INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2006/08–3–330–336
http://www.fspublishers.org

Impact of Cropping Season in Northern Thailand on the Quality of Smooth Cayenne Pineapple. II. Influence on Physico-chemical Attributes

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ABSTRACT

Fruits were harvested 110 - 160 days after full bloom (DAFB) during different crop seasons in 2002/2003. Significant differences ($P < 0.05$) were found among physico-chemical attributes of fruits from different crop seasons. In the winter harvested crop, total chlorophyll of peel decreased and carotenoids increased faster than other crops. Although flesh carotenoids of different cropping seasons were not significantly different, they were different in b* and chroma values. The panelist rated the flesh color of the rainy, summer and winter harvested crops as yellow, slight yellow and pale yellow, respectively. The percentages of fruit translucency in different cropping seasons neither differ nor did it increase fruit ripening. The flesh firmness of fruit from all cropping seasons showed significantly differences in all parts and positions and during harvesting time at 110 - 130 DAFB. Flesh firmness of the winter harvested crop was lower than other crops. Total soluble solids (TSS) and titratable acidity (TA) in the winter harvested crop was higher than other crops but TSS:TA ratio and pH were lower than other crops. The crude fiber and moisture contents of fruit from all cropping seasons were not significantly different.

Key Words: Pineapple; Color; Firmness; Chemical composition; Quality

INTRODUCTION

The physical and chemical changes during development, maturation and ripening of pineapple fruit (cv. Smooth Cayenne) have long been extensively studied (Gortner, 1965; Gortner & Singleton, 1965; Singleton, 1965; Singleton & Gortner, 1965). The shell colors of pineapple are generally used to determine the various stages of maturity. Smooth Cayenne produces a light yellow or golden yellow flesh color when ripe. Pineapples with slightly yellowed to one-half yellowed surface have better shelf-life than those with more surface color and fruit with no yellowing may not be mature enough for optimum eating quality (Pantastico, 1975). As the fruit ripens, the ‘eyes’ change from pointed to flat, slightly hollow at the center, the fruit becomes enlarged, less firm and more aromatic. The range of chemical constituents of ripe pineapple, depending upon stage of fruit ripeness and environmental factors, has been reported by Dull (1971) and Kermasha *et al*. (1987). Bartholomew and Malezieux (1994) reported that the rate of growth and development are positively correlated with temperature up to 29ºC. In cool season, the growth is delayed, leaves are narrow, rigid and short, the number of slips is high, fruit are small, with prominent eyes and the flesh is opaque, high in acidity and low in sugars (Bartholomew & Malezieux, 1994). The same as the growth of fruit in Hawaii winter, temperatures rarely falls below 10ºC, plants are small, leaves are short, fruitlets are more pointed, flesh color is pale yellow, flavor is poor and acid content is high (Collins, 1968). In Mexico, fruit produced for processing between June to August generally have low acid and TSS. This lower quality is due to combined effect of high temperature, excessive rain prolonged cloudy spell (Nakasone & Paull, 1998). The purpose of this experiment was studies to the influence of maturity and cropping season on physical attributes (shell & flesh color, L*, a*, b*, chroma, hue value & texture), chemical compositions (total soluble solids, titratable acidity, pH, soluble sugars, crude fiber & moisture content) and sensory attributes of pineapple fruits.

MATERIALS AND METHODS

Fruit sample. Pineapple cv. Smooth Cayenne was planted in a private farm at Thasadet village, Muang district, Lampang province. After full bloom and fruit set, 500 similar young fruits were selected and tagged. Thirty similar fruits were harvested 110, 120, 130, 140, 150 and 160, days after full bloom (DAFB) in the summer season (February 27- April 18, 2002 & April 1- May 21, 2003), rainy season (June 22 – July 11, 2002 & June 2 – July 30, 2003) and in the winter (November 2 – December 22, 2002 & November 9 – December 29, 2003). After harvesting, the fruits were transported immediately to The Postharvest Institute Technology laboratory, Chiang Mai University, un-loaded and prepared for analysis.

