CHAPTER 2

THEORY AND LITERATURE REVIEWS

2.1 Pineapple

2.1.1 Botany

Pineapple (*Ananas comosus* (L.) Merr.) is a monocotyledonous perennial in the family *Bromeliaceae*. The pineapple fruit shares the distinction of being selected, developed and domesticated by peoples in tropical America in prehistoric times (Collins, 1968). The place of origin of these cultivars includes the countries of South-Eastern Brazil, Paraguay and Northern Argentina (Baker and Collins, 1939). Nowadays, pineapple is one of the most important commercial fruits of the world. It is widely cultivated throughout the tropical and subtropical.

The pineapple is a perennial herb which grows up to a height of 90-100 cm with a spread of 130-150 cm. It bears a terminal inflorescence and fruit. Newly planted plants are known as main crop, and those produced later from axillary plant are called ratoon crop. In this way, the plant countries its growth and produces fruits for many years. Commercially, however, only one or two ratoon crops are taken. The trough-shaded leaves are spirally arranged in a dense rosette pattern. The leaves are densely covered with large trichomes covering strips of stomata located in furrows. Stomatal density is low and the pore size is small. The single spike-like inflorescence carries variable numbers of flowers and is terminated with a vegetative shoot or crown. Of the many pineapple varieties, 'Smooth cayenne' is the major commercial variety and worldwide, it has deficiencies as a fresh fruit (Brown, 1953; Collins, 1968; Samuels, 1970; Grazia *et al*., 1980; and Paull, 1992).

2.1.2 Inflorescence and flower

The first sign of floral initiation, whether natural or induced, is a rapid increase in diameter of the apical meristem. After 5-6 days this change has taken place, the peduncle begins to elongate. It continues to elongate as the inflorescence develops. There are 100-200 flowers per inflorescence, and at anthesis one to several flowers open each day, beginning at the base of the inflorescence, over a period of 3-4 weeks (Okimoto, 1948). When inflorescence development is initiated, the phyllotaxy changes from one of 5/13 for the leaf to that of 8/21 in the inflorescence. Production of many small leaves just below the base of the inflorescence marks this change. When flower production ceases, the apical meristem again revert to the 5/13 phyllotaxy, with a transition area of short leafly bracts, followed by the growth and development of the crown (Figure 2.1).

Flowers are hermaphroditic and trimerous, with three sepals, three petals, six stamens in two whorls of three and a three-carpellate, inferior ovary with numerous ovules (Figure 2.1). The ovules and pollen grains are functional, but seeds are not normally formed, as the 'Smooth Cayenne' is strongly self-incompatible.

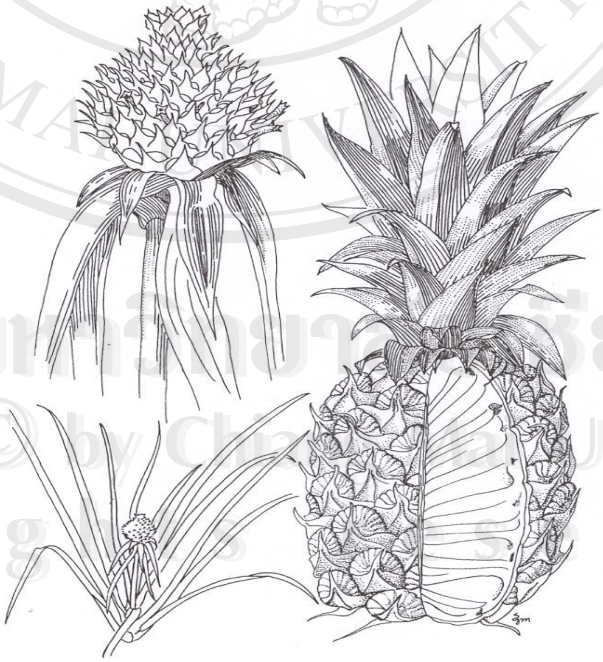


Figure 2.1 Pineapple flower and fruit (Nakasone and Paull, 1998).

2.1.3 Fruit development

The pineapple has three distinct phases of growth: (a) the vegetative phase of leaf growth, (b) the generative phase of fruit growth, and (c) another vegetative phase of shoot growth. These three phases overlap to a certain extent. The leaf growth continues even after bloom has been induced and stops only after the inflorescence has appeared. Further, shoot growth may start before the fruit is harvested (Samson, 1980). The flowering, fruit growth and development of pineapple had been recently reviewed (Bartholomew and Paull, 1986; Bartholomew and Malezieux, 1994). Natural inflorescence development is initiated by shortened day length and cool night. However, growth regulators (e.g. ethephon, 2-chloroethylphosponic acid) are used commercially to force flowering (Bartholomew, 1977; Bartholomew and Criley, 1983). Pollination is not required for fruit development. In the self-incompatible commercial cultivars, the fruit develops parthenocarpically.

