pitaya (*Hylocereus polyrhizus*) seed. *International Journal of Food Properties*. DOI: 10.1080/10942911003592787.
- Adnan, L., Osman, A. and Abdul Hamid, A. (2010b). Antioxidant activity of white flesh pitaya (*Hylocereus undatus*) fruit pulp. International Conference on Food Research, ICFR 2010, 22- 24 November 2010, Marriot Hotel, Putrajaya, Malaysia. Book of Abstract. P049.
- Ali, Z.M., Chin, L., Marimuthu, M. and Lazan, H. (2004). Low temperature storage and modified atmosphere packaging on carambola fruit and their effects on ripening related texture changes, wall modification and chilling injury symptoms. *Postharvest Biology and Technology*. 33: 181-192.

- Allegra, M., Furtmüller, P. G., Jantschko, W., Zederbauer, M., Tesoriere, L., Livrea, M. A. and Obinger, C. (2005). Mechanism of interaction of betanin and indicaxanthin with human myloperoxidase and hypochlorous acid. *Biochemical and Biophysical Research Communication*. 332: 837-844.
- Almela, V., Zaragoz, S., Primo Millo, E. and Augusti, M.A. (1994). Hormonal control of splitting of ‘Nova’ mandarin fruit. *Journal of Horticultural Science*. 69: 969-973.
- Anon (2006). Lipid Peroxidation. [http://en.wikipedia.org/wiki/ Lipid_peroxidation](http://en.wikipedia.org/wiki/Lipid_peroxidation). Retrived on May 2006.
- Anon (2011). New Malaysian project to improve produce labelling. <http://www.betko.co.za/framework/newsarticle.asp?AID=60&P=News>. Retrived on 3rd August 2011.
- Ariffin, A.A., Bakar, J., Tan, C.P., Abdul Rahman, R., Karim, R. and Loi, C.C. (2009). Essential fatty acids of pitaya (dragon fruit) seed oil. *Food Chemistry*. 114: 561-564.
- Azarakhsh, N., Osman, A., Tan, C.P., Ghazali, H.M. and Mohd Adzahan, N. (2010a). Effect of alginate and gellan-based edible coatings on quality of fresh-cut pineapple during cold storage. 7th international Pineapple Symposium 2010. 13-15 July 2010, PERSADA Johor international Convention Centre Johor Bahru, Johor, Malaysia. Book of Abstracts. pp.118.
- Azarakhsh, N., Osman, A., Ghazali, H.M., Tan, C.P. and Mohd Adzahan, N. (2010b). Evaluating the effect of different polysaccharide-based edible coatings on changes in weight loss, firmness, respiration rate and sensory characteristics of fresh-cut pineapples. International Conference on Food Research, ICFR 2010, 22- 24 November 2010, Marriot Hotel, Putrajaya, Malaysia. Book of Abstract. P081.
- Azarakhsh, N., Osman, A., Ghazali, H.M., Tan, C.P. and Mohd Adzahan, N. (2011). Optimization of alginate and gellan-based edible coating formulations for fresh-cut pineapples. *International Food Research Journal*. In press

- Aziz, A.G., Osman, A., Ghazali, H.M. and Abdul Rahman, R. (1999). Effect of pectinase concentration on the ease of peeling of Limau Bali (*C. grandis*). *Proceeding of the 11th National Biotechnology Seminar*. pp 186-188.
- Aziz, A.G., Osman, A., Ghazali, H.M. and Abdul Rahman, R. (2000). Effect of enzyme recycling on the ease of peeling of pommelo (*Citrus grandis*). *Proceedings of the 12th National Biotechnology Seminar*, 12-15 November 2000, Lumut, Perak. pp. 413-415
- Baker, R.A. and Grohman, K (1995). Enzyme application in citrus processing. *Fruit Processing*. 10/95: 332-335.
- Baker, R.A. and Wicker, L. (1996). Review: Current and potential applications of enzyme infusion in the food industry. *Trends in Food Science and Technology*. 7: 279-284.
- Bassin, R. (1993). *Kajian Keatas perubahan fiziko-kimia buah sukun (Artocarpus communis) semasa peringkat perkembangan buah*. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 58p.
- Bennet, A.B. and Christofferson, R.E. (1986). Synthesis and processing of cellulose from ripening avocado fruit. *Plant Physiology*. 81: 830-835.
- Ben-Yehoshua, S. (1987). Transpiration, water stress, and gas exchange. In: Weichmann, J. (Ed). *Post harvest Physiology of Vegetables*. Marcel Dekker, New York. pp. 113-170.
- Bernama (2011). 3P Regulations to be fully enforced by end 2013. <http://my.news.yahoo.com/3p-regulations-fully-enforced-end-2013-130553155.html>. Retrived on 3 August 2011.
- Besford, R.T., Richardson, C.M., Campos, J.L. and Tiburcio, A.F. (1993). Effect of polyamines on stabilization of molecular complexes of thylakoid membranes of osmotically stressed oat leaves. *Planta*. 189: 201-206.
- Biale, J.B. (1950). Postharvest, physiology and biochemistry of fruits. *Annual Review of Plant Physiology*. 1: 183-206.
- Biale, J.B. (1964). Growth, maturation and senescence in fruits. *Science*. 144(3646): 880-888.

- Bico, S.L.S., Raposo, M.F.J., Morais, R.M.S.C. and. Morais, A M.M.B. (2010). Chemical dips and edible coatings to retard softening and browning of fresh-cut banana. *International Journal of Postharvest Technology and Innovation*. 2(1): 13-24.
- Booncherm, P. and Siriphanich, J. (1991). Postharvest physiology of durian pulp and husk. *Kasetsart Journal*. 25: 119-125.
- Bora, P.S. and Narain, N. (1997). Passion Fruit. In: Mitra, S. (Ed.). *Postharvest physiology and Storage of Tropical and Subtropical Fruits*. CAB International, Wallingford, U.K. pp. 375-386.
- Borrell, A., Carbonell, L., Farras, R., Puig-Parellada, P. and Tiburcio, A.F. (1997). Polyamines inhibit lipid peroxidation in senescing oat leaves. *Physiologia Plantarum*. 99: 385-390.
- Bors, W., Langebartels, C., Michel, C., and Sandermann, H.Jr. (1989). Polyamines as radical scavengers and protectants against ozone damage. *Phytochemistry*. 28:1589-1595.
- Brouk, B. (1975). *Plants Consumed By Man*. Academic Press, London, U.K. 479 p.
- Bruemmer, J.H. (1981). Methods of preparing citrus fruit sections with fresh fruit flavour and appearance. U.S. Patent 4238651.
- Burdon, J. N. (1997). Postharvest handling of tropical and subtropical fruit for export. In: Mitra, S.K. (Ed.). *Postharvest Physiology and Storage of Tropical and Sub-tropical Fruits*. CAB International, Wallingford, U.K. pp. 1-19.
- Cai, Y., Sun, M. and Corke, H. (2003). Antioxidant activity of betalains from plants of the *Amaranthaceae*. *Journal of Agricultural and Food Chemistry*. 51: 2288-2294.
- Chiang, M.N. (1967). Effect of modified atmosphere on storage of bananas. Special Publication No. 20 . College of Agriculture, National Taiwan University, Taipei. pp. 104-109.
- Conway, W.S. and Sams, C.E. (1984). Possible mechanism by which postharvest calcium treatment reduces decay in apples. *Phytopathology*. 74(2): 208-210.

- Coombe B.G. (1996). The development of fleshy fruits. *Annual Review of Plant Physiology*. 27: 207-228.
- Couey, M.H. (1982). Chilling injury of crops of tropical and sub-tropical origin. *HortScience*. 17(2): 162-165.
- Craig, W.J. (1997). Phytochemicals: Guardians of our health. *Journal of the American Dietetic Association*. 97: 199-204.
- Crisosto, C.H., Mitchell, F.G. and Johnson, S. (1995). Review article: Factors in fresh market stone fruit quality. *Postharvest News and Information*. 6(2): 17-21.
- Dadzie, B.K. and Orchard, J.E. (1997). Routine Postharvest Screening of Banana/Plantain Hybrids: criteria and methods. *INIBAP Technical Guidelines*. INIBAP ISBN: 2-910810-22-4.
- Dangyang, K. and Kader, A.A. (1990). Tolerance of 'Valencia' oranges to controlled atmospheres, as determined by physiological responses and quality attributes. *Journal of the American Society for Horticultural Science*. 115(5): 779-783.
- Di Egidio, V., Sinelli, N., Limbo, S., Torri, L., Franzetti, L. and Casiraghi, E. (2009). Evaluation of shelf-life of fresh-cut pineapple using FT-NIR and FT-IR spectroscopy. *Postharvest Biology and Technology*. 54: 87-92.
- DOA (2009). Perangkaan Agro-makanan 2009. Ministry of Agriculture and Agro-based Industry Malaysia. 196p.
- Emmons, C.L.W. and Scott, J.W. (1998). Ultrastructural and anatomical factors associated with resistance to cuticle cracking in tomato (*Lycopersicon esculentum* Mill). *International Journal of Plant Science*. 159: 14-22.
- Esau, K. (1964). *Anatomy of Seed Plants*. 2nd edition. John Wiley and Sons, New York, U.S. 376 p.
- Escribano, J., Pedreño, M.A., García-Carmona, F. and Muñoz, R. (1998). Characterization of the antiradical activity from *Beta vulgaris* L. roots. *Phytochemical Analysis*. 9: 124-127.
- FAMA (2005). *Panduan Perlaksanaan Kontrak Pemasaran dan Pembungkusan Buah-buahan*. 51p.