Analysis of color qualities, color pigments and translucency of pineapple fruits. After shell color were evaluated, the middle portion of the fruit was measured from center of horizontal circumstance up to the top 4.5 cm and down to the base 4.5 cm were cut in to 3 slices, each 3 cm in thickness as basal, central and top pieces and measured for core diameter. Flesh color of each slice was measured at center of a pair of fruitlet from opposite side of the slices with a portable Minolta colorimeter model "CR- 200" (Minolta, Osaka, Japan). The L*, a* and b* values were calculated to hue angles as formula described by McGuire (1992). The instrument was calibrated against a standard white reflective plate, using CIE Illuminant D65 with a 2ºC Standard Observer. Other coordinates calculated from the CIELAB a* and b* values were chroma ($c^* = [a^{*}2 + b^{*}2]^{1/2}$) or saturated index (intensity or purity) and the hue angle ($Hab = tg^{-1}\, b^*/a^*$). Each value represents a mean of a duplicate determination of three different samples. Results were reported as average of individual values as L* (lightness), a* (+ a = red, - a = green) and b* (+ b = yellow, - b = blue). Fruit harvested from each maturity from each crop season were cut and detected for translucency and calculated as percentage of translucent fruits. Extraction and determination of shell and flesh pigments from 3 parts slices, about 5 g peel or flesh were cut finely by hand and added 20 mL alcohol 95%. The samples were kept in refrigerator overnight and then filtered with filter paper Whatman No.1. The solution was determined the optical density at 420, 447, 645 and 663 nm by Spectrophotometer UV-VIS Unicam 500 (Whitham *et al*., 1971). Carotenoid concentration was calculated as carotene components (mg 100 g^{-1} fresh weight) as described by AOAC (2000).

Analysis texture qualities of pineapple flesh. Slices of 3 cm thickness from basal, central and top parts of each pineapple fruit were measured for flesh texture. The maximum force (Newton) to rupture the pulp tissue (after removal of shell) was determined 3 times on each slice at inner, middle and outer positions with a stable micro systems TA-TXT2i texture analyzer (Texture Technologies Crop, UK) equipped with 6 mm cylinder probe (P/6) type penetrating at a velocity of 10 mm s^{-1} to a final dept of 15 mm.

Analysis of chemical attributes of pineapple fruits. Pineapple juice was prepared from 10 g of each slices and used for chemical analysis. The juice was analyzed for total soluble solids (TSS), pH and titratable acidity (TA). TSS was measured with a digital refractometer PR- 101 (ATAGO Company, Tokyo, Japan). The pH was measured at room temperature using Satorious Professional Meter PP– 50 Operation Manual pH Meter. TA was determined by titrating 10 mL juice with 0.1 m NaOH to pH 8.2. The titratable acidity was expressed as a percentages of citric acid (mole equivalent = 0.064). Sugar concentration was analyzed with high performance liquid chromatography (HPLC) model "10AD Series" (Shimadzu, Kyoto, Japan). The HPLC was operated under the following conditions; Column: Inertsil NH2 (4.6.I.D. 250 mm), GL Science, Japan; Mobile phase: Acetronitrile: water (83:17); Detector: reflective index detector (RID); Flow rate: 1.5 mL min^{-1} and column temperature: 35ºC.

Analysis of crude fiber of pineapple flesh (AOAC, 2000). Pineapple flesh from 3 slices (50 g) was blended; 100 mL hot water was added and boiled for 10 min followed by addition of 12.5 mL boiled NaOH (50% solution) was boiled and mixed about 5 - 15 min. The flesh fiber was washed and drained flowing on the net (30 meshes) then dried in hot-air oven at 100ºC for 2 h. Dry residue was weighed and calculated for % crude fiber.

Crude fiber (%) = dry weight of fiber × 100/dry weight of sample

Moisture content of pineapple flesh (AOAC, 2000). The moisture content was determined by drying a weighed about 20 - 50 g of homogenized pineapple flesh at 70ºC for 76 h and reweighing. The percentage moisture content was calculated as following:

Moisture content (%) = (flesh weight- dry weight) x 100 / flesh weight.

Data analysis. Analysis of Variance (ANOVA) with Randomized Complete Block (RCB) using pineapple fruits as a block was performed by SPSS® program (SPSS, Illinois, U.S.A.). Tukey's LSD was used to test the significant difference at 95% confidential of each variable.

RESULTS AND DISCUSSION

Total chlorophyll and carotenoid of peel. The average total chlorophyll of shell pineapple fruits showed decrease in chlorophyll during maturation of all crop seasons. When comparing the total chlorophyll content of the same maturity stage of different crop seasons showed no significant differences, except fruit at 110 DAFB, total chlorophyll of summer harvested crop was higher than rainy season and winter harvested crops (Fig. 1A). The decreased of total chlorophyll agree with the results reported by Gortner (1965) and Py *et al*. (1987). The shell chlorophyll declined towards final 10 - 15 days before full shell yellowing. Shell carotenoid pigment remained quite constant during this phase and slightly decline before rising again as the fruit senescence. The carotenoids of the peel were increased during maturation of all crops. The carotenoid content of winter harvested crop was higher than summer and rainy season harvested fruits (Fig. 1B). Shell carotenoids actually decrease during ripening and then increase in senescence (Dull, 1971). Goodwin (1980) reported that the development of carotenoids in ripening fruit is subject to a number of environmental and genetic factors. The most important environmental factors influencing carotenoids synthesis in fruit is temperature. Tomato fruit pigment development may be influenced by low or high temperature. The optimum temperature range for ripening in tomato is 16 - 20ºC. Temperature above 30ºC inhibits development of lycopene but not carotene and the fruit turn orange rather than red (Hobson & Grierson, 2000).