The pineapple fruit is composed of core, fruitlet, the collective flesh and fruit shell. Bract, calyx, and ovary tissue of sessile flowers have become fused within and between fruitlet during development, to form the collective fruit (Okimoto, 1948). The large bract subtending each fruitlet is freshly and widened at its base and bends over the flattened calyx surface, covering half of the fruitlet. No floral abscission occurs, so the withered style, stamens, and petals can be found on the mature fruitlet. The fused nature of the fruitlet means that the flesh of fruit is not sterile and contains yeast and bacteria (Rohrbach and Apt, 1986). The number of fruitlet comprising a fruit varies widely with plant condition and environmental condition; a typical Smooth Cayenne fruit about 150-200 fruitlet.

The fruit mass increase in a continuous sigmoid fashion once the florescence has been initiated. Cell division is completed prior to anthesis with all further development is the result of cell enlargement. Fruit mass increased about 20-fold from the time of flowering until maturation (Singleton, 1965; Teisson and Pineau, 1982). The crown probably has no direct effect on the growth of the fruit (Senanayake and Gunasena, 1975).

2.1.4 Physico-chemical changes during fruit maturation and ripening

Fruit development and composition changes during growth have been reviewed (Dull, 1971; Teisson and Pineau, 1982; Bartholomew and Paull, 1986; Paull, 1997). The present review concentrates on the marked changes in flesh composition that occur in the three to seven weeks prior to and at the half-yellow shell color stage (Tay, 1977; Chen and Paull, 1995). Fruit maturity is judged on the extent of fruit 'eye' flatness and skin yellowing. When the fruit is in the half-yellow stage it is regarded as ripe. At this stage, fruit weight is near maximum (Wardlaw, 1937) and Brix and titratable acidity have reached their maximum.

Pigment development

Shell chlorophyll levels showed little change until the final 10 to 15 days before full ripeness, and then declined (Gortner, 1965; Py, *et al*., 1987). Shell carotenoid pigments remained reasonably constant during this phase only, declining slightly before rising again as the fruit senesced. Flesh carotenoids increased during these final 10 days before full ripe stage (Gortner, 1965; Teisson and Pineau, 1982). A similar decrease in shell chlorophyll and increase in flesh carotenoids occurs in harvested fruit (Dull, *et al*., 1967; Chen and Paull, 1995).

Change in sugar content and acidity

Sugar content plays an important role in the flavor characteristics and commercial assessment of pineapple fruit quality (Py *et al*., 1987). Total soluble solids (TSS) mainly sugar are often used an indicator of fruit maturity and quality (Paull, 1992). TSS can be varied by $40gl^{-1}$ from the more mature, sweeter basal tissue to the crown end on fruit (Miller and Hall, 1953) and decline only slightly after harvest (Paull and Rohrbach, 1982; Chen and Paull, 1995). The more mature, basal tissue of the fruit, trends to be sweeter than the flesh near the crown end (Miller and Hall, 1953). The starch is not accumulated in the fruit (Dull, 1971) and this could explain the absence of dramatic changes in total soluble sugars postharvest. The major sugars in mature fruit are sucrose, glucose and fructose and the peak in sucrose concentration is attained at full-yellow stage and declines. Fruit sugars increase through to senescence, unless the fruit is harvested.

Chen (1999) showed the total soluble sugar content is low during fruit growth and compose mainly of glucose and fructose. Glucose is at a slightly higher concentration than fructose during the early stages of fruit development (Figure 2.2A). Sucrose accumulated rapidly six weeks before commercial harvest and ultimately exceeds the glucose and fructose concentrations (Lodh *et al*., 1972; Chen, 1999). Three sugar metabolic enzymes [sucrose synthase (SS), sucrose phosphate synthase (SPS) and invertase] are thought to control sugar accumulation by fruit tissue. The activity of sucrose synthase is high in younger pineapple fruit and declines to a very low level six weeks before harvest. The activity of sucrose phosphate synthase is relatively low and constant throughout fruit development (Chen, 1999) (Figure 2.2B). The activities of acid, neutral and cell wall invertase (CWI) are high in the younger fruit and decline to low levels six weeks before harvest (Figure 2.2C), when sucrose started to accumulate. The acitivity of cell wall invertase increase 4 weeks before harvest, while the activities of neutral invertase (NI) and acid invertase (AI) remain low, concomitant with the accumulation of sucrose. It indicated that these enzymes may be a prerequisite for sucrose accumulation in pineapple fruit flesh. The high activity of CWI, favoring apoplastic phloem unloading, may play a role in sugar accumulation in pineapple fruit flesh at the later stages of fruit development.