- FAO (2010). Medium-term prospects for agricultural commodities - projections to the year 2010. Available at: <http://www.fao.org/docrep/006/y5143e/y5143e1a.htm#fn19>. Retrieved on 8th August 2011.
- FAO (2011). Food and Agriculture Organization of United Nations. Statistical database. Available from <http://faostat.fao.org>. Retrieved on 2nd July, 2011.
- Ferguson, I.B., Ben-Yehoshua, S., Mitcham, E.J., McDonald, R.E., and Lurie, S. (2000). Postharvest heat treatments: Introduction and workshop summary. *Postharvest Biology and Technology*. 21: 1-6.
- Floros, J.D. (1993). The shelf life of fruits and vegetables. In: Charalambous, G. (Ed.) *Shelf Life Studies of Foods and Beverages*. Elsevier Science Publishers, Amsterdam, The Netherlands. pp.195-213.
- Gaillard, T. (1968). Aspects of lipid metabolism in higher plants. 1. Identification and quantitative determination of the lipids in potato tubers. *Phytochemistry*. 7: 1907-1914.
- Giovannoni, J.J. (2004). Genetic regulation of fruit development and ripening. *Plant Cell*. 16 (Suppl): 170-180.
- Gonzales-Aguilar, G.A., Zacarias, L., Mulas, M., and Lafuente, M.T. (1997). Temperature and duration of hot water dips influence chilling injury, decay and polyamine content in 'Fortune' mandarins. *Postharvest Biology and Technology*. 12: 61-69.
- Gonzalez-Aguilar, G.A., Ayala-Zavala, J.F., Olivas, G.I., de la Rosa, L.A. and Alvarez-Parrilla, E. (2010). Preserving quality of fresh-cut products using safe technologies. *Journal of Consumer Protection and Food safety*. 5: 65-72.
- Graham, H.D. and De Bravo, E.N. (1981). Composition of breadfruit. *Journal of Food Science*. 46:535-539.
- Gutiérrez, R.M.P., Solís, R.V., Baez, E.G. and Flores, J.M.M. (2007). Microvascular protective activity in rabbits of triterpenes from *Hylocereus undatus*. *Journal of Natural Medicine*. 61: 296-301.
- Haard, N.F. and Timbie, D. (1976). Chilling injury in green banana fruit: Changes in peroxidase isozymes in soluble and particulate pools. *Journal of Food Science*. 38(4): 642-645.

- Hassimotto, N.M.A., Genovese, M.I. and Lajolo, F.M. (2005). Antioxidant activity of dietary fruits, vegetables, and commercial frozen fruit pulps. *Journal of Agricultural and Food Chemistry*. 53: 2928-2935.
- He, X. and Liu, R.H. (2008). Phytochemicals of apple peels: Isolation, structure elucidation, and their antiproliferative and antioxidant activities. *Journal of Agricultural and Food Chemistry*. 56: 9905–9910.
- Izumi, H. and Watada, A.E. (1994). Calcium treatment affects storage quality of shredded carrots. *Journal of Food Science*. 59(1): 106-109.
- Jackson, D. (1999a). Flowers and fruit. In Jackson, D.I. and N.E. Looney (Eds.) *Temperate and Subtropical Fruit Production*. 2nd edition. CABI Publishing, New York, U.S. pp. 33-43.
- Jackson, D. (1999b). Climate and fruit plants. In Jackson, D.I. and N.E. Looney (Eds.) *Temperate and Subtropical Fruit Production*. 2nd edition. CABI Publishing, New York, U.S. CABI Publishing, pp. 7-14.
- Jackson, D. (1999c). Soil, nutrients and water. In Jackson, D.I. and N.E. Looney (Eds.) *Temperate and Subtropical Fruit Production*. 2nd edition. CABI Publishing, New York, U.S. pp. 109-126.
- Jackson, D. and Looney, N. (1999a). Producing and marketing quality fruit. In D.I. Jackson and N.E. Looney (Eds.) *Temperate and Subtropical Fruit Production*. 2nd edition. CABI Publishing, New York, U.S. pp. 85-108.
- Jackson, D. and Looney, N. (1999b). The distribution of fruits. In D.I. Jackson and N.E. Looney (Eds.) *Temperate and Subtropical Fruit Production*. 2nd edition. CABI Publishing, New York, U.S. pp. 1-5
- Jackson, J.E., Sharples, R.O. and Palmer, J.W. (1971). The influence of shade and within-tree position on apple fruit size, colour, and storage quality. *Journal of Horticultural Science*. 46:277-287.
- Jafarizadeh Malmiri, H., Osman, A., Tan, C. P. and Abdul Rahman, R. (2011a). Development of an edible coating based on chitosan-glycerol to delay ‘Berangan’ banana (*Musa sapientum* cv. Berangan) ripening process. *International Food Research Journal*. 18 (3): 989-997.

- Jafarizadeh Malmiri, H., Osman, A., Tan, C. P. and Abdul Rahman, R. (2011b). Evaluation of effectiveness of three cellulose derivative based edible coatings on changes of physico- chemical characteristics of 'Berangan' banana (*Musa sapientum* cv. Berangan) during storage at ambient conditions. *International Food Research Journal*. 18(4): 1381-1386.
- Jamilah, B., Shu, C. E., Kharidah, M., Dzulkifly, M. A. and Noranizan, A. (2011). Physico-chemical characteristics of red pitaya (*Hylocereus polyrhizus*) peel. *International Food Research Journal*. 18: 279-286.
- Janser, E. (1996). Enzymatic peeling of fruit. Special Print-juice treatment. *Journal of Fruit processing*. 3/96: 1-4.
- Janser, E. (1997). Enzyme applications for tropical fruits and citrus. Special Print-Juice Treatment. *Journal of Fruit Processing*. 10/97: 1-8.
- Jayaraman, K.S., Ramanuja, M.N., Dhakne, Y.S. and Vijayaraghavan, P.K. (1982). Enzymatic browning in some banana varieties as related to polyphenoloxidase activity and other endogenous factors. *Journal of Food Science and Technology*. 19:181-186.
- Jingtair, S. (1993). Minimally processing of tropical fruits. In: Champ, B.R., E. Highley, and G.I. Johnson (Eds). *Postharvest Handling of Tropical Fruits*. Chiang Mai, Thailand. pp. 430-433.
- Jones, U.S. (1982). *Fertilizers and Soil Fertility*. Prentice Hall, Virginia, U.S. 412p.
- Kader, A.A. (1987). Respiration and gas exchange of vegetables. In: Weichmann, J. (Ed). *Post harvest Physiology of Vegetables*. Marcel Dekker Inc., New York, U.S. pp.25-43.
- Kader, A.A., Zagory, D. and Kerbel, E.L. (1989). Modified atmosphere packaging of fruits and vegetables. *Critical Review of Food Science and Nutrition*. 28(11):1-30.
- Kader, A. A. (1992a). Postharvest biology and technology: An overview. In: Kader, A.A. (Ed.). *Postharvest Technology of Horticultural Crops*. 2nd edition. ANR Publications, California, U.S. pp.15-20.

- Kader, A.A. (1992b). Quality and safety factors: Definition and evaluation for fresh horticultural crops. In: Kader, A.A. (Ed.). *Postharvest Technology of Horticultural Crops*. 2nd edition. ANR Publications, California, U.S. pp.185-189.
- Kader, A..A. (2002). Fruits in the global market. In: M. Knee (Ed.). *Fruit Quality and Its Biological Basis*. Sheffield Academic Press, Sheffield, U.K. pp.1-16.
- Kader, A. A. and Barrett, D.M. (2004). Classification, composition of fruits and postharvest maintenance of quality. In: Barrett, D.M., L. Somogyi and H. Ramaswamy (Eds.) *Processing Fruits*. 2nd edition. CRC Press Boca Raton, Florida, U.S. pp.3-22.
- Karim, R., Yap, S.L., Mohd Adzahan, N., Mirhosseini, H., Osman, A. and Mohd Yusof, A. (2010). Optimisation of processing conditions of red pitaya (*Hylocereus polyrhizus*) International Conference on Food Research, ICFR 2010, 22-24 November 2010, Marriot Hotel, Putrajaya, Malaysia. Book of Abstract. P106.
- Kays, S.J. (1991). *Postharvest Physiology of Perishable Plant Products*. Van Nostrand Reinhold, New York, U.S. 532 pp.
- Kays, S.J. (1999). Preharvest factors affecting appearance. *Postharvest Biology and Technology*. 15: 233–247.
- Kendall, E.J. and McKersie, B.D. (1989). Free radical and freezing injury to cell membranes of winter wheat. *Physiologia Plantarum*. 76: 86-94.
- Ketsa, S., Chidtragool, S. and Lurie, S. (2000). Pre-storage heat treatment and post-storage quality of mango fruit. *HortScience*. 35: 247-249.
- Kim, M.H. and Lee, S.K. (1992). Effects of storage temperatures on mature green bananas. *Journal of Korean Society of Horticultural Sciencs*. 29(1): 64-70.
- King Jr., A.D. and Bolin, H.R. (1989). Physiological and microbiological storage stability of minimally processed fruits and vegetables. *Food Technology*. 43:132-135.
- Klein, J.D. and Lurie, S. (1990). Prestorage heat treatment as a means of improving post-storage quality apples. *Journal of the American Society for Horticultural Science*. 115: 255-259.