Fig. 1. Comparative changes of total chlorophyll (A) and carotenoids (B) of pineapple peel for the year 2003

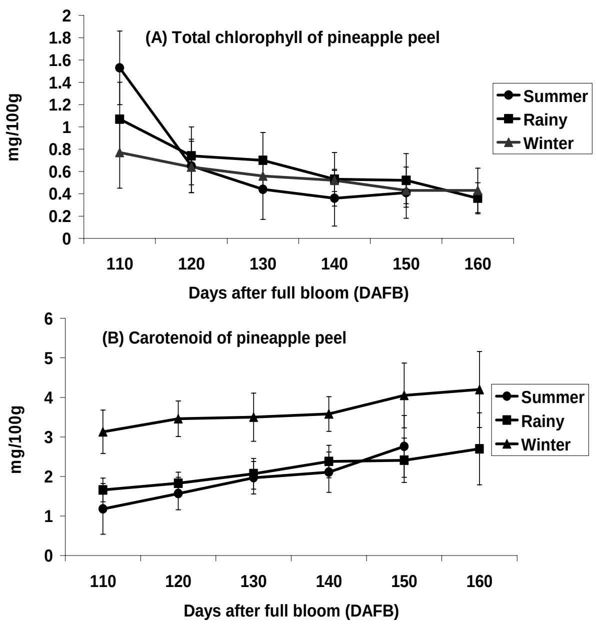
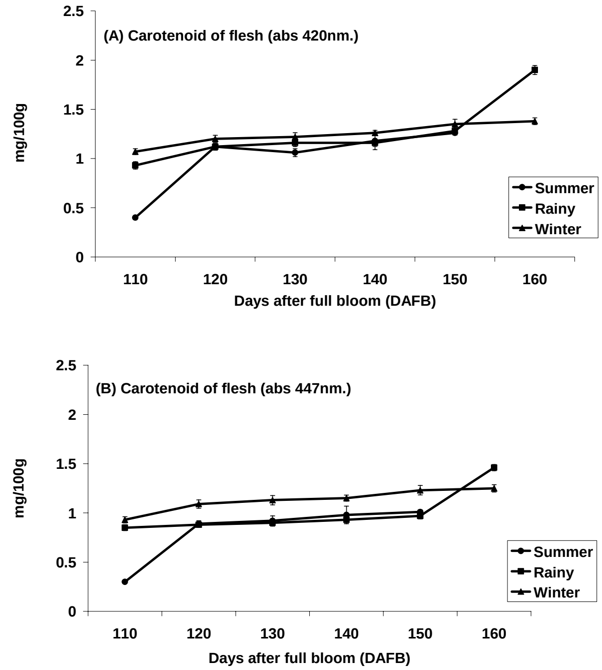


Fig. 2. Carotenoids of flesh pineapple from all crops at harvesting time for the year 2003 at absorbtion 420 nm (A) and 447 nm (B)



Flesh color and carotenoid. Carotenoid content of pineapple flesh increased at harvest (120 DAFB) but there was no significant difference 3 weeks past harvesting until overripe in all cropping seasons (Fig. 2). The flesh carotenoids increased during final ten days before the full ripe stage (Gortner, 1965; Dull *et al.*, 1967; Dull, 1971; Lodh *et al.*, 1972; Teisson & Pineau, 1982; Py *et al.*, 1987; Chen & Paull, 1995). The carotenoids showed lowest concentration about 40 days before ripeness and then indicated an extremely rapid increase during the last three weeks of ripening. Fruit carotenoids underwent rapid isomerization in tissue homogenates due to the high acidity (Dull, 1971). In this experiment, carotenoid content of the winter harvested crop was higher than other crop. The average carotenoid content of all crops was about 1 to 1.5 mg 100 g^{-1} fresh weight. Akamine (1976) reported that flesh pineapple carotene was 1.3 - 2.9 mg 100 g^{-1} fresh weight. The flesh color changed from white to bright yellow in the later harvested fruits, indicated by the decrease in hue angle, L* and increasing a*, b* and chroma values. The L* value of all cropping seasons decreased during harvesting period indicated that flesh was yellow in color. The b* and chroma values of the rainy harvested crop were higher than the winter and summer harvested crops in both years (Table I). The yellow color of pineapple flesh in the rainy harvests was

Table I. Physico-chemical properties of pineapple fruits harvested at 130 DAFB from all crops for the years 2002 and 2003.

