CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Longan is an evergreen tree belongs to the Sapindaceae family with many scientific names include *Dimocarpus longan* Lour., *Euphoria longana* Lam., *E. longan* Strend., *Nephelium longana* Cambess., *E. morigera* Gagnes., and *E. scandens* Winit & Kerr. Its English common name, "Longan", derives from a Cantonese name, which means "dragon's eye". Its vernacular names in different countries include: "Lamyai" in Thailand; "Lam Nhai" in Laos; "Kyet Mouk" in Myanmar; "Nhan" in Vietnam and "Lengkeng" in Indonesia and Malaysia. Plants in the same family which are also of economic value, include rambutan (*Nephelium lappaceum* L.), and lychee (*Litchi chinensis* Sonn.; *N. litchi* Camb.; *Scytalia chinensis* Gaertn.; *D. litchi* Lour.) (Tindall, 1994; Chomchalow and MacBaine, 2003). Longan fruit is grown commercially in many countries including China, Thailand, Vietnam, India, Indochina, Australia (Queensland), and the United States (Florida) (Campbell and Campbell, 2001; Jiang *et al*., 2002).

In Thailand, longans flower in December through February with the fruit maturing from July to August. The differences in times of flowering and fruit maturity are due to differences in rainfall and in day and night temperatures (Chomchalow and MacBaine, 2003). The limited natural flowering period leads to a short production and marketing window. Recent investigations of longan fruit growth and development indicate that flowering can be regulated by application of chemicals such as chlorate and/or plant growth regulators. Growers in Thailand and China have used chemical treatments to extend the fruiting season (Khaosumeru *et al*., 2001; Subhadrabandhu and Yapwattanaphun, 2001). In Thailand, production is centered in the tropical monsoon areas of Chiang Mai, Lamphun and Phrae provinces at elevations between 300 and 600 meters above the sea level. Export of longan fruit from Thailand and Vietnam is increasing rapidly. Thailand is currently being the biggest exporter, followed by Vietnam (Tongdee, 1992; Siriphanich *et al*., 1999).

2.2 Fruit morphology

The longan fruits are conical, heart-shaped or spherical to ovoid, growing in panicles of up to 80 fruits, 1-3 centimeters (cm) in diameter and 6-19 grams (g) in weight. The pericarp is indehiscent, can vary in color from yellowish to light brown, and the skin is thin, leathery, and smooth to warty. The pericarp of young fruit remains green until the fruit matures, at which point yellow pigment synthesis is initiated (Huang, 1995). The mature longan fruit pericarp consists of three layers. The outermost epicarp has a discontinuous cuticle, a uniseriate epidermis and subepidermal sclerenchyma. The middle mesocarp is parenchymatous tissue, while the inner endocarp is made up of small, thin-walled, unsuberized epidermal cells (Qu *et al*., 2001). The aril is white to off-white or pinkish, a thick edible translucent, juicy and is flavorful and sweet with 18-21% total soluble solids. The aril can be consumed in both fresh and processed products such as canned longan in syrup or as dried fruit. The fruit has one seed that is globular, shiny and of dark brown to black color (Chomchalow and MacBaine, 2003, Rangkadilok *et al*., 2005).

2.3 Anatomy of longan fruit pericarp

Only 3 studies have been published on the anatomy of longan fruit pericarp. Chinese scientists, Huang (1995) and Qu *et al*. (2001) reported that the mature longan fruit pericarp consists of three layers. The outermost exocarp has a discontinuous cuticle, some epidermal hairs and natural openings and subepidermal sclerenchyma. The middle mesocarp consists of an undeveloped cork layer, some stone cells and parenchyma cells with large intercellular spaces. The inner endocarp is made up of a single layer of small, thin-walled cells. Mesocarp cells were reported to be the first to turn brown, followed by the endocarp. This browning then spreads over the entire pericarp surface. Differences in storability among “Shixia”, “Chuliang” and “Tuzhong” were correlated with their pericarp structure (Pan, 1994).

2.4 Thai longan cultivar

There are several Thai longan cultivars, among the most common cultivars are Daw, Biew Kiew, Si Chomphu and Haeo. The characteristics of each cultivar describe as the following (Chomchalow and MacBaine, 2003):

2.4.1 Daw

This is the most popular cultivar of longans in Thailand since it is easier to flower, and set fruit more regularly, than other cultivars. It blooms in mid January and the fruits are harvested in July to August. Fruits are compressed round and lob-sided. The fruit skin is thick, rather tough and opaque white. The aril tastes sweet.

2.4.2 Biew Kiew

It is a late bearer and blooms in alternate years. In the bearing year, it flowers at the end of January and its fruits are harvested at the end of August. The fruits are rather large, compressed round and very lob-sided. Skin is brownish green and thick. The aril is thick, crispy, translucent and sharply sweet with 22-23% total soluble solids content.

2.4.3 Si Chomphu

It is medium fruit-baring habit. Flowering is medium easy, but with irregular fruit setting. It flowers at the end of January and its fruits are harvested at the end of July to August. The fruits are rather round with reddish brown skin. The aril is medium thick, pinkish, soft and crispy, sweet with a mild aroma.

2.4.4 Haeo

This variety bears fruits quite well, but tends towards alternate bearing. It flowers at the end of January and fruits are harvested in July to August. The fruits are large, round and lob-sided with a compressed base. Skin is brownish and thick. Aril is thick, dry, crispy, opaque white and sharply sweet.

2.5 Fruit growth

Longan fruit has a sigmoidal growth curve (**Figure 2.1**). Initially, the seed and the pericarp develop simultaneously, followed by aril growth, and the same growth pattern is seen in different cultivars (Li and Li, 1999; Jiang *et al*., 2002). Fruit development from fruit-set to maturity takes 20-28 weeks, varying with seasons, regions and cultivars (Tongdee, 1997).