- Kumar, G.N.M. (1990). Pomegranate. In: Nagy, S., P. Shaw and W. Wardowski (Eds.). *Fruits of tropical and subtropical origin*. Agscience Inc., Florida, USA. pp.328-347.
- Laurila, E. and Ahvenainen, R. (2002). Minimal processing in practice: fresh fruits and vegetables. In Ohlsson, T. and N. Bengtsson (Eds). *Minimal Processing Technologies in the Food Industry*. CRC press, Cambridge, U.K. pp.219-244.
- Le Bellec, F., Vaillant, F. and Imbert, E. (2006). Pitahaya (*Hylocereus* spp.): a new fruit crop, a market with a future. *Fruits*. 61: 237-250.
- Leather, S. (1995). Fruit and vegetables: consumption patterns and health consequences. *British Food Journal*. 97: 10-17.
- Leong L.P. and Shui G. (2002). An investigation of antioxidant capacity of fruits in Singapore markets. *Food Chemistry*. 76: 69–75.
- Liang, Y., Zhang, W., Chen, Q., and Ding, R. (2005). Effects of silicon on H⁺-ATPase and H⁺-PPase activity, fatty acid composition and fluidity of tonoplast vesicles from roots of salt-stressed barley (*Hordeum vulgare* L.). *Environmental and Experimental Botany*. 53: 29-37.
- Lim, H. K., Tan, C. P., Karim, R., Ariffin, A. A. and Bakar, J. (2010). Chemical composition and DSC thermal properties of two species of *Hylocereus cacti* seed oil: *Hylocereus undatus* and *Hylocereus polyrhizus*. *Food Chemistry*. 119: 1326-1331.
- Liu, F.W. (1970). Storage of bananas in poethylene bags with an ethylene absorbent. *Horticultural Science*. 5: 25-27.
- Liu, F., Osman, A. and Ghazali, H.M. (1999). Peeling of limau Langkat (*C.suhuiensis*) by enzyme aided infusion. *Proceeding of the 11th National Biotechnology Seminar*. pp.186-188.
- Liu, F., Osman, A. and Ghazali, H.M. (2000a). Peeling of Mandarin Orange (*Citrus suhuiensis*) by enzyme aided infusion. *Asia-pacific Journal of Molecular Biology and Biotechnology*. 8(2): 173-176.
- Liu, F., Osman, A. and Ghazali, H.M. (2000b). Membrane removal of Mandarin orange (*Citrus suhuiensis*) segments by enzyme infusion. *Proceedings of the 12th National Biotechnology Seminar*, 12-15 November 2000, Lumut, Perak. pp.386-388.

- Liu, F., Osman, A. and Ghazali, H.M. (2004). Effect of enzyme-aided peeling on the quality of honey mandarin segments. *Journal of Food Processing and Preservation*. 28: 336-347.
- Lizada, M.C.C., Pantastico, Er.B., Abd. Shukor, A.R. and Sabari, S.D. (1990). Ripening of banana. In: Abdullah, H. and Er.B. Pantastico (Eds.). *Banana: Fruit Development, Postharvest Phisiology, Handling and Marketing in ASEAN*. ASEAN Food Handling Bureau, Kuala Lumpur, Malaysia. pp. 65-84.
- Lutchmeah, R.S. (1992). Common disorders and diseases of pineapple fruit cv. Victoria in Mauritius. *Revue Agricole et Sucriere*. 71: 27-31.
- Lyons, J.M. (1973). Chilling injury in plants. *Annual Review of Plant Physiology*. 24: 445-466.
- Madakadze, R.M. (2004). Effect of preharvest factors on the quality of vegetables produced in the tropics. In Dris, R. and S. Mohen Jain (Eds.). *Preharvest Practice*. Volume 1. Kluwer Academic Publishers. Dordrecht, The Netherlands. pp. 3.
- Maftoonazad, N., Ramaswamy, H.S., Moalemiyan, M. and Kushalappa, A.C. (2007). Effect of pectin-based edible emulsion coating on changes in quality of avocado exposed to *Lasiodiplodia theobromae* infection. *Carbohydrate Polymers*. 68: 341-349.
- Mahani, A. and Mohd. Ghazali, M.S. (2007). Mata Naga. Malaysia. Dewan Bahasa dan Pustaka, Malaysia. p. 1-3.
- Maneenuam, T., Ketsa, S. and van Doorn, W.G. (2007). High oxygen levels promote peel spotting in banana fruit. *Postharvest Biology and Technology*. 43: 128-132.
- Maqbool, M., Ali, A., Ramachandran, S., Smith, D.R. and Alderson, P.G. (2010). Control of postharvest anthracnose of banana using a new edible composite coating. *Crop Protection*. 29: 1136-1141.
- Marcilla, A., Zarzo, M. and del Río, M.A. (2006). Effect of storage temperature on the flavour of citrus fruit. *Spanish Journal of Agricultural Research*. 4(4): 336-344.
- MARDI (1992). Penyelidikan Buah-buahan. 28p

- Matsuo, T., Ide, S., and Shitida, M. (1992). Correlation between chilling sensitivity of plant tissues and fatty acid composition of phosphatidylglycerols. *Phytochemistry*. 31:2289-2293.
- McArdle, R.N. and Culver, C.A. (1994). Enzyme infusion: A developing technology. *Food Technology*. 48:85-89.
- McCollum, T.G., D'Aquino, S. and McDonald, R.E. (1993). Heat treatment inhibits mango chilling injury. *HortScience*. 28: 197-198.
- McGlasson, W.B., Wade, N.L. and Adato, I. (1978). Phytochromes and fruit ripening. In: Letham, D.S., P.B. Goodman and T.J.V. Higgins (Eds.). *Phytochromes and Related Compounds: A Comprehensive Treatise*. Volume 2. Elsevier, Amsterdam, The Netherlands. pp447-493.
- Mitcham, E.J. and McDonald, R.E. (1992). Effect of high temperature on cell wall modifications associated with tomato fruit ripening. *Postharvest Biology and Technology*. 1: 257-264.
- Mizrahi, Y., Nerd, A. and Nobel, P. S. (1997) Cacti as crops. *Horticultural Reviews*. 18: 291-320.
- MOA (1999). *Third National Agricultural Policy (1998-2010)*. Ministry of Agriculture, Kuala Lumpur, Malaysia. 265p.
- Moßhammer, M.R., Stintzing, F.C. and Carle, R. (2005). Colour studies on fruit juice blends from *Opuntia* and *Hylocereus* cacti and betalain-containing model solutions derived therefrom. *Food Research International*. 38: 975-981.
- Mohamad Basri, N.S. (2009). The effect of different maturity stages of red flesh pitaya fruit (*Hylocereus polyrhizus*) on puree quality. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 83p
- Mohd Adzhim Khalili, R., Norhayati, A. H., Rokiah, M. Y., Asmah, R., Siti Muskinah, M. and Abdul Manaf, A. (2009). Hypocholesterolemic effect of red pitaya (*Hylocereus* sp.) on hypercholesterolemia induced rats. *International Food Research Journal*. 16: 431-440.
- Mohd Aripin, N.H. (2009). Effect of different concentrations of alginate as an edible surface coating on the storage quality of fresh-cut mango. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 45p.

- Mohd Hidzir, M. F. (1997). *Perubahan fiziko-kimia pada tiga variety pisang makan segar tempatan (Pisang Mas, Berangan dan Rastali) semasa peringkat tumbesaran dan kematangan* Bachelor of Food science and Technology thesis, Universiti Putra Malaysia. 62p.
- Mohd Maidin, N., Osman, A., Abdul Hamid, A. and Mohamad Ghazali, A. F. (2009). Determination of antimicrobial activity of fresh pulp of red pitaya (*Hylocereus polyrhizus*). International Congress of Malaysian Society for Microbiology(ICMSM) 2009, 1-4 December 2009, Parkroyal Hotel, Penang, Malaysia. Book of Abstract. pp.74.
- Mohd Maidin, N., Osman, A., Abdul Hamid, A. and Mohamad Ghazali, A. F. (2010a). Antimicrobial activity of white flesh pitaya (*Hylocereus undatus*) fruit pulp. International Conference on Food Research, ICFR 2010, 22- 24 November 2010, Marriot Hotel, Putrajaya, Malaysia . Book of Abstract. P098.
- Mohd Maidin, N., Adnan, L., Osman, A., Abdul Hamid, A. and Mohamad Ghazali, F. (2010b). Antioxidant and antimicrobial activity of fresh red flesh pitaya (*Hylocereus polyrhizus*) fruit pulp. 1st International Congress on Food Technology, Atlantis Hotel, Antalya, Turkey; 3-6 November 2010. Book of Abstract. pp.427.
- Mohd Yusof, I.N. (1997). Effect of vacuum infusion of calcium on the quality of minimally processed honeydew melons (*Cucumis melo* var reticulates) during storage. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 95p.
- Montero-Calderon, M., Rojas-Grau, M.A. and Martin-Belloso, O. (2008). Effect of packaging conditions on quality and shelf-life of fresh-cut pineapple (*Ananas comosus*). *Postharvest Biology and Technology*. 50: 182-189.
- Montero-Calderon, M., Rojas-Grau, M.A., Aguilo-Aguayo, I., Soliva-Fortuny, R. and Martin-Belloso, O. (2010). Influence of modified atmosphere packaging on volatile compounds and physicochemical and antioxidant attributes of fresh-cut pineapple (*Ananas comosus*). *Journal of Agricultural Food Chemistry*. 58: 5042-5049.
- Morris, L.L. (1982). Chilling injury of horticultural crops: An overview. *HortScience*. 17: 161-165.

- Morton, J.F. (1987). *Fruits of Warm Climate*. Florida Flair Books Miami, Florida, U.S. 505p.
- Murata, T. and Tatsumi, Y. (1979). Ion leakage in chilled plant tissues. In Lyons, J.M., D. Graham, and J.K. Raison (Eds). *Low Temperature Stress in Crop Plants*. Academic Press, New York, U.S. pp.141-151.
- Mustaffa, R., Osman, A., Mohamed, S. and Yusof, S. (1997). Changes in tannin and pectic substances at different positions within a bunch of Cavendish banana (*Musa cavendishii* L. var. Montel) during development and maturation. *Pertanika Journal of Tropical Agricultural Science*. 20(2&3): 157-162.
- Mustaffa, R, Osman, A., Yusof, S. and Mohamed, S. (1998). Physico-chemical changes in Cavendish banana (*Musa cavendishii* L. var. Montel) at different positions within a bunch during development and maturation. *Journal of the Science of Food and Agriculture*. 78: 201-207.
- Mustaffa, R., Osman, A., Mohamed, S. and Yusof, S. (2000). Effect of waxing with paraffin and modified atmosphere packaging on the storage of Cavendish banana (*Musa cavendishii* L. var Montel) *Pertanika Journal of Tropical Agricultural Science*. 23(1): 1-14
- Nanthachai, S. (1994). *Durian: Fruit development, postharvest, physiology, handling and marketing in ASEAN*. ASEAN Food Handling Bureau, Kuala Lumpur, Malaysia. 156p.
- Nguyen, T.B.T., Ketsa, S. and van Doorn, W.E. (2003). Relationship between browning and the activities of polyphenoloxidase and phenylalanine ammonia lyase in banana peel during low temperature storage. *Postharvest Biology and Technology*. 30: 187-193.
- Nik Saad, N.S. (1996). *Kajian ciri-ciri fiziko-kimia tiga variety pisang tempatan pada tiga peringkat kematangan yang berlainan*. Bachelor of Food science and Technology thesis, Universiti Putra Malaysia. 73p.
- Nurliyana, R., Syed Zahir, I., Mustapha Suleiman, K., Aisyah, M.R. and Kamarul Rahim, K. (2010) Antioxidant study of pulps and peels of dragon fruits: a comparative study. *International Food Research Journal*. 17: 367-375.