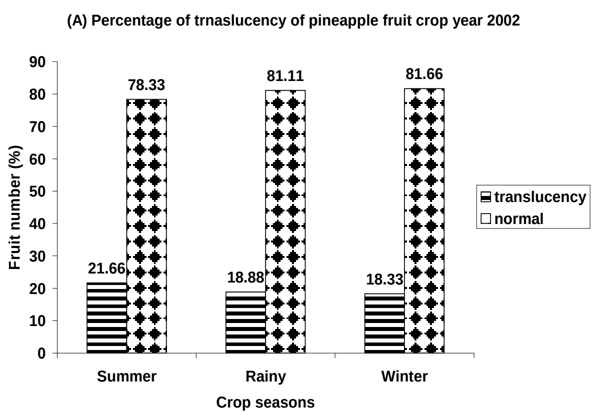
Assay	Season 2002			Season 2003		
	Summer	Rainy	Winter	Summer	Rainy	Winter
Shell color	Green	Yellow-green	Yellow	Green	Yellow- green	Yellow
Flesh color	Light yellow	Yellow	Pale Yellow	Light yellow	Yellow	Pale Yellow
Color L*	64.51^{b}	70.01^{c}	61.37^{a}	61.85^{a}	67.67^{bc}	62.78^{a}
a*	-1.63^{a}	-0.39^{b}	-0.14^{b}	-0.95^{b}	0.00^{bc}	0.32^{c}
b*	22.19^{a}	33.20^{c}	32.07^{c}	27.00^{b}	34.27^{c}	25.87^{a}
Chroma	22.26^{a}	33.22^{c}	31.57^{c}	27.04^{b}	34.28^{c}	25.87^{a}
Hue angle	94.34^{c}	90.75^{bc}	90.33^{ab}	92.09^{c}	90.03^{ab}	88.05^{a}
Texture (N)	11.18^{b}	11.18^{b}	10.63^{b}	8.54^{a}	8.95^{a}	10.13^{a}
Total soluble solids(%)	12.53^{a}	12.60^{a}	14.56^{b}	12.44^{a}	14.53^{b}	15.35^{c}
Titratable acidity (g citric acid/100g f.w.)	0.48^{a}	0.49^{a}	0.67^{c}	0.59^{b}	0.51^{ab}	0.65^{c}
TSS: TA ratio	31.09^{c}	29.74^{bc}	22.50^{a}	21.15^{a}	30.47^{c}	24.50^{b}
pH	4.28^{c}	3.54^{b}	3.19^{a}	4.03^{c}	3.78^{b}	3.79^{b}
Taste	Sweet	Sweet-slightly sour	Sweet-sour	Sweet	Sweet-slightly sour	Sweet-sour

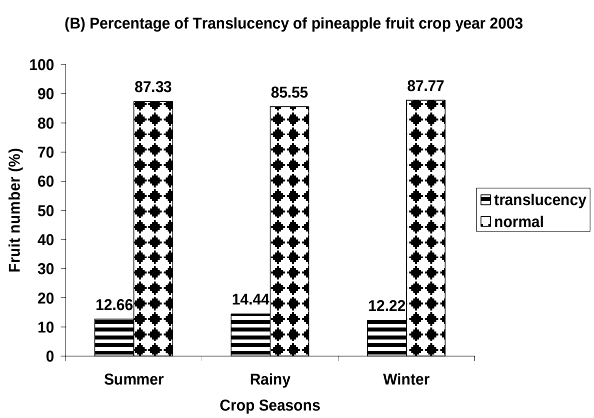
f.w. = fresh weight; Sample harvested at 130 days after full bloom; Different letters in the same row indicate significant differences, P≤0.05

more intense than in the summer and winter ones, although no significant differences were detected in flesh carotenoid content. The a* value in the winter and rainy harvested crops were higher than the summer harvested crop during harvesting time 110 - 140 DAFB in both years (data no show). The a* value of pineapple flesh from all cropping seasons were increased during ripening to senescence.

Flesh translucency. Pineapple fruit with flesh translucency detected in fruits harvested at 120 DAFB when the fruit mature with acceptable quality. They were no incident of transluscent fruit in harvest before 110 DAFB. The fruit is fully mature with the highest sensory quality at 130 DAFB. The incident of fruit translucency was increase to about 10% to 20% (Fig. 3). The increase of flesh translucence might have occurred 140 DAFB, which is 20 days after harvesting date. However, there was no increase in percentages of translucent from the fruit that were prolonged on the field until 160 DAFB. These data supported the previous study by Srisang (2002) on the effect of fruit age in relation to the percentage of translucency. It was found that in the winter harvested crop, the percentage of fruit translucency was 11% at harvesting date and increase to 22% after one week in the field but no increase after 3 weeks of prolongs harvesting. Therefore, the translucent flesh may not be concomitant with ripening fruit because this attribute was not increased when the ripening stage progressed. In this experiment, the percentage of translucent fruit average from each crop season was not significant differences. Although many attempts have been conducted in studying of factors related to pineapple fruit translucence. However, relationships between preharvest environmental factors and fruit translucence does not exist (Paull & Reyes, 1996; Chen & Paull, 2000; Chen & Paull, 2001).