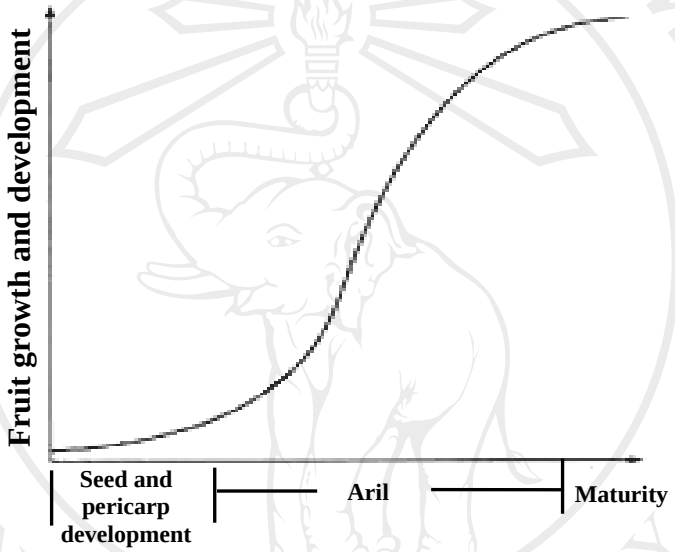


Figure 2.1 Sigmoidal curve of longan fruit growth and development.
(Source : Modified from Li and Li, 1999)

2.6 Harvest maturity

Longan fruit is non-climacteric and will not continue to ripen once removed from the tree (Huang, 1995). Fruit must be harvested when their skins become yellow-brown and their flesh reaches optimal eating quality (Wara-Aswapati *et al*., 1994). General guidelines for harvesting are, however, difficult to prescribe because of the wide range of varieties grown. Maturity can be determined by fruit weight, skin color, flesh sugar concentration, flesh acid concentration, sugar : acid ratio, flavor and/or days from anthesis (Jiang *et al*., 2002). Wara-Aswapati *et al*. (1994) recommended the soluble solids content as a maturity index, and established 15.5-16.0% as a minimum maturity standard. For most longan fruit cultivars in China,

titratable acidity and total soluble solids considered together are good indicators of flavor (Lu *et al*., 1992).

2.7 Harvesting method

Fruits are harvested in the morning all the way to the afternoon by cutting off the whole fruit bunch and placed in the shade immediately after harvest. The bunch is trimmed to about 15 cm, and the fruit not attaining standard size and appearance are pulled off, then bundle together. If individual fruits are intended for sale, the fruit stalks must be less than 2 millimeters (mm). The bunches are laid in an orderly fashion in a 10 kilograms (kg) plastic basket, lined with fresh longan leaves or a piece of sponge, both at the bottom and on the top of the basket (Chomchalow and MacBaine, 2003).

2.8 Postharvest physiology

2.8.1 Respiration rate of longan fruit

Longan fruit is non-climacteric and exhibits a very low respiration rate (Kader, 2002). The respiration rate of longan fruit under different temperatures at 5°C (3.5 to 11.3 milligrams (mg) CO_2 kg/hour), 10°C (16 to 25 mg CO_2 kg/hour), and 20°C (30 to 53 mg CO_2 kg/hour). In addition, the respiration rate of longan fruit at 22 and 5°C range from 10 to 16 milliliters (mL) CO_2/kg/hour and 2 to 6 mL CO_2/kg/hour, respectively (**Figure 2.2**) (Tongdee, 1997). Shi (1990) recorded a gradual increase in respiration rate in harvested "Tongpe" fruit at 25°C. The respiration rate of longan fruit cv. "Shixia" decreased on the first day after harvest and then increased (Pan *et al*., 1996). A later rapid increase in respiration was possibly associated with disease development (Zhou *et al*., 1997). Low temperature storage effectively inhibited longan fruit respiration (Tongdee, 1997).

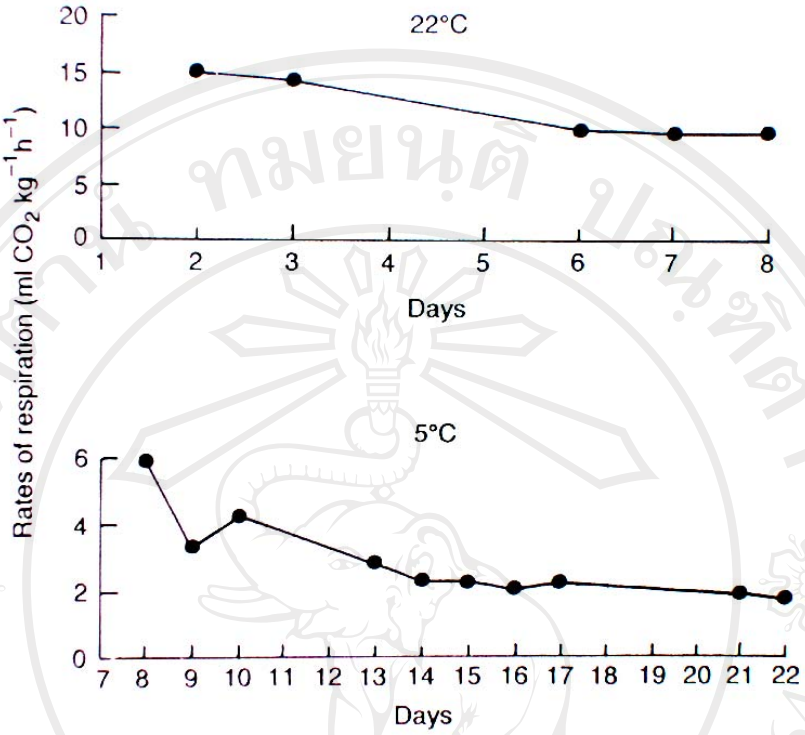


Figure 2.2 Respiration rates of longan fruits stored at at 22 and 5°C.
(Source : Tongdee, 1997)