The pH of pineapple juice declines as the fruit approach the fully-yellow stages (Teisson and Pineau, 1982), ranging from 3.9 to 3.7, and increasing only as the fruit senesce, while titratable acidity shows opposite trends (Singleton and Gortner, 1965; Teisson and Pineau, 1982; Chen and Paull, 1995). The flesh acidity increased distally from the central core (4mEq 100 ml^{-1}) outwards to 10mEq 100 ml^{-1} (Huet, 1958). A major portion of the total nonvolatile acids occurs as free organic acids, with the two major nonvolatile organic acids being citric and malic acids (Chan *et al*., 1973).

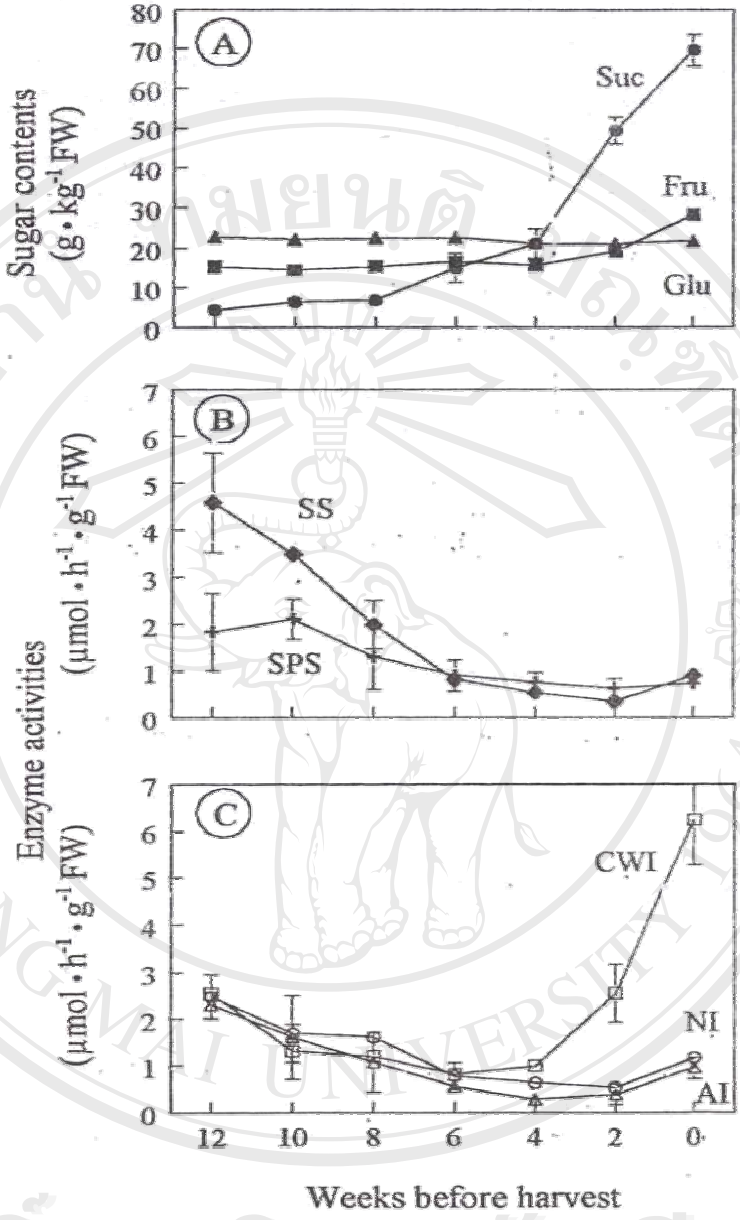


Figure 2.2 Changes in sugar contents and the activities of sugar metabolic enzymes in developing pineapple flesh (A) sucrose (Suc), glucose (Glu), and frustose (Fru) contents. (B) Activities of sucrose synthase (SS) and sucrose phosphate synthase (SPS). (C) Activities of acid invertase (AI), neutral invertase (NI), cell-wall invertase (CWI). Fruit were harvested every 2 weeks from 12 weeks before harvested. Symbols represent mean ± SD of three replications. (Chen and Paull, 2000)