Fig. 3. Percentage of translucency and normal fruit of all crops for the year 2002 and 2003





Flesh firmness. The flesh firmness declined during fruit maturation. During harvesting time at 110 - 130 DAFB the flesh firmness of all part and position of late crop declined to lower value than other crops in both years (Table II & III). After fruit harvested at 130 DAFB the flesh firmness began to loose and its fiber tended to resist to the puncture force and caused the measurable firmness to increase until overripe. Therefore, after ripe the texture of the flesh become more tough. Firmness of inner and middle position of all part of summer harvested fruit decreased until the 3 rd harvest, which was 130 DAFB and the fruit were fully ripe (Table II & III), while in winter and rainy crop the firmness decline more rapidly within the 2nd harvest at 120 DAFB. For inner position the fruit firmness already decline to the minimum point at first harvest. The rapid in decreasing in firmness of winter harvested crop may indicate that the crop was mature and ripe sooner than other crop. The flesh firmness of outer position of all parts in winter harvest fruit declined prior to rainy and summer harvested crop in both years. Fruit of winter harvested crop developed during high temperature during the monthly of July to November. The high temperature may hasten fruit ripening. Flesh firmness at inner and outer positions of the basal, central and top was higher than the middle. The flesh texture of inner and outer positions were hard become they are different in structure of parenchyma tissues near inflorescence axis (Okimoto, 1948) and shell structure, respectively. The firmness of middle positions was low because the tissue was homogeneous and composed of fruitlet, which is fleshy ovary and sepal tissue. The flesh firmness of basal part was lower than others due to the pineapple fruit comprises of many fruitlets where maturity gradient exist within fruit. Fruitlet in the lower portion of the fruit are more mature than the upper portion (Tay, 1977; Ramlah, 1981; Abdullah & Rohaya, 1997) and trend to be ripe faster than others (Miller & Hall, 1953). Although the flesh firmness values were varied within each part and position but it was interesting to note that the firmness value variation was lowest at the middle of the fruit as indicated by the SD value (Table II & III). Therefore, the middle position could be the best position to represent the precise measurement of firmness of the fruit.

Table II. Flesh firmness of all parts and positions of pineapple fruit crop year 2002

Crop	Stage	Basal			Central			Top		
		Inner	Middle	Outer	Inner	Middle	Outer	Inner	Middle	Outer
Summer	110 D	13.85^{h}	12.79^{h}	21.49^{f}	14.00^{f}	12.95^{j}	18.99^{f}	15.56^{f}	14.06^{h}	19.11^{g}
	120 D	13.44^{gh}	11.40^{fg}	14.80^{d}	12.60^{de}	12.35^{i}	15.42^{e}	13.54^{e}	13.06^{g}	16.56^{f}
	130 D	11.83^{e}	10.99^{f}	11.86^{c}	12.22^{cd}	11.18^{g}	12.48^{c}	12.54^{d}	11.68^{f}	12.04^{e}
	140 D	11.41^{de}	9.78^{bc}	9.62^{ab}	10.08^{a}	9.61^{bc}	10.24^{ab}	10.41^{ab}	9.91^{bc}	9.63^{abc}
	150 D	10.87^{bcd}	9.99^{cd}	9.14^{a}	9.98^{a}	9.71^{cd}	10.10^{ab}	10.11^{a}	9.95^{bc}	10.10^{bcd}
	160 D	11.35^{de}	9.91^{cd}	9.32^{a}	10.16^{a}	9.85^{cd}	9.63^{ab}	10.63^{abc}	10.52^{de}	10.18^{bcd}
Av. SD		±3.26	±2.90	±3.15	±1.83	±1.67	±4.17	±2.57	±1.86	±4.33
Rainy	110 D	13.15^{g}	14.24^{i}	26.78^{g}	13.09^{e}	13.30^{j}	22.87g	19.36^{g}	14.04^{h}	21.44^{h}
	120 D	12.31^{f}	11.06^{f}	17.78^{e}	11.84^{c}	10.52^{ef}	12.74^{c}	12.71^{de}	10.64^{de}	11.98^{e}
	130 D	10.97^{cd}	9.26^{a}	11.88^{c}	9.83^{a}	9.18^{ab}	10.21^{ab}	10.68^{abc}	8.79^{a}	9.10^{ab}
	140 D	10.77^{bc}	8.96^{a}	11.35^{c}	9.90^{a}	8.98^{a}	9.98^{ab}	9.98^{a}	8.40^{a}	8.82^{a}
	150 D	9.98^{a}	9.39^{ab}	17.45^{e}	9.71^{a}	9.11^{a}	12.17^{c}	10.46^{abc}	8.37^{a}	10.33^{cd}
	160 D	12.43^{f}	10.17^{cde}	15.04^{d}	10.73^{b}	9.42^{abc}	10.38^{ab}	11.41^{c}	9.64^{b}	9.17^{ab}
Av. SD		± 1.46	± 2.01	± 6.35	± 1.51	± 1.72	± 4.83	± 3.71	± 2.33	± 4.75
Winter	110 D	10.88^{bcd}	11.81^{g}	14.17^{d}	10.95^{b}	11.76^{h}	13.97^{d}	12.98^{de}	11.00^{e}	12.20^{e}
	120 D	11.06^{cd}	10.49^{e}	12.22^{c}	12.45^{d}	10.16^{de}	10.69^{b}	12.62^{d}	10.30^{cd}	10.98^{d}
	130 D	10.39^{ab}	10.36^{de}	11.13^{bc}	11.76^{c}	10.63^{f}	9.92^{ab}	10.92^{abc}	9.98^{bc}	10.07^{bcd}
	140 D	11.17^{cd}	10.23^{cde}	10.50^{abc}	11.75^{c}	9.78^{cd}	9.49^{a}	11.26^{bc}	9.48^{b}	9.46^{abc}
	150 D	-	-	-	-	-	-	-	-	-
	160 D	-	-	-	-	-	-	-	-	-