2.8.2 Ethylene production of longan fruit

Longan fruit produces relatively low levels of ethylene after harvested (<2.3 microliters (µL)/kg/hour) in comparison with climacteric fruits. However, high ethylene production rates (28.3 µL/kg/hour) have been recorded in association with fungal infection (Shi, 1990). Moderate to high ethylene production rates have also been reported coincident with skin desiccation and after storing at high temperatures of 26-32°C (Pan *et al*., 1996). The ethylene production rate of fruit stored at 1 or 4°C remained relatively constant for 30 days after stabilizing on the first day. An increase in ethylene production rate after 30 days was associated with decay (Shi, 1990; Zhou *et al*., 1997).

2.9 Chemical composition

Longan aril is very sweet. The main sugars present in longan fruit are sucrose, fructose and glucose (**Table 2.1**). The total sugars and soluble solids content increase during ripening and then decrease gradually after harvest. The pH and titratable acidity were 6.7-7.6 and 0.7-1.1 (meq 100 g^{-1}), respectively (Paull and Chen, 1987; Lu *et al*., 1992; Li and Li, 1999). The chemical compositions and nutritional values of fresh longan fruit is shown in **Table 2.2**.

Table 2.1 Longan fruit compositions at harvest.

Constituent	Approximate value
Aril (% dry weight)	16.50
Pericarp (% dry weight)	35.60
Soluble solids (%)	18.30
Total sugars (mg/g)	154.00
Sucrose (mg/g)	29.00
Glucose (mg/g)	17.00
Fructose (mg/g)	23.00
Titratable acidity (meq/g)	2.10
pH	6.40
Citric acid (meq/g)	0.12
Malic acid (meq/g)	0.35
Succinic acid (meq/g)	1.15
Ascorbic acid (meq/g)	1.40
Total phenols (mg/g)	0.50

(Source: Paull and Chen, 1987; Li and Li, 1999)

Table 2.2 The chemical compositions and nutritional values of fresh longan fruit.

Chemical compositions and nutritional values	Fresh longan (pulp only)
Moisture (%)	81.11
Fat (%)	0.11
Fiber (%)	0.28
Protein (%)	0.97
Ash (%)	0.56
Carbohydrates (%)	16.98
Energy (kJ 100 g^{-1})	305.70
Calcium (mg 100 g^{-1})	5.70
Iron (mg 100 g^{-1})	0.35
Phosphorus (mg 100 g^{-1})	35.30
Vitamin C (mg 100 g^{-1})	69.20
Sodium (mg 100 g^{-1})	-
Potassium (mg 100 g^{-1})	-
Niacin (mg 100 g^{-1})	-
Pantothenic acid (mg 100 g^{-1})	-
Vitamin B_2 (mg 100 g^{-1})	-
Vitamin A (IU)	-
Thiamin (mg 100 g^{-1})	-

(Source : Tongdee, 1997).

2.10 Postharvest storage

Longan fruit shelf life is limited by a decline in visual appearance, a reduction in organoleptic quality and the development of disease. Rapid moisture loss occurs from fruit during storage despite a pericarp with few stomata or lenticels. Under low humidity conditions, visual appearance declines to unacceptable levels due to skin dehydration and browning. The visual appearance of longan fruit can deteriorate rapidly under room temperature (24-29°C) within just 3-4 days following harvest (Su and Yang, 1996; Jiang and Li, 2001). Ideally, fruits should be hydrocooled or

forced air cooled at 95% relative humidity (RH) and then stored at 5-10°C and 90-95% RH (Jiang *et al*., 2002).

In Thailand, most fruits are marketed in branches on the fruit stalk and are consumed within 3 days after picking, without any postharvest treatment. For exporting, longan fruits are pre-cooled by dipping in 2-5°C cool water for 10-15 minutes. The basket is then stored in a refrigerated room, or loaded onto a truck for a long distance transport. The optimal storage conditions for exportation are at 5°C, 90-95% RH, which can keep longan fruit for 40-45 days, or at 10°C for 20 days (Chomchalow and MacBaine, 2003). The minimum temperature at which fruit can be stored without exhibiting chilling symptoms varies among cultivars (**Table 2.3**).

Table 2.3 Optimal storage temperature recommendations for longan fruit cultivars.

Cultivar	Optimal storage temperature (^oC)	Maximum postharvest life (days)	References
Shixia	1-2	40	Jiang (1999)
Tongpi	1-3	35	Shi (1990)
Wulongling	3-5	30	Hong *et al*. (1984), Pan *et al*. (1996)
Wuyuan	3-5	30	Jiang (1999)

(Source: Jiang *et al*., 2002)

Hydrocooling is an important step in the cold chain for longan fruit. Pre-cooling can remove field heat and provide effective temperature management during subsequent shipment (Tongdee, 1992). Chen *et al*. (1998) reported that immediate hydrocooling using iced-water at 0-2°C can result in good fruit color appearance after 40 days of storage. In Australia, fruit subjected to hydrocooling or forced air cooling maintain acceptable eating quality up to three weeks at 7.5°C and 90% RH (Crane *et al*., 2003). Controlled atmosphere (CA) of 4-6% O_2 and 6-8% CO_2 for

"Shixia" fruit prolonged storage life, maintained quality of the fruit and reduced pericarp browning (Jiang, 1999). The use of 15% CO_2 markedly reduced fruit decay and extended storage life (Tian *et al*., 2002).