Table 2.1 Proximate analysis of "Smooth Cayenne" fruit

Chemical composition	Unit	Amount per 100 g edible portion			
		Flesh pineapple[1]	Flesh pineapple[2]	Flesh pineapple[3a]	Flesh pineapple[3b]
Water	g	81.2-86.2	86.0	86.0	80.0-86.0
Energy	KJ	-	218.0	158.0	-
Protein	g	-	0.5	1.0	0.2
Lipid	g	-	0.2	0.01	0.0
Carbohydrate	g	-	13.5	8.0	-
Total sugar	g		-	8.0	10.0-18.0
Starch	g	∠0.02	-	0.0	-
Fiber	g	0.3-0.6	0.5	2.0	-
Ash	g	0.3-0.4	0.3	0.5	0.3-0.6
Cholesterol	g	-	-	0.0	-
Total nitrogen	mg	45.0-115	-	-	45.0-120.0
Carotene	g	1.3-2.9	-	-	-
Xanthophyll	g	0.3	-	-	0.2-0.3
Minerals					
Calcium	mg	-	18.0	27.0	3.0-16.0
Iron	mg	-	0.3	0.3	0.05-0.3
Magnesium	mg	-	12.0	11.0	10.0-19.0
Phosphorous	mg	-	12.0	-	-
Potassium	mg	-	98.0	180.0	11.0-330.0
Sodium	mg	-	1.0	2.0	14.0
Zinc	mg	-	-	0.2	0.0
Vitamins					
Ascorbic acid	mg	10.0-25.0	10.00	21.00	3.00-25.0
Thiamine	mg	0.06-0.10	0.09	0.04	0.06-0.15
Riboflavin	mg	0.02-0.08	0.04	0.03	0.02-0.08
Niacin	mg	0.20-0.28	0.24	0.03	-
Vitamin A	IU	20.0-40.0	53.00		

[1] Akamine, 1976
[2] Nakasone and Paull, 1998
[3a] Smith, 1993 (Queensland fruit data from Composition of food Australia, Australian food Publishing Service, Canberra, 1989.)
[3b] Smith, 1993 (From Py *et al.*, 1987): data presumably based on fruit from Ivory coast.)

Chen and Paull (2000) conducted the study on sugar metabolism in relation to flesh translucency of pineapple fruit. They found that sugar accumulation and activities of sugar metabolizing enzymes were related to the occurrence of pineapple fruit flesh translucency. During early fruit development, glucose and fructose were the predominant sugar. Sucrose began to accumulate 6 weeks before harvest at the higher rate in the fruitlet than in the inter-fruitlet tissue. Electrolyte leakage from pineapple fruit flesh increased rapidly from 6 weeks before harvesting and paralleled with sucrose accumulation.

Fruit texture change

Most fruit soften during ripening and this is a major quality attribute that often indicates shelf life. Fruit softening could arise from one of three mechanisms: loss of tugor, degradation of starch or breakdown of fruit cell walls. Loss of tugor is largely a non-physiological process associated with the postharvest dehydration of the fruit. Loss of water equivalent to about 5-10% of a fruit's fresh weight although having little effect on fruit's biochemistry can render the fruit commercially unacceptable. Degradation of starch probably results in a pronounced texture change such as banana and mango where starch accounts for a high percentage of the fruit weight. In general however, texture change during the ripening of most fruit is thought to be largely the result of cell wall degradation.

(I) Cell wall changes

Changes in cell wall structure during ripening have been observed under the electron microscope in many fruit, including avocado, pear and tomato (Crookes and Grierson, 1983). These changes usually consist of an apparent dissolution of the pectin-rich middle lamella region of the cell wall. At a biochemical level, major changes can be observed in the pectin polymers of the wall. During ripening there is a loss of neutral sugars, in most fruit this is predominantly galactose, but some loss of arabinose also occurs (Tucker and Grierson, 1987). These two sugars are the major components of the wall's neutral pectin. There are also major changes observed in acidic pectin or rhamnogalacturonan fraction of the wall. During ripening there is an increase in the solubility of these polyuronides and in several cases these have been shown to become progressively depolymerized. The degree of esterfication of the polyuronide fraction can also change during ripening. Tomato polyurinide is about

75% esterified in green fruit and this declines to around 55% during ripening (Tucker, 1993). Conversely an increase in the degree of esterification of the soluble polyuronide from apple fruit (Knee, 1978).