- Nurmahani, M.M., Osman, A., Abdul Hamid, A., Mohamad Ghazali, F. and Pak Dek, M.S. (2011). Antibacterial property of *Hylocereus polyrhizus* and *Hylocereus undatus* peel extracts. *International Food Research Journal*. In press.
- Olivas, G.I. and Barbosa-Canovas, G.V. (2005). Edible coatings for fresh-cut fruits. *Critical Reviews in Food Science and Nutrition*. 45: 657-670.
- Olorunda, A.O., Meherjuk, M. and Looney, M.E. (1978). Some postharvest factors associated with the occurrence of chilling injury in banana. *Journal of the Science of Food and Agriculture*. 29(3): 213-218.
- Oms-Oliu, G., Rojas-Grau, M.A., Gonzalez, L.A., Varela, P., Soliva-fortuny, R., Hernando, M.I., Munuera, I.P., Fiszman, S., Martin-Belloso, O. (2010). Recent approaches using chemical treatments to preserve quality of fresh-cut fruit. *Postharvest Biology and Technology*. 57:139-148.
- Ong, B.T., Sheikh Abdul Hamid, N. and Osman, A. (2006). Physico-chemical and flavour changes in jackfruit (*Artocarpus heterophyllis* L.) cultivars J3 during ripening. *Journal of Postharvest Biology and Technology*. 40: 279-286.
- Opara, L.U. (1996a). What is stem-end splitting in apples. *Good Fruit Growers*. 47: 57-59.
- Opara, L.U. (1996b). Some characteristics of internal ring-cracking in apples. *Fruit Varieties Journal*. 50: 260-264.
- Osman, A., Abdul Karim, M.N. and Bassin, R. (1994). The physico-chemical changes in Malaysian breadfruit (*Artocarpus communis*). In: Halim, R.A., S.W. Kamaruddin, C.C. Wong and A.S. Mamat (Eds.). *Transaksi Persatuan Fisiologi Tumbuhan Malaysia 5*. Persatuan Fisiologi Tumbuhan Malaysia, Kuala Lumpur, Malaysia. pp.130-131.
- Osman, A., Ramli, F. and Saleh, G. (1996a). Physico-chemical changes of three passion fruit accessions during fruit development. Paper presented at the Second Asia-Pacific Conference on Plant Physiology. 20-22 August 1996, Shah Alam, Selangor, Malaysia.
- Osman, A., Sulaiman, Z. and Ghazali, H.M. (1996b). Effect of various postharvest treatments on changes in texture, polygalacturonase

- activity and several other physico-chemical properties of starfruit (*Averrhoa carambola* L.) during storage. *Proceeding of the 8th National Biotechnology Seminar*. pp.363-366.
- Osman, A., Chiew, B.W. and Ghazali, H.M. (1996c). Effect of various postharvest treatment on several physico-chemical properties of guava (*Psidium guajava* L.). In: Vijayasegaran, S., M. Puziah, M.S. Mohamed and S. Ahmed Tarmizi (Compilers). *Proceedings International Conference on Tropical Fruits*. 1: 377-380.
- Osman, A., Wan Mustapha, W.A. and Abdul Rahman, R. (1998a). Development of ripening peel colour index for Pisang Rastali (*Musa sapientum* var. Rastali). *Proceedings of the First National Banana Seminar*. pp.281-219.
- Osman, A., Nik Saad, N.S. and Mohamed, S. (1998b). Comparing the physico-chemical characteristics of Mas, Rastali and Berangan Bananas at 3 stages of maturity. *Proceedings of the First National Banana Seminar*. pp.157-163.
- Osman, A. Ghazali, H.M., Mamat, F. and Abdul Karim, M.N. (1998c). Polygalacturonase activity and several physico-chemical properties of sapota (*Achras sapota* L.) as a result of different postharvest treatment. *Proceeding of the 10th National Biotechnology Seminar*. pp.251-254..
- Osman, A., Nallusamy, S., Ghazali, H.M. and Abdul Rahman, R. (1999a). Effects of different postharvest treatments on the polygalacturonase activity and several physico-chemical properties of papaya (*Carica papaya* L. var. Eksotika) during storage. *Proceedings of the 11th National Biotechnology Seminar*. pp.191-194.
- Osman, A., Abdul Rahman, R. Moh, C.C. and Febrimeli, D. (1999b). Effect of different postharvest treatments prior to low temperature storage on the physico-chemical characteristics of P.Rastali (*Musa sapientum* cv. Rastali). *Proceedings of the Malaysian Science and Technology Congress '99*. pp.149-155.
- Osman, A., Ng, H.T., Ghazali, H.M. and Abdul Rahman, R. (1999c). Effect of vacuum infusion of calcium on the quality of minimally processed guavas (*Psidium guajava* L.) during storage. *Proceeding of the Malaysian Science and Technology Congress '99*. pp.156-163.

- Osman, A., Ishak, M.Q., Ghazali, H.M. and Abdul Rahman, R. (2000a). Effect of different postharvest treatments on textural, polygalacturonase (PG) activity and other physico-chemical characteristics of honeydew melon (*Cucumis melo* var. *Recticulatus*). *Proceeding of the 12th National Biotechnology Seminar*. 12-15 November 2000, Lumut Perak. pp.370-374.
- Osman, A., Abdul Rahman, R. and Keng, W.W. (2000b). Effects of vibrations on the quality of Pisang Berangan (*Musa sapientum* cv. Berangan) during the simulation of truck transportation. *Proceedings of the Malaysian Science and Technology Congress*. pp. 346-353.
- Osman, A., Sharipuzan, M.S, Liu, F., Ghazali, H.M. and Abdul Rahman, R. (2001). Effect of vacuum infusion of the pectinase and calcium on the texture and colour of minimally processed guava (*Psidium guajava*). *Transactions of the Malaysian Society of Plant Physiology*. 19: 160-163.
- Osman, A., Saad, S. and Abdul Rahman, R. (2002). Effect of different heat treatments prior to low temperature storage on the changes in the physico-chemical characteristics and manifestation of chilling injury of Pisang Berangan (*Musa sapientum* var. Berangan). 3rd National Banana Seminar, 29-30 August 2002, Avillion Village Resort, Port Dickson, Negeri Sembilan, Book of abstract. pp.41.
- Osman, A., Mohd Aripin, N.H., Mohamad Ghazali, F. and Malmiri, H.J. (2009a). Microbiological examination of sodium alginate edible coating on fresh cut *Chokanan* mango. International Congress of Malaysian Society for Microbiology(ICMSM) 2009, 1-4 Decmber 2009, Parkroyal Hotel, Penang, Malaysia. Book of Abstract. pp.207.
- Osman, A., Saari, N., Saleh, R., Jamilah, B., Zainal, N.D., and Yacob, M. (2009b). Postharvest handling practices on selected local fruits and vegetables at different levels of distribution chain. *Journal of Agribusiness Marketing*. 2: 38-51.
- Osman, A., Jamilah, B., Saari, N. and Saleh, R. (2009c). Postharvest technology and value added possibilities for fruits and vegetables. Final Report: FAMA-IPTA Collaborative Research (Programme 1-Project 4). 269p.

- Paliyath, G. and Murr, D. P. (2008). Biochemistry of fruits. In: Paliyath, G., D.P. Murr, A. K. Handa and S. Lurie (Eds.). *Postharvest Biology and Technology of Fruits, Vegetables, and Flowers*. Wiley-Blackwell Publishing, Maiden MA, U.S. pp.21-25.
- Pantastico, Er.B., Grierson, W. and Soule, J. (1967). Chilling injury in tropical fruits: 1. Bananas (*Musa paradisiaca* var. *sapientum* cv. Lakatan). *Proceeding of Tropical Region of American Society for Horticultural Science* 11. pp.82-91.
- Pantastico, Er. B., Azizan, M.A., Abdullah, H., Acedo, A.L., Dasuki, I.M. and Kosiyachinda, S. (1990). Physiological disorders of Banana fruit. In: Abdullah, H. and Er.B. Pantastico (Eds.). *Banana: Fruit Development, Postharvest Physiology, Handling and Marketing in ASEAN*. ASEAN Food Handling Bureau, Kuala Lumpur Malaysia. pp.85-103.
- Pao, S. and Petracek, P.D. (1997). Shelf life extension of peeled oranges by citric acid treatments. *Food Microbiology*. 14: 485-491.
- Paul, R.E. (1996a). Postharvest atemoya fruit splitting during ripening. *Postharvest Biology and Technology*. 8: 329-334.
- Paul, R.E. (1996b). Effects of temperature and relative humidity on fresh commodity quality. *Postharvest, Biology and Technology*. 15: 263-277.
- Pauziah, M., Hamilah, H., Tarmizi, S. and Nik Masdek, N.H. (1992). Quality evaluation of hand harvested durian clone D24. *Proceeding of the National IRPA (Intersterification of Research in Priority Areas) Seminar Agricultural sector*. pp. 634-635.
- Pavlov, A., Kovatcheva, P., Tuneva, D., Ilieva, M. and Bley, T. (2005). Radical scavenging activity and stability of betalains from *Beta vulgaris* hairy root culture in simulated conditions of human gastrointestinal tract. *Plant Foods for Human Nutrition*. 60: 43-47.
- Peacock, B.C. (1975). 'Mixed ripe' - a problem for the banana industry. *Queensland Agricultural Journal*. 101: 201-204.
- Peacock, B.C. and Blake, J.R. (1970). Some effects of non-damaging temperatures on the life and respiratory behaviour of bananas. *Queensland Journal of Agricultural and Animal Sciences*. 27:147-168.