Table III. Flesh firmness of all parts and positions of pineapple fruit crop year 2003

Crop	Stage	Basal			Central			Top		
		Inner	Middle	Outer	Inner	Middle	Outer	Inner	Middle	Outer
Summer	110 D	18.05^{i}	14.18^{h}	28.18^{def}	19.83^{e}	15.77^{f}	27.69^{g}	25.38^{h}	17.56^{h}	26.93^{h}
	120 D	12.10^{def}	10.04^{f}	3.33^{f}	12.70^{d}	10.42^{de}	20.32^{f}	13.81^{g}	11.30^{g}	20.48^{f}
	130 D	10.69^{a}	8.31^{ab}	22.04^{bc}	10.81^{abc}	8.45^{a}	12.56^{b}	11.77^{cdef}	9.20^{bc}	11.25^{a}
	140 D	12.23^{ef}	8.56^{b}	20.52^{b}	11.54^{c}	8.70^{a}	10.98^{a}	12.13^{ef}	9.16^{bc}	14.59^{bcd}
	150 D	12.08^{def}	8.09^{a}	29.10^{def}	11.19^{bc}	8.74^{a}	14.81^{d}	11.59^{cdef}	8.77^{ab}	14.99^{cd}
	160 D	-	-	-	-	-	-	-	-	-
Rainy	110 D	12.91^{g}	9.83^{ef}	34.27^{g}	11.80^{cd}	9.98^{cd}	20.70^{f}	11.54^{bcdef}	8.87^{ab}	17.92^{e}
	120 D	12.53^{fg}	9.26^{d}	26.96^{d}	21.15^{f}	8.94^{ab}	16.89^{e}	11.34^{bcde}	10.75^{f}	15.61^{d}
	130 D	11.89^{cde}	8.74^{bc}	27.58^{def}	10.81^{abc}	8.95^{ab}	15.46^{d}	10.97^{bc}	8.56^{a}	13.75^{bc}
	140 D	11.10^{ab}	8.74^{bc}	24.02^{c}	9.82^{a}	8.92^{ab}	15.46^{d}	9.36^{a}	8.60^{a}	14.29^{bcd}
	150 D	11.55^{bcd}	8.29^{ab}	24.47^{c}	10.11^{ab}	8.62^{a}	15.37^{d}	9.63^{a}	8.36^{a}	14.14^{bcd}
	160 D	12.11^{def}	9.11^{cd}	29.68^{def}	11.20^{bc}	9.33^{b}	18.02^{e}	11.00^{bcd}	8.80^{ab}	14.16^{bcd}
Winter	110 D	13.71^{h}	10.76^{g}	28.88^{def}	12.79^{d}	10.53^{e}	14.38^{d}	12.35f	9.93^{de}	13.98^{bcd}
	120 D	14.01^{h}	10.31^{f}	27.35^{de}	12.96^{d}	10.01^{cd}	14.97^{d}	11.62^{cdef}	9.69^{de}	14.18^{bcd}
	130 D	12.61^{fg}	10.14^{f}	29.88^{ef}	11.42^{c}	10.13^{cde}	12.97^{bc}	11.16^{bcd}	9.56^{cd}	13.13^{b}
	140 D	11.36^{bc}	9.49^{de}	22.60^{bc}	11.41^{c}	10.14^{cde}	14.46^{d}	10.76^{b}	9.83^{de}	13.85^{bcd}
	150 D	12.58^{fg}	9.87^{ef}	16.49^{a}	11.06^{bc}	9.90^{c}	14.00^{cd}	10.96^{bc}	9.90^{de}	15.67^{d}
	160 D	12.92^{g}	10.86^{g}	29.60^{def}	11.89^{cd}	10.20^{cde}	14.90^{d}	11.82^{def}	10.16^{e}	24.28^{g}