Changes during ripening of cell wall components other than pectin have been poorly documented. It appears that levels of sugars commonly associated with either hemicellulose or cellulosic fractions remain constant throughout ripening. Much work has been carried out to identify enzymes in fruit responsible for these changes in the cell wall during ripening (Huber, 1983; Tucker and Grierson, 1987; Brady, 1987; and Fischer and Bennett, 1991). However, such studies are hampered by an incomplete understanding of plant cell wall structure in general and fruit wall structure in particular.

Cell wall structure

Cell walls are consists of 3 types of layers (middle lamella, primary cell wall and secondary cell wall). Middle lamella is the first layer formed during cell division. It makes up the outer wall of the cell and is shared by adjacent cells. It is composed of pectic compounds and protein. The primary cell wall is formed after the middle lamella and consists of a rigid skeleton of cellulose microfibrils embedded in a gel-like matrix composed of pectic compounds, hemicellulose and glycoprotein. Secondary cell wall formed after cell enlargement is completed (Brett and Hillman, 1985). The secondary cell- wall extremely rigid and provide compression strength. It is made of cellulose, hemicellulose and lignin.

The main ingredients in cell wall are polysaccharides (or complex carbohydrates or complex sugars) which are built from monosaccharides. Eleven sugars are common in these poysaccharide including glucose and galactose. Carbohydrates are good building blocks because they can produce a nearly infinite variety of structures (Carpita, 2000). There are a variety of other components in the wall including protein and lignin. The major polysaccharides in the primary cell wall are cellulose, hemicellulose, pectic polysaccharides, protein, lignin, suberin, wax, cutin and water

Tabel 2.2 Structure component of cell wall (Taiz and Zeiger, 1998).

Class	**Samples**
- Cellulose	Microfibrils of (1→4) β-D glucan
- Pectin	Homogalacturonan Rhamnogalacturonan Arabinan Galactan
- Hemicellulose	Xyloglucan Xylan Arabinoxylan Glucomannan Callose (1→3) β-D glucan (1→3,1→4) β-D glucan (grass only)
- Lignin	Coniferyl alcohol, sinapyl alcohol
- Structural protein	Glycine Glycoprotein Proline

(a) Cellulose

Cellulose is composed of linear chains of covalently 1,4- linked β-D-glucose residues. It is very stable chemically and extremely insoluble. In the primary cell wall consists one glucose polymer of roughly 6,000 glucose units, and in the secondary wall is their number increased to 13,000-16,000 units (Figure 2.3a). Cellulose chains form crystalline structure call microfibrils. A micorfibril with a diameter of 20-30 nm contains about 2,000 molecules.

(b) Hemicellulose

Hemicellulose is a polysaccharide composed of variety of sugars including xylose, arabinose, and mannose. Hemicellulose that are structurally homologous to cellulose because they have a backbone composed of 1,4-linked β-D-hexosyl residues

(Figure 2.3b). The predominant hemicellulose in primary cell wall is xyloglucan. Other hemicellulose in many primary cell walls include arabinoxylan, glucomannan and galactomannan.

(c) Pectin polysaccharides

Pectic is a family of complex polysaccharides that all contain 1,4-linked ∝-D-galacturonic acid. To date three classes of pectic polysaccharides have been characterized: homogalactutonans, rhamnogalacturonans and substituted galacturonans. Although most pectic polysaccharides are acid, others are composed of neutral sugars including arabinans and galactans (Figure 2.3c). The pectic polysaccharides serve in variety of functions including determining wall porosity, providing a charges wall surface for cell-cell adhesion (middle lamella), cell-cell recognition, pathogen recognition and other.

(d) Protien

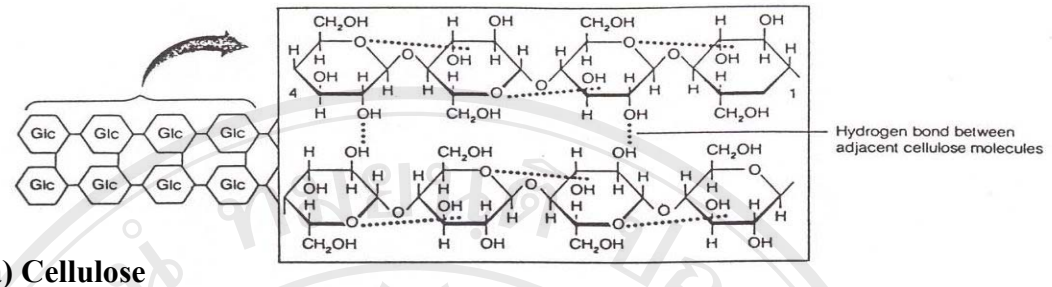
Wall proteins are typically glycoproteins. The proteins are particularly rich in to amino acids hydroxyproline, proline and glycine. Protein appears to be cross-linked to pectic substances and may have sites for lignification.