- Peet, M.M. (1992). Fruit cracking in tomato. *Hort Technology*. 2:216-219.
- Peter, K.V. (2007). *Vegetables Crops: Horticulture Sciences (Series 4)*. New India Publishing Agency. New Delhi, India. 343p.
- Popenoe, W. (1920). *Manual of Tropical and Subtropical Fruits*. Collier-Macmillan, New York, U.S. 474p.
- Praditdoug, S. (1986). Cold storage of durian (English abstract). *Kasetsart Journal*. 20: 44-49.
- Prasad, S. (2003). *Agro's Dictionary of Horticulture*. 3rd edition. Agrobios India. Jodhpur, India. 392p.
- Ramli, F. (1995). *Kajian keatas perubahan ciri-ciri fisiko-kimia semasa peringkat perkembangan bagi tiga aksesori buah markisa (Passiflora edulis f. Flavicarpa)*. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 73p.
- Ratule, M.T., Osman, A., Ahmad, S. H. and Saari, N. (2004). Electrolyte leakage and peel discolouration in banana (*Musa sapientum* cv. Berangan) during storage under chilling temperature. *Proceeding of APEC Symposium on Quality Management in Postharvest Symptoms*. pp.243-248.
- Ratule, M.T. (2006). Application of hot water dip in reducing chilling injury of banana cv. Berangan during low temperature storage. PhD thesis, Universiti Putra Malaysia. 272p.
- Ratule, M.T., Osman, A., Ahmad, S.H. and Saari, N. (2006). Development of chilling injury of 'Berangan' banana [*Musa* cv. Berangan (AAA)] during storage and low temperature. *Journal of Food Agriculture and Environment*. 4(1): 128-134.
- Reagan-Shaw, S., Eggert, D., Mukhtar, H. and Ahmad, N. (2010). Antiproliferative effects of apple peel extract against cancer cells. *Nutrition and Cancer*. 62: 517-524.
- Reeves, R.M.(1973). Histological structure and commercial dehydration of the breadfruit. *Economic Botany*. 28: 32-42.
- Rice-Evans, C. and Miller, N. J. (1995). Antioxidants – the case for fruit and vegetables in the diet. *British Food Journal*. 97: 35-40.

- Rico, D., Martin-Diana, A.B., Barat, J.M. and Barry-Ryan, C. (2007). Extending and measuring the quality of fresh-cut fruit and vegetables. *Trends in Food Science and Technology*. 18: 373-386.
- Roberts-Nkrumah, L. (1993). Breadfruit in the Caribbean - a bicentennial review. *Tropical Fruits Newsletter*. 6: 3-4
- Rodov, V., Ben-Yehoshua, S., Albagli, R., and Fang, D.Q. (1995). Reducing chilling injury and decay of stored citrus fruit by hot water dips. *Postharvest Biology and Technology*. 5: 119-127.
- Rouhana, A. and Mannheim, C.H. (1994). Optimisation of enzymatic peeling of grapefruit. *Lebensmittel-Wissenschaft & Technologie*. 27: 103-107.
- Rowley, G. (1978) *The Illustrated Encyclopedia of Succulents*. Salamander Books Ltd., London, U.K. 256p.
- Roy, S.K. and Waskar, D.P. (1997). Pomegranate. In: Mitra, S. (Ed.). *Postharvest Physiology and Storage of Tropical and Subtropical Fruits*. CAB International, Wallingford, U.K. pp.365-374.
- Rukayah, A. (1999). *Buah-buahan Malaysia*. Percetakan Dewan Bahasa dan Pustaka, Kuala Lumpur, Malaysia. 283p.
- Saad, S. (1999). *Kesan rawatan haba lepastuai yang berlainan sebelum penyimpanan pada suhu rendah ke atas jangkahayat simpanan dan kualiti P. Berangan (Musa sapientum cv. Berangan)*. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 89p.
- Sabehat, A., Weiss, D. and Lurie, S. (1996). The correlation between heat-shock protein accumulation and persistence and chilling tolerance in tomato. *Plant Physiology*. 110: 531-537.
- Saltviet, M.E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. *Postharvest Biology and Technology*. 15: 279-292.
- Salunkhe, D.K. and Desai, B.B. (1984a). *Postharvest Biotechnology of Fruits*. Volume 1. CRC Press Inc., Florida, U.S. 168p.
- Salunkhe, D.K. and Desai, B.B. (1984b). *Postharvest Biotechnology of Fruits*. Volume 2. CRC Press Inc., Florida, U.S. 147p.
- Sams, C.E. (1999). Preharvest factors affecting postharvest texture. *Postharvest Biology and Technology*. 15: 249-254.

- Sandhya (2010). Modified atmosphere packaging of fresh produce: current status and future needs. *LWT*. 43: 381-392.
- Scott, K.J. and Roberts, E.A. (1966). Polyethylene bags to delay ripening of bananas during transport and storage. *Australian Journal of Experimental Agriculture and Animal Husbandry*. 6:197-199.
- Scott, K.J., McGlasson, B. and Roberts, E.A. (1970). Potassium permanganate as an ethylene absorbent in polyethylene bags to delay ripening of bananas during storage. *Australian Journal of Experimental Agriculture and Animal Husbandry*. 10: 237-240.
- Sew, C.C. (2009). Effect of different maturity stages of red flesh pitaya (*Hylocereus polyrhizus*) fruit on the juice quality. Bachelof of Food Science and Technology thesis, Universiti Putra Malaysia. 79p.
- Sharma, M., Sitbon, C., Subramanian, J. and Paliyath, G. (2008). Changes in nutritional quality of fruits and vegetables during storage. In: Paliyath, G., D. P. Murr, A.K. Handa and S. Lurie. *Postharvest Biology and Technology of Fruits, Vegetables, and Flowers*. Wiley-Blackwell Publishing, Maiden MA, U.S. pp.443-465.
- Sharom, M., Willemot, C. and Thompson, J.E. (1994). Chilling injury induces lipid phase changes in membranes of tomato fruit. *Plant Physiology*. 105: 305-308.
- Shen, M. and Wang, M.X. (1997). Advances in research on chilling-resistance mechanisms of plants. *Chinese Bulletin of Botany*. 14: 1-8.
- Shukla, A. K., Singh, D., Shukla, A.K. and Meena, S.R. (2007). Pruning and training of fruit crops. In: Yadav, P.K. (Ed.). *Fruit Production Technology*. International Book Distribution Co., Lucknow, India. 372p.
- Siriphanich, J. (1994). Minimal processing of tropical fruits. In: Postharvest Handling of Tropical Fruits. *Proceeding of an International Conference*. pp 127-137.
- Siti Hawa, J. (2003). Recent advances in fruit production: Varietal improvement. *Proceeding of National Horticultural Conference 2003*. Equatorial Hotel, Bangi, Malaysia, 20-22 October 2003. pp.5-14.

- Skog, L.J. (1998). Chilling Injury of Horticultural Crops. Ontario Ministry of Agriculture, Food and Rural Affairs. *Fact Sheet No. 98-021*. Ministry of Agriculture and Food. Ontario, Canada.
- Smith, N.J.S., Tucker, G.A. and Jeger, J. (1989). Softening and cell wall changes in bananas and plantains. *Aspects of Applied Biology*. 20: 57-65.
- Smock, R.M. (1967). Methods of storing bananas. *Philippine Agriculture*. 51: 501-517.
- Soffer, T. and Mannheim, C.H. (1994). Optimisation of enzymatic peeling of oranges and pomelo. *Lebensmittel-Wissenschaft & Technologie*. 27: 245-248.
- Soliva-fortuny, R.C. and Martin-Belloso, O. (2003). New advances in extending the shelf-life of fresh-cut fruits. *Trends in Food Science & Technology*. 14: 341-353.
- Spencer, M. (1966). Fruit ripening. In: Bonner, J. and J. Varner (Eds). *Plant Biochemistry*. Academic Press, New York, U.S. 1054p.
- Sreekanth, D., Arunasree, M.K., Roy, K.R., Reddy, T.C., Reddy, G.V. and Reddanna, P. (2007). Betanin a betacyanin pigment purified from fruits of *Opuntia ficus-indica* induces apoptosis in human chronic myeloid leukemia cell line-K562. *Phytomedicine*. 14: 739-746.
- Stewart, O.J., Raghavan, G.S.V., Golden, K.D. and Gariepy, Y. (2005). MA storage of Cavandish banana using silicone memberane and diffusion chanel systems. *Postharvest Biology and Technology*. 35: 309-317.
- Stintzing, F.C., Schieber, A. and Carle, R. (2002). Betacyanins in fruits from red-purple pitaya, *Hylocereus polyrhizus* (Weber) Britton & Rose. *Food Chemistry*. 77: 101-106.
- Tapia, M.S., Rojas-Grau, M.A., Carmona, A., Rodriguez, F.J., Soliva-Fortuny R. and Martin- Belloso, O. (2008). Use of alginate- and gellan-based coatings for improving barrier, texture and nutritional properties of fresh-cut papaya. *Food Hydrocolloids*. 22: 1493-1503.
- Tariq, M.A., Muhamad Tahir, F., Asi, A.A., and Pervez, M.A. (2001). Effect of Controlled Atmosphere Storage on Damaged Citrus Fruit Quality. *International Journal of Agriculture & Biology*. 3(1): 9-12.