Chemical attributes. TSS of flesh in all harvests increased a week before ripening at 120 DAFB and slightly increased compared to fruits harvested at 130 DAFB to 160 DAFB. TSS of the winter harvested crop was higher than the summer and rainy harvested crops in both years (Table I). TSS of fruit harvested in rainy harvested crop of year 2002 was lower than crop of year 2003. Incident of high rainfall in May was a month before harvesting in crop year 2002 may reduce TSS content. Bartholomew and Paull (1986) reported that the TSS content of fruit related to the light levels during fruit maturation. They pointed out that the fruit initiated in the late summer when the temperature is high will be large in size. Because it matures through winter when light intensity is substantially reduced. The final TSS of fruit will be low. Fruit with the highest TSS were initiated in winter, giving a small fruit, but matures through spring and early summer when light level are high, giving a large production of TSS. Compared with our results, the solar radiation during crop development of summer harvested crop fruit was lowest in the both years (2293.5 MJ mm^{-3}, 2376.05 MJ mm^{-3}) compare to solar radiation in the rainy and winter harvested crop (3005.1 MJ mm^{-3}, 2802.4 MJ mm^{-3} & 2479.9 MJ mm^{-3}, 2752.6 MJ mm^{-3}) (Joomwong & Sornsrivichai, 2005). The summer harvested crop fruit also matured during lower temperatures compared to other crop, which may have caused the summer harvested crop to show low TSS content at harvest period. Although during development of the rainy harvested crop, the solar radiation level was the highest but the day temperature during fruit development was also very high (37 - 38ºC) which may modulate the TSS levels during various seasons. Acidity expressed as grams of citric acid per 100 g fresh weight, similar to TSS, fruit harvested in winter harvested crop was higher than harvested in summer and rainy harvested crops (Table I). The high acid content of the winter harvested crop may due to the decrease in temperatures on field during harvest. Similarly, high acid content of the winter harvested crop were reported by Smith (1984). Titratable acid in all crops did not significant decrease during 60 days of harvesting period. The TSS and acid content are the factors influence consumption quality. Smith (1988a, b) reported that TSS show the highest correlation with the eating quality among nine parameters tested. However, the significant correlation occurs only with the fruit harvested in early crop with TSS above 14%. Although the late crop in our experiment had high TSS than others, it also contained high level of TA, which cause reduce the TSS:TA ratio (Table I) and gave sour taste and the panelist trend leading to lower eating quality (acceptability) than regular crop (data not shown). However, TSS:TA ratio of all crop were not below 22 (Table I). Singleton and Gortner (1965) point out the fruit sample having TSS:TA ratio higher than 22 - 23 tend to the better received by consumers than those below this average. It showed be noted that the pineapple grow in northern Thailand in subtropical climate, un-like in Australia or Hawaii, the temperature in cool season was not below 15ºC. Therefore the average TSS of all crop were not much different and above 12% and acceptable in range around scale 6, except the summer harvested crop fruit, which developed during cool season, show less sweet resulted in flat taste, while winter harvested crop showed sour taste, thereby causing inferior taste than the rainy harvested crop. Rainy harvested crop had less acid and gave highest TSS:TA ratio and also showed to better eating quality. The pH value increased with maturity but no significant differences. The pH value in of three harvested crops was ranging from 3.4 - 4.5, which corroborated the report of Teisson and Pineau (1982). The pH value in winter harvested crop was lower than other crops agree with total titratable acidity of each crop (Table I). The results from our experiment, total sugars content of pineapple fruit harvested in the rainy harvested crop in the year 2004 was 13.84 - 16.63% compared to 15% of the summer harvested crop and 11% in the winter harvested crop of pineapple grown in Australia (Leverington, 1968). The total sugar in our experiment composed of 9.2 - 11.76% sucrose, 2.13 - 3.24% fructose and 2.11 - 2.88% glucose. The proportion of sucrose, fructose and glucose were 5.5: 1.3: 1.1 (Dull, 1971; Wills *et al*., 1998; Chen & Paull, 2000). During pineapple fruit development, glucose and fructose are the predominant sugars until 6 week before harvesting sucrose begin to accumulate rapidly and ultimately exceeded the glucose and fructose concentration. Glucose and fructose remained relatively constant throughout development (Morris & Arthur, 1984; Chen & Paull, 2000). In this experiment, sucrose accumulation was higher than fructose and glucose during harvested time.