(f) Lignin

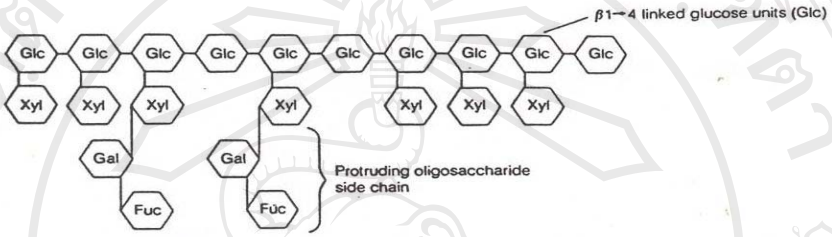
Lignin is composed of polymer of phenolic, especially phenylpropanoids. Lignin is primary strenghtening agent in the wall. It also resists fungal and pathogen attack.

(g) Water

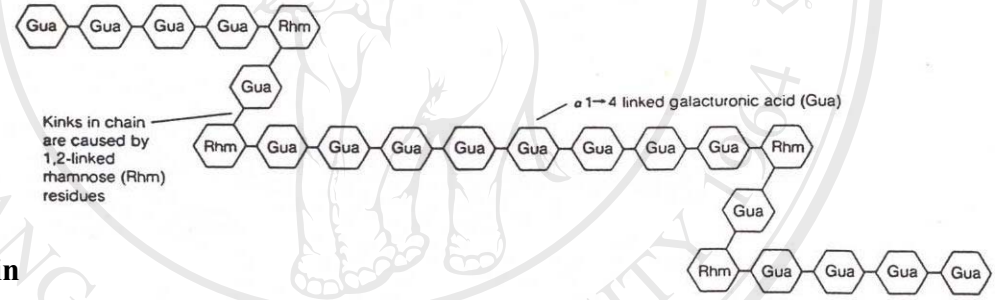
The wall is largely hydrated and comprised of between 75-80% water. This is responsible for some of the wall properties.



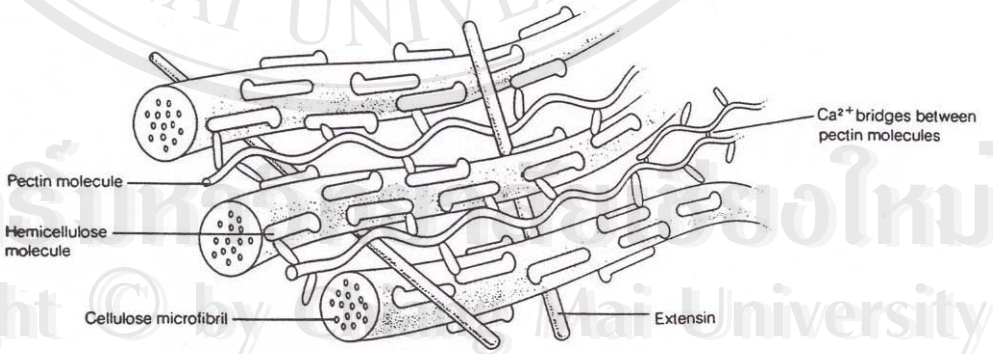
(a) Cellulose



(b) Hemicellulose



(c) Pectin



(d) Idealized cell wall model

Figure 2.3 Chemical structure (a) cellulose, (b) hemicellulose, (c) pectin and (d) idealized cell wall model.

(II) Cell wall softening

The cell wall consists of long molecules of cellulose joined to other cellulose chains by polysaccharide bridges composed of a mixture of sugars such as galactose, arabinose, and xylose. These polysaccharide bridges form part of the wall that used to be called hemicellulose. Because the long cellulose molecules are bound together by these crosslinks, the cell wall is rigid. When the cell wall stretches irreversibly as during growth the cellulose chains have to slide past one another and the only way this can be accomplished is by breaking the crosslinks attaching one cellulose chain to the next. Cell wall hydrolase can be identified in fruit tissue and found in a wide variety of fruit (Huber, 1983; Tucker and Grierson, 1987). The enzymes most studied are pectinesterase (PE), polygalacturonase (PG), β-(1-4) glucanase or cellulase and β-galactosidase. Pectinesterase acts to remove the methyl group from the C-6 position of galacturonic acid. Polygalacturonase hydrolyses the ∝(1-4) link between adjacent demethylated galacturonic acid residues. These two enzymes can act synergistically with PE, generating sites for PG action. Cellulase hydrolyses the β-(1-4) link between adjacent glucose residues.