- Teh, K.P. (1999). Minimally processed refrigerated local fruits practices in Malaysia. Bachelor of Food Studies (Food Quality Management) thesis, Universiti Putra Malaysia. 61p.
- Teklemariam, T. and Blake, T.J. (2003). Effects of UVB preconditioning on heat tolerance of cucumber (*Cucumis sativus* L.). *Environmental and Experimental Botany*. 50: 169-182.
- Tey, C.S. (2010). Effect of different postharvest storage conditions on red flesh pitaya (*Hylocereus polyrhizus*) fruits prior to juice production on the final juice quality. Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 99p.
- Thitilertdecha, N., Teerawutgulrag, A. and Rakariyatham, N. (2008). Antioxidant and antibacterial activities of *Nephelium lappaceum* L. extracts. *LWT - Food Science and Technology*. 41: 2029-2035.
- Thomas, P. (1986). Radiation preservation of foods of plant origin, Part IV: Sub-tropical fruits: Citrus, grapes and avocados. *Criteria Reviews in Food Science and Nutrition*. 24: 53-59.
- Thompson, A.K and Burden, O.J. (1995). Harvesting and Fruit Care. In Gowen, S. (Ed.). *Banana and Plantains*. Chapman and Hall, London, U.K. pp.403-433.
- Tiburcio, A.F., Altabella, T., Borrel, A., and Masgrau, C. (1997). Polyamine metabolism and its regulation. *Physiologia Plantarum*. 100: 664-674.
- Tongdee, S.C., Suwanagul, A., Neamprem, S. and Bunruengsri, U. (1990). Effect of surface coatings on weight loss and internal atmosphere of durian (*Durio zibethinus* Murray) fruit. *ASEAN Food Journal*. 5: 103-107.
- Trakulnaleumsai, C., Ketsa, S. and van Doorn, W.G. (2006). Temperature effects on peel spotting in 'Sucrier' banana fruit. *Postharvest Biology and Technology*. 39: 285-290.
- Tung, H.F., Nair, H. and Lim, A.L. (1987). The effect of water loss on the ripening of Pisang Mas (*Musa acuminata* Colla). *ASEAN Food Journal*. 3: 135-137.

- Turner, D.W. (1997). Bananas and Plantains. In: Mitra, S. (Ed.). *Postharvest Physiology and Storage of Tropical and Subtropical Fruits*. CAB International, Wallingford, U.K. pp.47-83.
- Ulrichova, M. and Sosnova, V. (1970). Effect of phosphorous deficiency and anthocyanin content in tomato plants. *Biology Planta*. 12: 231-235.
- Voon, Y.Y., Sheikh Abdul Hamid, N., Rusul, G., Osman, A. and Quek, S.Y. (2006). Physicochemical, microbial and sensory changes of minimally processed durian (*Durio zibethinus* cv. D24) during storage at 4 and 28 °C. *Postharvest Biology and Technology*. 42: 168-175.
- Voon, Y.Y., Sheikh Abdul Hamid, N., Rusul, G., Osman, A. and Quek, S.Y. (2007). Characterization of Malaysian durian (*Durio zibethinus*) cultivars: Relationship of physico-chemical flavour properties with sensory properties. *Food Chemistry*. 103: 1217-1227.
- Vursavus, K. and Ozguven, F. (2004). Determining the effects of vibration parameters and packaging method on mechanical damage in golden delicious apples. *Turkish Journal of Agriculture and Forestry*. 21: 311-320
- Wade, N.L., Kavanagh, E.E. and Tan, S.C. (1993). Sunscald and ultraviolet light injury of banana fruits. *Journal of Horticultural Science*. 68: 409-419.
- Walker, M.A., Mckersie, B.D. and Pauls, K.P. (1991). Effect of chilling injury on the biochemical and functional properties of thykaloid membranes. *Plant Physiology*. 97: 663-669.
- Wan Ibrahim, W.D. (2003). Enhancing the quality of agricultural produce under Malaysia's Best. *Proceeding of National Horticultural Conference 2003*. Equatorial Hotel, Bangi, Malaysia, 20-22 October 2003. pp.1-4.
- Wan Mustapha, W.A. (1998). The development of ripening peel colour index for pisang Rastali (*Musa sapientum* cv. Rastali). Bachelor of Food Science and Technology thesis, Universiti Putra Malaysia. 53p.

- Wang, X.M. and Hildebrand, D.F. (1988). Biosynthesis and regulation of linolenic acid in higher plants. *Plant Physiology and Biochemistry*. 26: 777-792.
- Wang, C.Y. (1989). Relation of chilling stress to ethylene production.. In Li, P.H. (Ed). *Low Temperature Stress Physiology in Crops*. CRC Press, Florida, U.S. pp.177-189.
- Wang, C.Y. (1994). Combined treatment of heat shock and low temperature conditioning reduces chilling injury in zucchini squash. *Postharvest Biology and Technology*: 4: 65-73.
- Wang, H., Cao, G. and Prior, R.L. (1996) Total antioxidant capacity of fruits. *Journal of Agricultural and Food Chemistry*. 44: 701-705.
- Wang, C.Y. and Qi, L. (1997). Modified atmosphere packaging alleviates chilling injury in cucumbers. *Postharvest Biology and Technology*. 10: 195-200.
- Watada, A.E. and Qi, L. (1999). Quality of fresh cut produce. *Postharvest Biology and Technology*. 15: 201-205.
- Weaver, C and Charley, H. (1974). Enzymatic browning of ripening bananas. *Journal of Food Science*. 39: 1200–1202.
- Whaley, C.I.E. and Scott, J.W. (1997). Environmental and physiological effects on cuticle cracking in tomato. *Journal American Society of Horticultural Science*. 122: 797-801.
- Wild, B.L. and Hood, C.W. (1989). Hot dip treatments reduce chilling injury in long-term storage of ‘Valencia’ oranges. *HortScience*. 24: 109-110.
- Wild, B.L. (1990). Hot dip treatments reduce chilling injury during storage of citrus fruit at 1°C. *Food Research Quarterly*. 50: 36-41.
- Williamson, G. (1996) Protective effects of fruits and vegetables in the diet. *Nutrition & Food Science*. 1: 6–10.
- Wills, R.B.H., Lee, T.H., Graham, D., Mcglasson, W.B. and Hall, E.G. (1981). *Postharvest-An Introduction to the Physiology and Handling of Fruit and Vegetables*. New South Wales University Press Limited, Kensington, Australia. 161p.

- Wills, R., Mcglasson, B., Graham, D. and Joyce, D. (1998). *Postharvest - An Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals*. 4th edition. University of New South Wales Press Ltd, Kensington, Australia. 262p.
- Wills, R.B.H., McGlasson, W.B., Graham, D. and Joyce, D.C. (2007). *Postharvest: An Introduction to the Physiology and Handling of Fruits, Vegetables, and Ornamentals*. 5th edition. CABI: Oxfordshire, U.K. 227p
- Wo, S.M., Osman, A., Saari, N., Ahmad, S.H. and Abdul Rahman, R. (2003a). Identification of areas with peel/pulp splitting (PPS) disorder in Pisang Mas (*Musa sapientum* cv. Mas) and its physico-chemical characteristics. In: Zaharah A.R. et al. (Eds.). *Investing in Innovation 2003*, Volume 1. Agriculture, Food, Forestry. Universiti Putra Malaysia Press, Selangor, Malaysia. pp.169 – 172.
- Wo, S.M., Osman, A., Saari, N. and Ahmad, S.H. (2003b). Physico-chemical characteristics of Pisang Mas (*Musa sapientum* cv. Mas) with peel/pulp splitting disorder. *Transaction of the Malaysian Society of Plant Physiology*. 12: 145-150.
- Wo, S.M., Osman, A., Ahmad, S.H. and Saari, N. (2004). The effect of different levels of relative humidity (RH) on peeling quality of Pisang Mas [*Musa* cv. Mas (AA)] during ripening. Agriculture Congress 2004. "Innovation Towards Modernized Agriculture". Malaysian International Exhibition and Convention Centre, Seri Kembangan Selangor. 4-7 October 2004. Book of Abstract. pp.234-237.
- Wo, S.M., Osman, A., Ahmad, S.H. and Saari, N. (2005). Peel and pulp splitting disorder in Mas banana [*Musa* cv. Mas (AA)]. *Journal of Food Agriculture & Environment*. 3(2): 213-217.
- Wo, S.M. (2007). Identification of the causal factors of peel-pulp splitting and peeling difficulty disorders in "Mas' banana [*Musa sapientum* cv Mas(AA)]. MSc. thesis, Universiti Putra Malaysia. 168p.
- Wo, S.M., Osman, A., Ahmad, S.H. and Saari, N. (2007). Ultrastructure of Mas Banana [*Musa* cv. Mas (AAA)] in relation to peel pulp splitting disorder. *Proceeding of 10th ASEAN Food Conference*. Kuala Lumpur, Malaysia, 21-23 August 2007. PP-20. pp 1-10.

- Wolfe, K., Wu, X. and Liu, R.H. (2003). Antioxidant activity of apple peels. *Journal of Agricultural and Food Chemistry*. 51: 609-614.
- Woodruff, R.E. (1969). Modified atmosphere storage of bananas. Horticulture Report No.9, p. department of agriculture, Michigan State University, U.S. pp.80-94.
- Wolf, A.B., Watkins, C.B., Bowen, J.H., Lay-Yee, M., Main-Donald, J.H. and Ferguson, A.B. (1995). Reduction of external injury in stored 'Hass' avocado fruit by dry heat treatments. *Journal of the American Society for Horticultural Science*. 120: 1050-1056.
- Wooton, M. and Tumaalii, F. (1984). Breadfruit production, utilisation and composition – a review. *Food Technology in Australia*. 6(10): 464-465.
- Worrel, D.B. and Sean Carrington, C.M. (1997). Breadfruit. *Postharvest physiology and Storage of Tropical and Subtropical Fruits*. CAB International, Wallingford, U.K. pp.347-363.
- Wu, L., Hsu, H., Chen, Y., Chiu, C., Lin, Y. and Ho, J.A. (2006). Antioxidant and antiproliferative activities of red pitaya. *Food Chemistry*. 95: 319-327.
- Wybraniec, S., Platzner, I., Geresh, S., Gottlieb, H.E., Haimberg, M., Mogilnitzki, M. and Mizrahi, Y. (2001). Betacyanins from vine cactus *Hylocereus polyrhizus*. *Phytochemistry*. 58: 1209-1212.
- Yamauchi, N., Lida, S., Minamide, T. and Iwata, T. (1986). Polar lipid content and their fatty acid composition with reference to yellowing in stored spinach leaves. *Journal of the Japanese Society for Horticultural Science*. 55: 355-362.
- Yilmaz, Y. and Toledo, R.T. (2004). Health aspects of functional grape seed constituents. *Trends in Food Science and Technology*. 15: 422–433.
- Zaulia, O., Suhaila, M., Osman, A. and Mohammed Selamat, M. (2000). Effect of short term heat treatment and combination of surface coating and heat treatment on physico-chemical changes and physiological disorder of fresh pineapple (cv. N36 and gandul) prior to storage at 10 °C. *Joint Proceedings of the 11th Malaysian Society of Plant Physiology Conference and the 2nd National Banana Seminar 2000*. pp.284-287.