Table IV. Moisture content (%) and crude fiber (%) of pineapple fruit from all crops for the year 2002

Part	Stage (DAFB)	Moisture content (%) Summer	Rainy	Winter	Crude fiber (%) Summer	Rainy	Winter
Basal	110	94.97^{f}	91.61^{e}	87.67^{bcd}	0.357^{abcd}	0.330^{abc}	0.386^{d}
	120	90.29^{de}	88.54^{bcde}	86.58^{bcd}	0.360^{abcd}	0.335^{abc}	0.376^{cd}
	130	89.37^{cde}	87.82^{bcd}	86.24^{abc}	0.378^{cd}	0.331^{abc}	0.355^{abcd}
	140	89.06^{cde}	87.72^{bcd}	85.13^{ab}	0.312^{a}	0.336^{abc}	0.324^{ab}
	150	88.87^{bcde}	87.03^{bcd}	-	0.311^{a}	0.321^{a}	-
	160	83.05^{a}	83.03^{a}	-	0.372^{bcd}	0.343^{abcd}	-
Central	110	96.02^{i}	92.05^{h}	89.53^{defgh}	0.335^{abc}	0.336^{abc}	0.359^{cd}
	120	91.12^{gh}	88.93^{cdefg}	87.56^{bcde}	0.382^{d}	0.307^{a}	0.364^{cd}
	130	90.59^{fgh}	88.45^{cdefg}	87.20^{bcd}	0.383^{d}	0.308^{a}	0.338^{abc}
	140	90.26^{fgh}	88.72^{cdefg}	86.82^{bc}	0.325^{abc}	0.335^{abc}	0.312^{ab}
	150	90.01^{efgh}	85.61^{b}	-	0.309^{a}	0.310^{a}	-
	160	84.43^{a}	88.00^{bcdef}	-	0.353^{bcd}	0.332^{abc}	-
Top	110	96.24^{g}	92.25^{h}	89.72^{def}	0.389^{bcd}	0.344^{abcd}	0.404^{d}
	120	91.82^{gh}	89.51^{cdf}	89.24^{bcd}	0.388^{bcd}	0.321^{ab}	0.378^{bcd}
	130	91.40^{gh}	89.03^{bcd}	88.49^{bcd}	0.392^{cd}	0.337^{abc}	0.384^{bcd}
	140	91.32^{gh}	88.78^{bcd}	88.14^{b}	0.327^{abc}	0.352^{abcd}	0.341^{a}
	150	90.81^{fg}	88.23^{bc}	-	0.342^{abcd}	0.326^{abc}	-
	160	86.47^{a}	88.25^{bc}	-	0.359^{abcd}	0.389^{bcd}	-
All	110	95.74^{i}	91.97^{h}	88.97^{def}	0.361^{bcd}	0.337^{ab}	0.383^{d}
	120	91.08^{gh}	88.99^{def}	87.79^{bcd}	0.377^{cd}	0.321^{a}	0.373^{cd}
	130	90.45^{fg}	88.43^{cde}	87.31^{bc}	0.385^{d}	0.325^{a}	0.359^{bcd}
	140	90.21^{fg}	88.41^{cde}	86.70^{b}	0.321^{a}	0.341^{ab}	0.326^{a}
	150	89.89^{efg}	88.96^{bc}	-	0.319^{a}	0.319^{a}	-
	160	84.65^{a}	86.43^{b}	-	0.362^{bcd}	0.355^{bc}	-

Crude fiber. The average crude fiber content was 0.33 mg 100 g^{-1} fresh weight (Table IV) and not significant different in all crops. This result for crude fiber was similar to those of Akamine (1976), Nakasone and Paull (1998) and Smith (1993). The difference in method used may affect crude fiber content.

Moisture content. The moisture content of pineapple fruit was not significant difference in all harvests. The average moisture content was 88 to 90% (Table IV) that agree with previous reported Salunkhe and Desai (1984) and Smith (1993). The moisture content of pineapple flesh showed high values in all crops.

CONCLUSION

In the winter harvested crop, total chlorophyll of peel decreased, while carotenoids of peel increased faster than other crops. Although flesh carotenoids of different cropping seasons were not different, they were different in b* and chroma values. The percentages of fruit translucency in different cropping seasons were not much different and it did not increase in the ripen fruit after 140 DAFB. The flesh firmness of fruit from all cropping seasons was significantly different in all parts and positions and during harvesting time at 110 - 130 DAFB. Flesh firmness of the winter harvest was lower than others. TSS and TSS:TA was the greatest at 120 - 130 DAFB in all crops, indicating that the fruits were ripe. At 120 DAFB, the proportion of sucrose increased 3.5 times to fructose and glucose, which also indicated full maturity of the fruit. TSS and TA in the winter harvested crop were higher than other crops. However, fruit of all crops had TSS values above 12%Brix and TSS:TA ratio was higher than 22. Therefore, pineapples grown in northern district of Thailand had a year round acceptable eating quality. The crude fiber and moisture contents of fruit from all cropping seasons were not significant differences.

Acknowledgements. This work was supported by the Postgraduate Education and Research Development Project in Postharvest Technology under Asia Development Bank (ADB), Chiang Mai University, Thailand. I would like to thank Postharvest Technology Institute, Chiang Mai University, Chiang Mai, Thailand, for providing laboratory facilities.

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(Received 09 December 2005; Accepted 25 February 2006)