The cell walls of pineapple fruit parenchyma are regarded as unlignified, but do contain esterified feruric acid (Smith and Harris, 1995). Overall, the non-cellulosic walls are intermediate between the unlignified Poaceace and typical dicotyledon cell walls. Glucuronoarabinoxylans are the major component of the non-cellulose fraction. Xyloglucans, along with smaller amounts of pectic polysaccharides and glucomannans are present. Pineapple juice contains predominantly galactomannans (Chenchin and Yamamoto, 1978) and no acid sugars are detected, suggesting little pectin hydrolysis during ripening. This juice neutral polysaccharide forms a gum on processing equipment, which is ready hydrolysed by commercial cellulase, hemicellulase and pectinase preparation (Chenchin *et al.,* 1984). Glucan (1→3, 1→4) linkages absent, in constant to Poaceae cell walls. Glucuroarabinoxylans have also been isolated from lignified cell walls of pineapple leaf (Bhaduri *et al*., 1983; Jarvis *et al.,* 1988). In pineapple, there are no marked changes in fruit texture during ripening, though water loss can lead some to reduction in fruit firmness. Senescence-related loss of membrane integrity leads to water-soaked, translucent flesh that tends to be softer. Pineapple fruit have a moderate respiration rate, producing around 22 ml $CO_2.Kg^{-1}.h^{-1}$ at 23°C. No dramatic respiratory or biochemical change during ripening (Dull *et al*., 1967), with ethylene production increasing as each fruitlet ages but with no pronounced peak. The absence of a peak in ethylene production and lack of relationship of respiration with

pronounced biochemical ripening changes supports the conclusion of a non-climacteric pattern of development.

2.2 Quality of pineapple fruit and environmental factors affected quality

2.2.1 Quality of pineapple fruit

Fruit quality in pineapple fruit is subjective, because consumer preferences vary. However, the generally accepted factors influencing quality include color, translucency, sugar, acidity, esters, aroma, and taste (Bartholomew and Paull, 1986). Superior quality fruit have a high TSS content and relative low titratable acidity (TA), usually less than 1% as citric acid. However, low acidity can also lower quality (Bartholomew *et al*., 2001a).

Smith (1988a) determined quality indices as specific gravity (SG), skin color, flesh color, TSS, TA, TSS/TA ratio of pineapple fruit using sample from three different harvest seasons and found that flesh TSS not only gave the highest correlation to eating quality (R^2 = 0.70) but TSS was the only parameter found suitable as a year-round index of pineapple eating quality. SG had a higher average coefficient than did skin color and SG was considered the best index for grading whole, intact fruit for eating quality. Smith (1984) reported that a quadratic relationship between eating quality and SG was determined with the maximum eating quality occurring at an SG of 0.96 - 1.004 with little effect of fruit weight or season. Season affected the rate of change of eating quality with SG, with the greatest rate of change occurring in winter and least in summer.

Several studies compared the quality attributes with sensory evaluation score produced by group of panelists. Bowden (1967) reported the level of flesh translucency as index of ripeness in pineapple. Those of low translucency being too sour and lacking pineapple flavor and while those of high translucency being too flat and having over-ripe off-flavors. This finding was supported by chemical analysis which showed the relationship between flesh translucency and acidity, pH, TSS/acid ratio and ester concentration. Bowden (1969) investigated the relationship between translucency and various quality characteristics including pH, TSS/acid ratio, flesh ester, fruit weight and palatability of flesh. He found that TSS, flesh pigment and palatability increased to maximum level in the medium range of translucency and then decreased with further increase in translucency. Boonchaisri (1997) reported that the degree of translucency was related to the acid content rather than TSS and not related to skin color.

2.2.2 Environmental factors affected fruit quality

There are few definitive data on the effects of environmental factors on quality during fruit development of pineapple. Irradiance or temperature or both are correlated with some compositional change in the fruit. Relatively short term effects have been observed with respect to malic and ascorbic acids. Over a 100-day sampling period that ended at maturity, the percentages of malic acid in fruit was inversely related to weekly pan evaporation for the week prior to sample collection. It was assumed that the change in malic acid were associated with irradiance, since pan evaporation is highly correlation with irradiance (Gortner, 1963) Ascorbic acid content fluctuated in concert with daily irradiance, through the peak ascorbate level lagged the peak irradiance by about 2 weeks (Singleton and Gortner, 1965). It is not known whether the effect of irradiance on ascorbate or malate impact fruit quality at maturity in any way.