Sulfur dioxide (SO_2) fumigation has been the most effective practical postharvest treatment for control of color change (Tongdee, 1994; Pan *et al*., 1999). Fumigated fruits absorb about 30-50% of the SO_2 dosage applied. Fruit SO_2 residues were maximal at 150-300 ppm immediately after fumigation (Jiang *et al*., 2002). SO_2 contents were higher in the pericarp than in the aril and decreased rapidly during the first few days after fumigation (Pan *et al*., 1999). Some pre- and post-fumigation treatments, including aeration and washing, had little effect on SO_2 residues in longan fruit (Tongdee, 1992; Sardsud *et al*., 1994). In recent years, there has been increasing concern about SO_2 residues in fruit, particularly as some people are sensitive to sulfites (Tongdee, 1994). Europe, Australia and Japan have set a maximum residue limit of 10 ppm. In the USA, SO_2 is only registered for postharvest use on grapes (Paull *et al*., 1995).

2.11 Chilling injury

2.11.1 Chilling temperature of longan fruit

Temperature plays a key role in metabolism of fruits and vegetables. Low temperature decreases metabolism and prolongs the shelf life. Refrigeration is a common method used in postharvest technology to maintain the quality of fruits and vegetables. Unfortunately, the tropical and subtropical commodities face a serious problem during low temperature storage, because of the physical and /or physiological disorders induced by low temperature such as chilling injury (Kays, 1991). However, longan fruits are more tolerant of low temperature than many other tropical and subtropical fruits. Thompson *et al*. (2002) recommended that long-term chilled storage of longan fruit at 4-7°C and 90-95% RH. The highest freezing temperature reported was -1.72°C. The low temperatures that induce chilling injury of longan fruit varies among cultivars such as Kohala (7.5°C), Homestead (6.5-7.5°C), Kuhko (10°C) and Si Chomphu (7-8°C) (Drinnan, 2004). The other tropical and subtropical fruits were injured by temperatures in a range of 7-13°C such as banana (12-13°C),

mango (10-13°C), lime, muskmelon and pineapple (7-10°C) and cucumber, eggplant, and papaya (7°C) (Kays, 1991).

2.11.2 Symptoms of chilling injury

Chilling injury symptoms of longan fruit were water-soaking or drying and darkening of the pericarp. Longan fruit cv. “Shixia” after exposure to less than 4°C showed irregular patches of browning on the pericarp (Wang, 1990; Zhou *et al*., 1997). Longan fruits cv. Daw, Baew Kiew and Si Chomphu were stored at 1°C developed chilling injury symptoms more severe than at 5°C. The inner skin color changed and electrolyte leakage increased as indicators of chilling injury in these longan fruits (Boonyakiat *et al*., 2002).

2.11.3 Mechanism of chilling injury

The current knowledge strongly suggests that membranes of chilling sensitive fruit undergo alterations in biophysical properties related to their composition that can alter functionality. Modern theories focus on the plasma membrane as the site for chill-induced membrane damage (Marangoni *et al*., 1996). The primary event in chilling injury is the induction of a phase change in the membrane lipids. This would be reversible until secondary events had caused a modification in the normal properties of the membrane lipids. Lateral phase separations may be reversible up to the point in time where lipid degradation and accumulation of lipid degradation products induce irreversible membrane damage (**Figure 2.3**). Permanent and extensive chilling injury symptoms may be due to the irreversible phase of the reaction (Marangoni *et al*., 1996).

Further support for the membrane damage hypothesis comes from the observation that sensitive fruits can be acclimated. If fruits are exposed to non-chilling low temperature prior to refrigerated storage, their tolerance is increased. This “preconditioning” caused a compositional change in membrane lipids such as decreased rate of phospholipid degradation, increased unsaturation of phosphatidylcholine, decreases in free sterol : phospholipid ratio, increases in linoleic acid and

free sterols. All these changes demonstrated the relationships between membranes and chilling injury (Marangoni *et al*., 1996).

Ion leakage has been used as an indicator of damage to the plasma membrane and chilling injury. If damage to biological membranes is the cause of chilling injury, one would expect to detect earlier increases in ion leakage during the chilling treatment. A possible problem with ion leakage measurements is that phase transitions and formation of lateral phase separations are reversible (Marangoni *et al*., 1996). Ion leakage measurements are usually performed at room temperature that may reverse the effect. Perhaps ion leakage measurements should be performed on chilled fruit tissue at chilling temperatures, without allowing the tissue to warm up at all (Palta, 1990).

2.12 Phenolic compounds in fruits

Phenolic compounds widely exist in most fruits and vegetables. These groups of compounds are the main classes of secondary plant metabolites with a large range of structures and functions. Plant phenolic compounds being regarded as those substances derived from the shikimic pathway (**Figure 2.4**) and phenylpropanoid metabolism. Some members are characterized as “polyphenols”, an unfortunate term since not all are polyhydroxy derivatives. In particular, a number of compounds, for example, cinnamic acid, elenolic acid, shikimic acid and quinic acid are treated as phenolics because of metabolic considerations although they lack a phenolic group or even an aromatic ring. The major classes of phenols in fruits are listed in **Table 2.4**. The structure of selected phenolic compounds are shown in **Figure 2.5** (Macheix *et al*., 1990; Robards *et al*., 1999).

Plant phenolics have been classified into major groupings distinguished by the number of constitutive carbon atoms in conjunction with the structure of the basic phenolic skeleton. The most widespread and diverse of the phenolics are the flavonoids which are built upon a C_6-C_3-C_6 flavone skeleton in which the three-carbon bridge between the phenyl groups is commonly cyclised with oxygen. Several classes of flavonoid are differentiated on the degree of unsaturation and degree of oxidation of the three-carbon segment (Robards *et al*., 1999).