- Zaulia, O., Suhaila, M., Osman, A. and Mohammed Selamat, M. (2007). Effect of various coatings on the chemical changes of different pineapple cultivars (N36 and Gandul) at low temperature storage. *Journal of Tropical Agriculture and Food Science*. 35(1): 107-120.
- Zaulia, O. (2008). Effects of postharvest coatings and heat treatment on quality of stored pineapple fruits. PhD thesis, Universiti Putra Malaysia. 373p.
- Zhang, D. and Quantick, P.C. (1998). Antifungal effects of chitosan coating on fresh strawberries and raspberries during storage. *Journal of Horticultural Science and Biotechnology*. 73: 763-767.
- Zhou, R., Mo, Y., Li, Y., Zhao, Y., Zhang, G. and Hu, Y. (2008). Quality and internal characteristics of Huanghua pears (*Pyrus pyrifolia* Nakai cv. Huanghua) treated with different kinds of coatings during storage. *Postharvest Biology and Technology*. 49: 171-179.
- Zhuang, H., Barth, M.M., and Hildebrand, D. (2002). Fatty acid oxidation in plant tissues. In: Akoh, C.C. and D.B. Min (Eds.). *Food Lipids*. Marcel Dekker, New York, U.S. pp.413-463.

BIOGRAPHY

Azizah Osman was born on April 13, 1954, in a small village town called Semenyih located about 30 km south of Kuala Lumpur. She received both her primary and secondary education at Convent School located in Kajang about 10 km from her house, those days administered by the missionaries. She did her A levels at Tun Fatimah School, Johor Bahru, Johor. She then furthered her tertiary education at University of Malaya and graduated with a Bachelor of Science (Hons.) in Ecology in 1979. As she hailed from a rural town, she was inspired to be an educationist and she went on to pursue a Diploma in Education, to equip her with the necessary pedagogical skills so as to be an effective educator.

While pursuing her Diploma in Education, her interest in research was aroused and she looked around for opportunities in Universities where she could teach, carry out research and disseminate her research findings. She was lucky to be offered the post of a tutor with opportunities to pursue post-graduate studies overseas by the Head, Department of Food Science & Technology, Universiti Pertanian Malaysia (now known as Universiti Putra Malaysia - UPM) in 1980.

Realising the importance of advance post graduate training in research, she went to pursue her Masters in Food Technology at the School of Food Technology, University of New South Wales, Australia under the sponsorship of the Australian-Asian Universities Cooperation Scheme (AAUCS) / Australian Universities International Development Programme (AUIDP). At New South Wales, she had the opportunity to attend advance courses in food technology and carried out research on the “Mutagenic Activity of Heated Potato-Oil Systems”. She returned to Malaysia in 1983 and was appointed as a lecturer. She spent six months (1984/1985) at the College of Agriculture, University of the Ryukyus, Okinawa,

Japan working on “Post Harvest Handling of Fruits and Vegetables” where she began to realise that there were lot of opportunities in working with post harvest handling of tropical fruits and vegetables in Malaysia. Upon returning from Japan, she started to involve with post harvest handling of tropical fruits and vegetables. She was again avail an opportunity in 1986 to continue her studies, with a fellowship from the Association of Commonwealth Universities (ACU) Award, United Kingdom. She did her Ph.D on “Pre and postharvest factors affecting the quality of strawberry (*Fragaria x ananassa* Duchesne) cv Ostar” at Wye College, University of London. She graduated with a PhD in 1989.

Since 1983 (except from 1986-89) she has been involved in the teaching (either as a sole lecturer or co-lecturer) of the following courses, namely Food Quality Control, Food Science, Nutrition and Health, Food Analysis, Food Quality Management and Quality Assurance of Plant Products to undergraduate students at the Faculty of Food Science and Technology, UPM. She developed an elective in Post-harvest Handling of Fruits and Vegetables, which was very popular (1990-2002) among final year Bachelor of Food Science and Technology undergraduates, and postgraduates conducting research in this area. She also teaches a very popular course, Introduction to Food Science to students of other faculties every semester and this course is heavily subscribed. Nevertheless, for the last 4-5 years, this course is only offered one semester a year.

On the international scene, she was invited by CIRAD Montpellier, France and SEARCA, to teach the module on “Advances in Tropical Fruit Processing” to students pursuing the Asian–European International Master’s Degree of Food Science and Technology jointly organised under the ASIA-LINK Programme.

She has been instrumental in establishing the Post-harvest Laboratory at the Faculty of Food Science and Biotechnology

(now known as Faculty of Food Science and Technology). With the availability of facilities, many students have chosen to carry out their research work at this laboratory. To her credit, she has supervised more than **30** postgraduate (PhD and MSc) and 137 undergraduate [BSTM, BS (Food Studies) and BS (Biotechnology)] students either as the main or co-supervisor. Currently, she has 13 postgraduates under her, either as the main or co-supervisor.

Her research has been focussed in the area of post harvest handling of fruits and fruit products as well as vegetables. As a project leader, she is successful in obtaining nine research grants and collaborated in 16 others. Source of funding for these research projects include MOSTI (IRPA and AgriScience Fund), Ministry of Higher Education (FRGS), UPM Research University Grant Scheme (RUGS) and the FAMA-IPTA Collaborative Research grant. These projects were successfully completed and the research findings were published in international and local journals. Some of these findings were also presented at local and international conferences and seminars. To date, 232 papers have been published, 69 of which are in refereed journals. She has 39 monographs and has also co-authored two articles in a book. She was a co-editor of a seminar proceeding. In collaboration with other committee members, she was involved in developing nine Malaysian fresh fruits standards while two others are on-going projects. She contributed one entry (an article on “cuka” (vinegar) in the *Ensiklopedia Sains dan Teknologi*, the only Science and Technology encyclopedia written in Bahasa Malaysia).

She was happy to note that her research findings have not gone unnoticed. Her research on “Enzyme-aided peeling of local citrus fruits” was awarded a gold medal at the Invention and Research Exhibition UPM 2002 and a bronze medal at the Expo S&T 2002. In the Invention and Research Exhibition UPM 2003, one research

project under her leadership namely: “Identification of areas with peel/pulp splitting disorder of Pisang Mas (*Musa sapientum* cv Mas) and its physico-chemical characteristics”, was awarded a bronze medal; two other research projects, in which she was a team member, namely: “The response surface methodology: Optimisation of pandan (*Pandanus amaryllifolius*) powder by using spray drying method” was awarded a silver medal; and “Functional ingredients derived from rice bran” was awarded a bronze medal. Another research project under her leadership, “Establishment and improvement of postharvest physiological disorders of local dessert bananas” was awarded two bronze medals at the Invention, Research and Innovation Exhibition UPM 2005. In 2006, findings from this research grant was awarded another silver medal at the Invention, Research and Innovation Exhibition UPM 2006, and a bronze medal at the 17th International Invention, Innovation, Industrial Design and Technology Exhibition 2006 (ITEX 2006). Her achievement at this ITEX 2006 renders her the rare opportunity of receiving a Certificate of Recognition from the Minister of Higher Education Malaysia. At UPM Invention, Research and Innovation Exhibition 2010, her research entitled “Screening and optimization of edible coating components for coating of Berangan banana (*Musa sapientum* cv Berangan” was awarded a bronze medal while two others where she was a team member was awarded a gold medal [research entitled “Equilibrium headspace analysis of volatile flavour compounds extracted from soursop (*Annona muricata*) using comprehensive two-dimensional Gas Chromatography Time-of-Flight Mass Spectrometry (GCxGC-TOFMS) with headspace solid phase microextraction (HS-SPME)”] and a silver medal (research entitled “Physico-chemical properties of honeydew melon and musk lime seed oils”) medals. In the recent UPM Invention, Research and Innovation Exhibition 2011, another research of hers entitled

“Development of edible coating formulations to delay ripening and maintain quality of Berangan banana (*Musa sapientum* cv. Berangan) “was awarded a silver medal.

She was also a team member to the Appreciation Prize of the MPKSN Award 2000 for Public Awareness Towards the Understanding of Science and Technology category which was awarded by the Ministry of Science, Technology and the Environment of Malaysia. This award was a recognition for her active involvement in contributing an article on fruits or food each month to Dewan Kosmik (a Science and Technology Magazine published by Malaysia’s main national publisher, Dewan Bahasa & Pustaka) from mid 1995 – 2000. Its target readers are high school and pre-university students.

As a recognition to her contributions in the field of postharvest handling of fruits and vegetables, she has been appointed on a number of technical committees and panels evaluating research proposals in post harvest handling of fruits and vegetables at UPM and at the national level (for example, Technical Panel Evaluator for IRPA Projects (EA Category) applied by MARDI). She was also invited to be a team member of the Priority Setting Top-down National R&D Programme for the Agro-industry Sector IRPA RMK8. Currently, she is a member of SIRIM (Standards and Industrial Research Institute of Malaysia) Technical Committee for the preparation of standard specification for fresh fruits. She was also a member (2003-2008) of SIRIM Working Group for the standard preparation for fresh fruits. She has been requested to review a number of manuscripts on post harvest handling of fruits and vegetables by local and international journals. She has also served as external examiner for Masters and PhD theses and chairperson of examination committees for MSc and PhD students.