Changes in irradiance can apparently affect fruit TSS and TA. Bartholomew *et al*. (2001b) reported that TSS was unaffected by 50% shade, but juice acidity as citrate increased from 0.79 for control fruit to 1.12% for fruit that ripened in 50% light. Titratable acidity, expressed as citric acid, increased from 0.74 to 1.4% as a light was decreased from ambient to 50% of ambient level. The increase acidity was attributed to the effect of shade on fruit temperature rather than available light**.**

Malezieux and Lacoeuilhe (1991) found that fruit TSS in Cote d′ Ivory was relatively unaffected by seasonal changes in irradiance during the 30 days prior to harvest. Fruit TA varied relatively more than TSS and levels were highly negatively correlated with irradiance. Bartholomew *et al*. (2001a) reported that Smooth Cayenne fruit grown in Thailand, where average temperatures are high, have such low acid levels that citric acid must be added to the fruit permit low-temperature processing and also in Hawaii. Fruit TA as citric acid in Smooth Cayenne fruit varies from a low of about 0.85% in fruit harvested in summer to as much as 1.25% for fruit harvested in the winter. This seasonal variation in TA make Smooth Cayenne fruit less suitable for winter fresh fruit production because TA reach levels that lower eating quality. Data from a study of the effects of elevation and season on growth, yield and fruit quality of Smooth Cayenne pineapple showed that TA varied relatively more over the year than TSS.

The degree of skin yellowness (skin color) present at optimum ripeness varies with season, rainfall, temperatures and irradiance. Gortner (1960) found that green-shell fruit had a higher temperature than did yellow ones. Alternatively, Smith (1988a) reported that the process of degreening in many fruits for example tomatoes, mangoes and bananas is often affected by high temperatures above 30°C. Growers and market agents commonly believe the "green-ripe" effect results from use of increased nitrogenous fertilizer and have suggested a relationship between heavy rain during the 20 days prior to ripening and the green-ripe phenomenon.

2.2.3 Translucency in pineapple

Pineapple flesh translucency showed similar symptoms to watercore in apple and pears (Marlow and Loescher, 1984; Chen and Paull, 2001). Roper (1999) reported that in watercore fruit, the internal fruit tissues look glassy and water soaked around the vascular bundles near the core. Normal apples contain about 20 to 35% airspaces while in watercore apples these airspaces are filled with liquid. Flesh translucency of pineapple fruit shows water soaking and has low porosity (Chen and Paull, 2001) and inter cellular free spaces is translucent fruit flesh are filled with liquid which reduces the porosity and light scattering ability of tissue. Flesh translucent pineapple fruit, possibly caused by the interaction of several factors. The factors have been suggested to be involved in apple watercore include heredity, environment, source-to-sink ratio, sorbital metabolism and fruit maturation and ripening (Marlow and Loescher, 1984).

Pineapple translucency starts to occur 3 to 4 weeks before harvest in Hawaii and the incidence and severity increase with development (Chen and Paull, 2000). Srisang (2002) found that pineapple fruits with flesh translucent could be detected during age of 120 DAFB to 130 DAFB. The percentage of fruit translucency was 11% at 120 ADFB and increase to 22% at 130 DAFB. The percentages of flesh translucent did not increase during the rest of 3 weeks of prolong harvest. Bartholomew *et al*. (2001a) reported that the effected fruit become more translucent as the fruit ripen and air cavities in the fruit flesh become filled with juice. Flesh translucency increases from the base of the fruit to the top. The incidence of fruit translucency varies with the season being more prevalent in the spring in Hawaii than other times of the year. Fruit translucency also tended to become excessively

translucent in Australia in spring especially if heavy rain near fruit maturity follows dry conditions.

Bowden (1969) suggesting that translucency is related to the ratio of total soluble solids to acidity of pineapple juice increases with increasing translucency. Paull and Reyes (1996) suggested that translucency is related to maturity and possible to sugar accumulation. The intercellular free air spaces are filled with liquid due possible to increase membrane permeability of fruit flesh cells or enhanced water movement into apoplast caused by sugar-induced solute potential gradient between sympoplast and apoplast (Chen and Paull, 2001). To date, the cause or cases of pineapple translucency are unknown.