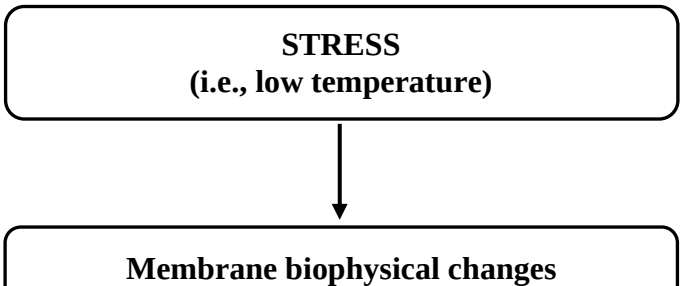


Figure 2.3 Sequences of metabolic events leading from a stress-induced alteration in the properties of membranes to observable macroscopic tissue damage.
(Source: Wang, 1982; Marangoni *et al*., 1996)

At the subcellular level, the phenolics are located mainly in the vacuoles with small amounts in free space and none in the cytoplasm (Yamaki, 1984). The occurrence of phenolics is in soluble, suspended and colloidal forms, and in combination with cell wall components. Some certain simple molecules (flavonoids and ferulic acid esters)

accumulate in the cell wall while soluble phenolic compounds are stored in the vacuoles (Lichtenthaler and Schweiger, 1998). Many phenolic compounds (e.g. caffeic esters and catechins) are both good browning substrates and good antioxidants. They are functional as antioxidants at relatively low concentrations while, at higher concentrations, since they themselves are susceptible to oxidation. They can behave as pro-oxidants due to their involvement in initiation reactions (Robards *et al.*, 1999).

The plant phenolics are the most important group of natural antioxidants. They possess several common biological and chemical properties, namely, antioxidant activity. They have the ability to scavenge both active oxygen species and electrophiles, the ability to inhibit nitrosation and to chelate metal ions, the potential for autoxidation, and the capability to modulate certain cellular enzyme activities (Helser and Hotchkiss, 1994).

Zhang *et al*. (2000) reported that lychee pericarp contained mainly flavan-3-ol monomers and dimers that were major phenolic compounds representing about 87% of the total phenolic compounds detected. There are a few reports on the major phenolic compounds, substrate specificity and affinity of longan fruit polyphenol oxidase (PPO). Longan pericarp contains higher amounts of phenolic compounds than the aril. Hsu and Chyn (1991) found that phenolic compounds in longan pericarp and seed to be acetonylgeraniin A and B, and gallic acid which is further oxidized by PPO. Jiang (1999) reported that substrates for PPO in longan cultivar "Shixia" include pyrogallol, 4-methyl catecol, and catechol. Phonolic compounds from fresh and dried longan pericarps, extracted with 70% methanol, with compounds identified using HPLC-UV/VIS, were made up of gallic acid, corilagin (an ellagitannin) and ellagic acid (**Figure 2.6**). Both cv. Biew Kiew and Daw contained the highest levels of gallic acid and ellagic acid (Rangkadilok, *et al*., 2005). However, longan seed was found to contain 14 positively identified phenolic compounds (Soong and Barlow, 2005).