She has served as a committee member at department, faculty and university level, in which she involved in curriculum development, research activities, postgraduate studies, extension, student practical trainings and other *ad-hoc* activities. As a recognition to her extensive involvement in administrative, teaching and research, she was appointed as the Head of the Department of Food Science, Faculty of Food Science and Biotechnology (now known as Faculty of Food Science and Technology) from 1999 to 2001. She believes that she is successful in managing the department. As her heart was more for teaching and research, she politely refused reappointment as a Department Head. As an ordinary member of the faculty, she is actively involved in various activities related to teaching, students, research and extension. She was also a member of the Faculty's Internal Auditor. Her active involvement as a chairperson (2003-2004) and deputy chairperson (2004-2005) in the faculty's Safety and Health Committee was not left unnoticed. The committee was awarded the most active committee at the faculty in 2004. Azizah Osman was appointed as a member of the university's SENATE and the university's Postgraduate committee in December 2008 and two month's later respectively, until her sabbatical leave in April 2010.

She is a life professional member of Malaysian Institute of Food Technologists, life member of the Malaysian Society of Plant Physiology, member of Nutrition Society of Malaysia, Malaysian Scientific Association, MOSTA, Institute of Food Technologists (USA) and Australian Institute of Food Science and Technology. She believes that professional organisations provide a platform for interaction with other scientists, avenue for latest information and developments and opportunity for networking.

She strongly believes that one should not only devote in enhancing one's professional career but should also play a role in the community. She is actively involved in Parents-Teachers

Association (PTA) in her children's schools. This gives her an opportunity to interact with her children's teachers and understand her children better. She was elected as the President of Parents-Teachers Association of SK Convent Kajang, Selangor from 1998 to 2001 and she was instrumental in providing leadership, which led the school win several awards for its academic achievements, and the most outstanding PTA in the district, state and also at national level.

As a Malaysian citizen born in the state of Selangor, Malaysia, she is indebted to the Selangor state government and its people for awarding her the "*Biasiswa Kecil Negeri Selangor*" when she was in secondary school at Convent Secondary School Kajang, Selangor from 1968-1971 (Form 2 until Form 5) and the Selangor State Government Scholarship to pursue her BSc (Hons.) degree at the University of Malaya from 1974-1978. She is then instrumental in becoming a life member of GIBS (*Gabungan Ikhtisas dan Usahawan Bumiputra Selangor*). In addition, she was a member of its Education and Training Committee from 2006-2008.

As a contribution to the public and nation, she was also involved, as a team member, in consultancy activities. She was involved in the (i) Menu preparation for primary and secondary schools in Sarawak for Global Mas Sdn Bhd; (ii) Review of the menu planning for the residents of prisons and Henry Gurney schools in Malaysia for Ibu Pejabat Penjara Malaysia, Kajang, Selangor; and (iii) Production of pineapple powder for Lembaga Perindustrian Nenas Malaysia. She was the project leader of the IPTA-FAMA project entitled "Postharvest Technology and Value Added Possibilities for Fruits and Vegetables".

As recognition to her contributions and achievements, she was awarded the Excellent Service Award in 1996 and 2003; the Excellent Service Recognition in 1995, 1999, 2000, 2001, 2002,

2004, 2005, 2006, 2007, 2008 and 2009. She was appointed as an Associate Professor in 1997 and as a Professor in 2008 by UPM.

Over the last 32 years, she has dedicated her life in becoming an excellent educator, researcher, a loving mother and wife, and homemaker. She has made many contributions and she takes pride when she sees her students being successful and contributing towards the growth and development of the nation. She believes in UPM's vision of becoming a World Class University and she has strived very hard in fulfilling this dream and she hopes UPM will give her the due recognition and opportunity to keep serving her to the best of her abilities.

Alhamdulillah, she is happily married to Dr. Masahuling Bin Benong, Director of the Production Development Division with Malaysian Rubber Board/*Lembaga Getah Malaysia* and they are blessed with two lovely daughters (Aida Maliza and Azwa Maliza) and a charming son (Amir Mazli).

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I would like to take this opportunity to express my heartfelt gratitude and appreciation to the following individuals who have made it possible for me to reach to the position that I am today: Puan Hajjah Asiah Zain for giving me the chance to be a part of UPM way back in 1980, Prof. Dato' Dr. Mohamed Mahyuddin Mohamed Dahan, Prof. Dr. Gulam Rusul Rahmat Ali, Prof. Dr. Jinap Selamat, Prof. Dr. Mohd Yazid Manap, Emeritus Prof. Dato' Dr. Abdul Latif Ibrahim who has been my idol since my school days, colleagues and staff from the Faculty of Food Science and Technology, my research team members and collaborators both within (at FSTM and other faculties in UPM) and outside UPM, my postgraduate students, my undergraduate students, and to all others who have contributed directly or indirectly to my success. Although it is impossible for me to list all the names, it is a real pleasure to have known and work with all of you.

I would also like to take this opportunity to sincerely thank Universiti Putra Malaysia and sponsors of my research grants [MOSTI (IRPA and Agri-Science Fund), Ministry of Higher Education (FRGS), UPM Research University Grant Scheme (RUGS) and the FAMA-IPTA Collaborative Research grant] for the opportunities rendered to me to pursue my research activities. I am greatly and forever indebted to my late parents (Allahyarham

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

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To All- Billion of Thanks and May ALLAH SWT Bless all of
You.

LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
The Challenge to Communication Research in Extension
22 July 1989
2. Prof. Ir. Abang Abdullah Abang Ali
Indigenous Materials and Technology for Low Cost Housing
30 August 1990
3. Prof. Dr. Abdul Rahman Abdul Razak
Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
30 January 1993
4. Prof. Dr. Mohamed Suleiman
Numerical Solution of Ordinary Differential Equations: A Historical Perspective
11 December 1993
5. Prof. Dr. Mohd. Ariff Hussein
Changing Roles of Agricultural Economics
5 March 1994
6. Prof. Dr. Mohd. Ismail Ahmad
Marketing Management: Prospects and Challenges for Agriculture
6 April 1994
7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
The Changing Demand for Livestock Products
20 April 1994
8. Prof. Dr. Ruth Kiew
Plant Taxonomy, Biodiversity and Conservation
11 May 1994
9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
Engineering Technological Developments Propelling Agriculture into the 21st Century
28 May 1994
10. Prof. Dr. Shamsuddin Jusop
Rock, Mineral and Soil
18 June 1994

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

11. Prof. Dr. Abdul Salam Abdullah
Natural Toxicants Affecting Animal Health and Production
29 June 1994
12. Prof. Dr. Mohd. Yusof Hussein
Pest Control: A Challenge in Applied Ecology
9 July 1994
13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
Managing Challenges in Fisheries Development through Science and Technology
23 July 1994
14. Prof. Dr. Hj. Amat Juhari Moain
Sejarah Keagungan Bahasa Melayu
6 Ogos 1994
15. Prof. Dr. Law Ah Theem
Oil Pollution in the Malaysian Seas
24 September 1994
16. Prof. Dr. Md. Nordin Hj. Lajis
Fine Chemicals from Biological Resources: The Wealth from Nature
21 January 1995
17. Prof. Dr. Sheikh Omar Abdul Rahman
Health, Disease and Death in Creatures Great and Small
25 February 1995
18. Prof. Dr. Mohamed Shariff Mohamed Din
Fish Health: An Odyssey through the Asia - Pacific Region
25 March 1995
19. Prof. Dr. Tengku Azmi Tengku Ibrahim
Chromosome Distribution and Production Performance of Water Buffaloes
6 May 1995
20. Prof. Dr. Abdul Hamid Mahmood
Bahasa Melayu sebagai Bahasa Ilmu- Cabaran dan Harapan
10 Jun 1995

21. Prof. Dr. Rahim Md. Sail
Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues
22 July 1995
22. Prof. Dr. Nik Muhammad Nik Abd. Majid
The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure
19 August 1995
23. Prof. Dr. Ang Kok Jee
The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century
14 October 1995
24. Prof. Dr. Sharifuddin Haji Abdul Hamid
Management of Highly Weathered Acid Soils for Sustainable Crop Production
28 October 1995
25. Prof. Dr. Yu Swee Yean
Fish Processing and Preservation: Recent Advances and Future Directions
9 December 1995
26. Prof. Dr. Rosli Mohamad
Pesticide Usage: Concern and Options
10 February 1996
27. Prof. Dr. Mohamed Ismail Abdul Karim
Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia
2 March 1996
28. Prof. Dr. Wan Sulaiman Wan Harun
Soil Physics: From Glass Beads to Precision Agriculture
16 March 1996
29. Prof. Dr. Abdul Aziz Abdul Rahman
Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia
13 April 1996

Fruits: Nutritious, Colourful, Yet Fragile Gifts of Nature

30. Prof. Dr. Chew Tek Ann
Sharecropping in Perfectly Competitive Markets: A Contradiction in Terms
27 April 1996
31. Prof. Dr. Mohd. Yusuf Sulaiman
Back to the Future with the Sun
18 May 1996
32. Prof. Dr. Abu Bakar Salleh
Enzyme Technology: The Basis for Biotechnological Development
8 June 1996
33. Prof. Dr. Kamel Ariffin Mohd. Atan
The Fascinating Numbers
29 June 1996
34. Prof. Dr. Ho Yin Wan
Fungi: Friends or Foes
27 July 1996
35. Prof. Dr. Tan Soon Guan
Genetic Diversity of Some Southeast Asian Animals: Of Buffaloes and Goats and Fishes Too
10 August 1996
36. Prof. Dr. Nazaruddin Mohd. Jali
Will Rural Sociology Remain Relevant in the 21st Century?
21 September 1996
37. Prof. Dr. Abdul Rani Bahaman
Leptospirosis-A Model for Epidemiology, Diagnosis and Control of Infectious Diseases
16 November 1996
38. Prof. Dr. Marziah Mahmood
Plant Biotechnology - Strategies for Commercialization
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