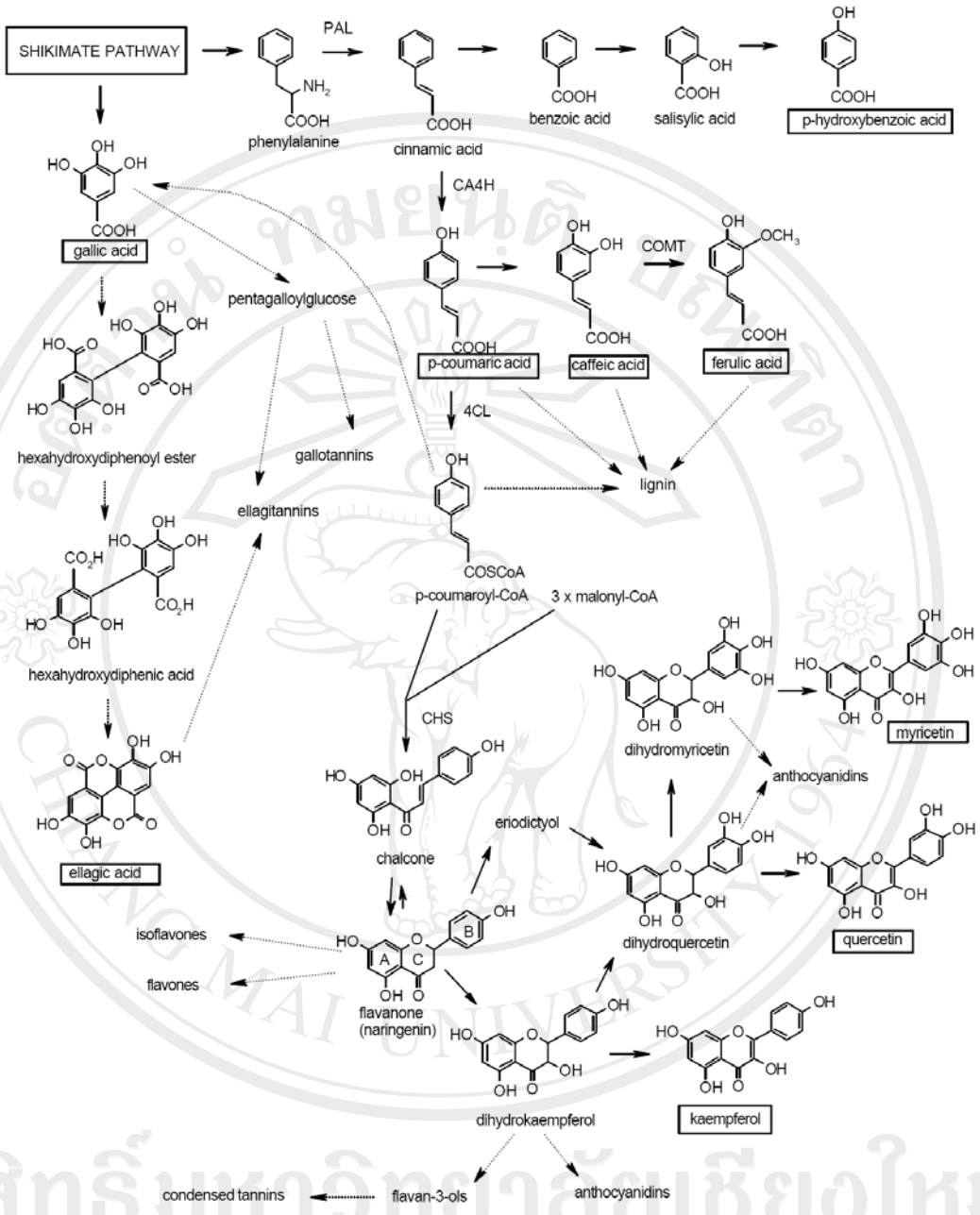


Figure 2.4 Biosynthesis **pathways** of hydroxycinnamic acids, hydroxybenzoic acids and flavonoids. (Source : Häkkinen, 2000)

Table 2.4 The major classes of phenolics in fruits.

Number of carbon atoms	Basic skeleton	Class	Example	Fruit (example)
7	C_6-C_1	Hydroxybenzoic acid	*p*-Hydroxybenzoic	Strawberry
9	C_6-C_3	Hydroxycinnamic acid	Caffeic, ferulic acid	Apple
		Coumarins	Scopolin, aesculetin, umbelliferone	Citrus
10	C_6-C_4	Naphthoquinones	Juglone	Walnut
13	C_6-C_1-C_6	Xanthones	Mangiferin, mangostin	Mango
14	C_6-C_2-C_6	Stilbenes	Resveratrol	Grape
15	C_6-C_3-C_6	Flavonoids	Quercetin, cyanidin	Cherry
			kaempferol	Apple
		Isoflavonoids	Daidzein	French bean
18	$(C_6$-$C_3)_2$	Lignins	Pinoresosinal	Stone fruits

(Source : Macheix *et al*., 1990; Robards *et al*.,1999; Antolovich *et al*., 2000)

2.13 Enzymatic browning of **longan pericarp**

One of the most important problems in marketing longan fruit is a rapid pericarp browning within a few days after harvest (Prapaipong and Rakariyatham, 1990; Wu *et al*., 1999). Although this is only a visual symptom and has no effect on flavor, color deterioration causes the fruit to bring a lower price at market and even becomes unmarketable because of consumer preference for visual appearance (Jiang *et al*., 2002). Browning can be associated with desiccation heat stress and/or chilling injury. Tissue browning is dependent upon the concentration of phenolic compounds, the activity of PPO, oxygen and the concentration of antioxidants (Nicolas *et al*., 1994; Kader, 2002). PPO and its substrates vary and change markedly in various fruits (Mayer and Harel, 1991). PPO is activated by moisture loss from the fruit and/or chilling injury (Lu *et al*., 1992; Su and Yang, 1996). Water is lost from fruit in the form of water vapor. Water from fruit cells vaporizes into the intercellular spaces and maintains a nearly saturated atmosphere within the product. Water vapor moves to the outside atmosphere through lenticels, stomata, natural openings, injured areas,

or directly through the cuticle. Most perishables should be held in cold storage conditions near 95% RH because cooled products have much lower vapor pressure (Thompson *et al*., 2002).

The enzyme, PPO, has been isolated and purified from "Shixia" fruit pericarp, and has been shown to have the optimum pH and temperature of 6.5 and 35°C, respectively (Jiang, 1999). PPO activity was relatively low at harvest, decreased initially during low temperature storage for 7 days, increased again, reached a peak after storage for 30 days, and finally decreased again (Wu *et al*., 1999). There are a few reports on the major phenolic compounds, substrate specificity and affinity of longan fruit PPO. Longan pericarp contains higher amounts of phenolic compounds than the aril. The activity of PPO in the pericarp sharply increased while phenol content decreased during storage (Jiang, 1999). Degree of discoloration in longan samples varied, depending upon the activity of PPO and phenolic substances present (Prapaipong and Rakariyatham, 1990). It is possible that the polymerization of tannic acid caused pericarp hardness and discoloration that inhibited effective gas and water movement.

SO_2 is an effective inhibitor of PPO and reduces fruit browning (Tongdee, 1994). Fruit fumigated with SO_2 for 20 minutes could be stored for about 45 days at 4°C without exhibiting pericarp browning (Han *et al*., 1999; Li and Li, 1999). However, evidence for the role of PPO in longan fruit pericarp browning is correlative, and the underlying biochemistry and physiology require further investigation.

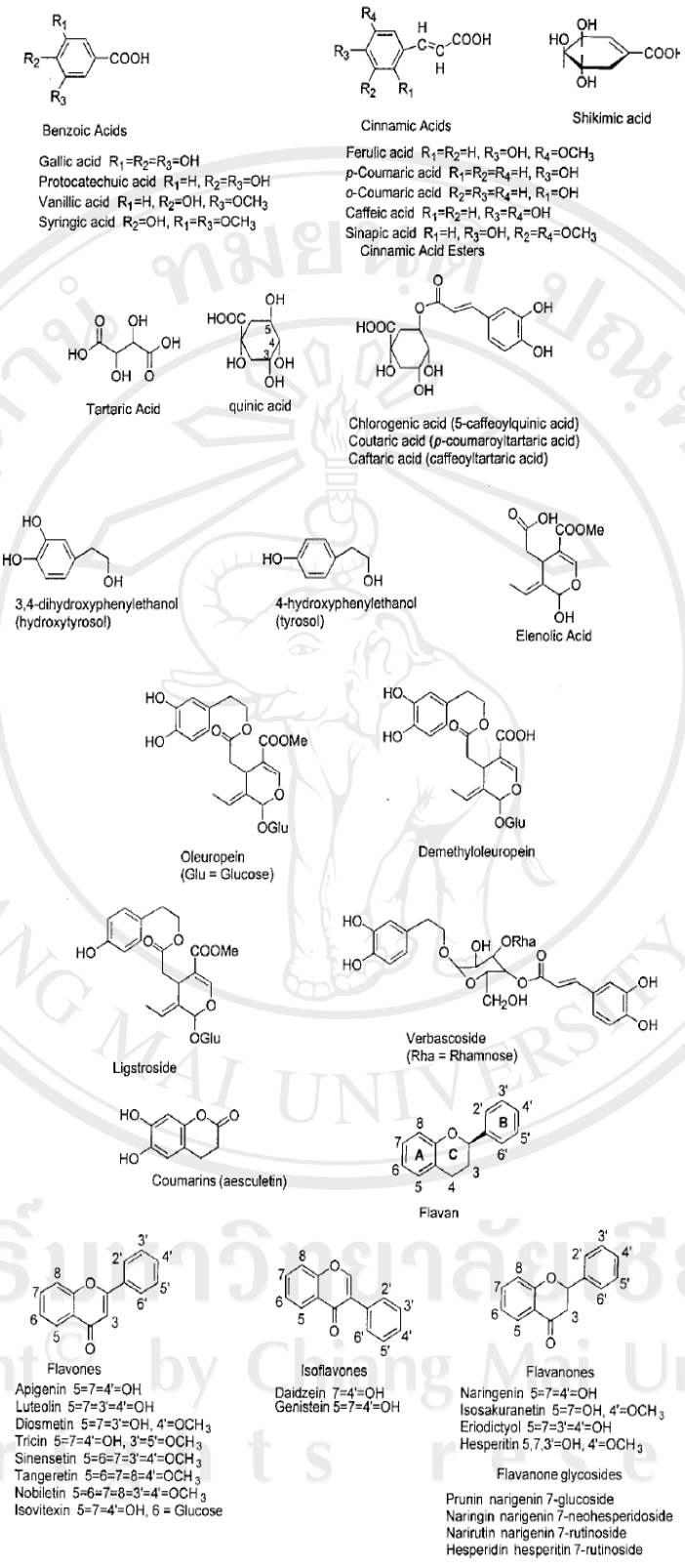
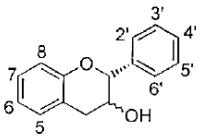


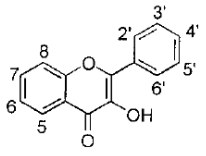
Figure 2.5 Structure of selected phenolic compounds in fruits.

(Source : Robards *et al*., 1999)



Flavanols

Catechin (2R, 3S) 5=7=3'=4'=OH
Epicatechin (2R, 3R) 5=7=3'=4'=OH
Epigallocatechin (2R, 3R) 5=7=3'=4'=5'=OH
Epicatechin gallate (2R, 3R) 5=7=3'=4'=OH, 3-gallic acid ester
Epigallocatechin gallate (2R, 3R) 5=7=3'=4'=5'=OH, 3-gallic acid ester

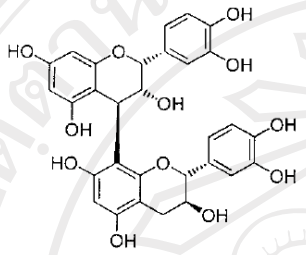


Flavonols

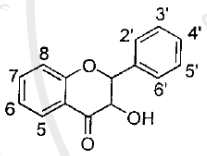
Fisetin 7=3'=4'=OH
Kaempferol 5=7=4'=OH
Morin 5=7=2'=4'=OH
Herbacetin 5=7=8=4'=OH
Quercetin 5=7=3'=4'=OH
Robinetin 7=3'=4'=5'=OH
Isorhamnetin 5=7=4'=OH, 3'=OCH_3
Myricetin 5=7=3'=4'=5'=OH
Gossypetin 5=7=8=3'=4'=OH

Flavonol glycosides

Rutin quercetin 3-*O*-rhamnosylglucoside
Hyperin quercetin 3-*O*-β-D-galactopyranoside

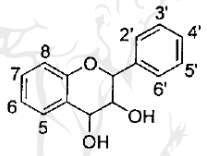


Procyanidin B-1

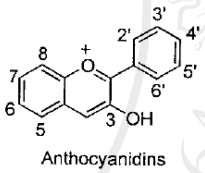


Flavanonols

Taxifolin 5=7=3'=4'=OH (dihydroquercetin)



Flavan-3,4-diols (leucoanthocyanidins)

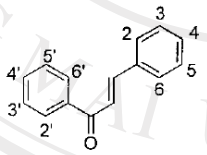


Anthocyanidins

Pelargonidin 5=7=4'=OH
Cyanidin 5=7=3'=4'=OH
Peonidin 5=7=4'=OH, 3'=OCH_3
Delphinidin 5=7=3'=4'=5'=OH
Petunidin 5=7=4'=5'=OH, 3'=OCH
Malvidin 5=7=4'=OH, 3'=5'=OCH_3

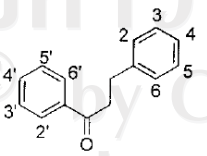
Anthocyanins

Cyanidin 3-glucoside
Cyanidin 3-galactoside
Cyanidin 3-arabinoside
Cyanidin 3-rutinoside
Malvidin 3-glucoside
Malvidin 3,5-diglucoside



Chalcones

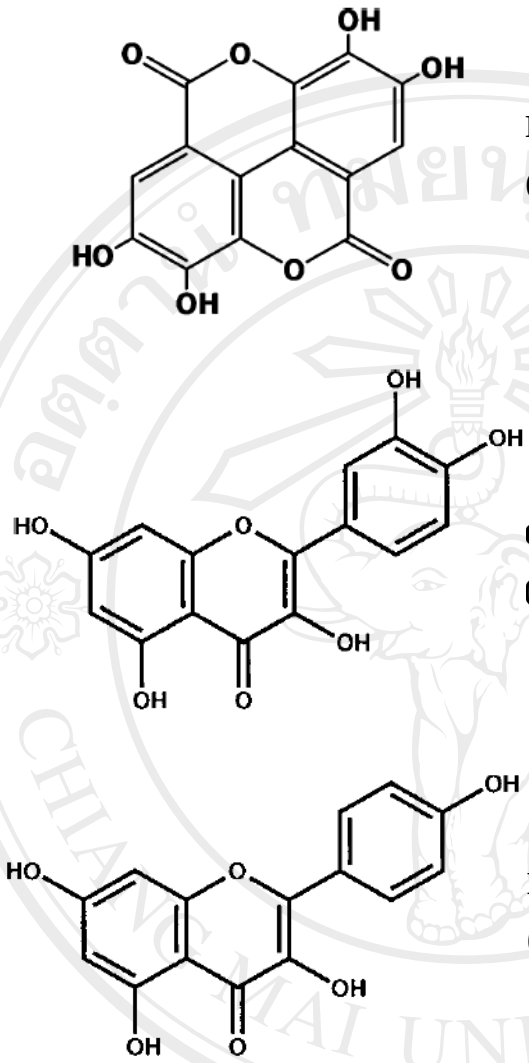
Butein 2'=4'=3=4=OH
Licochalcone B 4'=3=4=OH, 2=OCH_3
Okanin 2'=3'=4'=3=4=OH
Chalconarigenin 2'=4'=6'=4=OH



Dihydrochalcones

Phloridzin 4'=6'=4=OH, 2'= *O*-glucosyl

Figure 2.5 (continued).



Ellagic acid

($C_{14}H_6O_8$, Molecular weight 302)

Quercetin

($C_{15}H_{10}O_7$, Molecular weight 302)

Kaempferol

($C_{15}H_{10}O_6$, Molecular weight 286)

Figure 2.6 Basic structures of ellagic acid, quercetin and kaempferol.
(Source : Ciolino *et al*., 1999; Rangkadilok *et al*., 2005)

2.14 Plant cell wall components

All the cell wall layers consist of two phases: a microfibrillar phase and matrix phase (**Table 2.5**). The microfibrillar phase is distinguishable from the matrix phase by its high degree of crystallinity and its relatively homogeneous chemical composition. The microfibrillar phase of the wall is composed of extremely long, thin structures called “microfibrils”. The microfibrils are made up of cellulose molecules, which are aligned parallel to the long axis of the microfibril. About 30 to 100 cellulose molecules lie side-by-side at any one point along the microfibril (Brett and Waldron, 1996). Cellulose, hemicellulose, pectic polysaccharide, structural protein and lignin have been identified as the major components of the plant cell wall (Talmadge *et al*., 1973). Cellulose is an unbranched β-1,4-glucan, with a degree of polymerization (number of sugar residues per molecule) of up to at least 15,000. The cellulose chains are held in a crystalline or paracrystalline lattice within the microfibril, giving rise to a structure of considerable tensile strength (Brett and Waldron, 1996).

The non-crystalline phase of the cell wall is called “wall matrix”. The matrix is extremely complex. It consists of a variety of polysaccharides, proteins and phenolic compounds. These compositions vary in different parts of the wall, types of cell, species and probably also at different stages of the cell cycle. The pectic polysaccharides are made up of a group of polysaccharides rich in galacturonic acid, rhamnose, arabinose and galactose. They are characteristics of the middle lamella and primary wall of plant (Brett and Waldron, 1996). The hemicellulose fraction of the cell wall consists of those polysaccharides which are extracted by aqueous alkali. Commonly occurring hemicelluloses include xylans, arabinoxylans, mannans, arabiongalactans, glucomannans and galactoglucomannans. Lignin is a characteristic component of secondary cell walls (Talmadge *et al*., 1973). Lignin is found principally in sclerenchyma, tracheids and vessels of the xylem (Brett and Waldron, 1996).

Table 2.5 Cell wall components.

Phase	Component	
Microfibrillar	Cellulose (β1,4-glucan)	
Matrix*	Pectins	Rhamnogalacturonan, arabinan, glucan,
		arabinogalactan, homogalacturonan
		rhamnogalacturonan II
	Hemicelluloses	Xylan, glucomannan, mannan
		galactomannan, glucoronomannan
		xyloglucan, callose (β1,3-glucan)
		β1,3-, β1,4-glucan, arabinogalactan II
	Proteins	Extensin, arabinogalactan-proteins
		others, including enzymes
	Phenolics	Lignin, ferulic acid
		others, e.g. coumaric acid, truxillic acid

*Not all these matrix components are found in all cell walls.

(Source : Brett and Waldron, 1996)