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Impact of Cropping Season in Northern Thailand on the Quality of Smooth Cayenne Pineapple I. Influence on Morphological Attributes

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ABSTRACT

In Nortern Thailand pineapple is harvested three times per year in the summer, rainy season and winter. Fruits were harvested 110-160 days after full bloom (DAFB) during different crop seasons in 2002/2003. Significant differences ($P < 0.05$) were found in morphological attributes of fruits from different crop seasons. The crop harvested in summer had the highest fruit weight and the fruit was mainly conical in shape with a rosette crown, while most of fruits harvested in the rainy season and in winter crops were cylindrical and spherical with elongate crowns. A correlation analysis by multiple linear regressions (MLR) showed that the environmental factors that most affect fruit weight amongst the different seasonal crops were night temperature, solar radiation and heat unit. With one, two and three models of MLR analysis the coefficients of determination (R^2) were 0.442, 0.450 and 0.569 respectively. At harvest time of 120 DAFB, fruits of the crop harvested in summer and rainy season were ripe with a sweet taste but the shell color was mostly green for 75-85% of the fruit. The development of shell color was suppressed in the rainy season crop when the crop had superior flesh color and taste, cylindrical to spherical shape, and fruits were appropriate for both fresh consumption and canning. For the crop harvested in winter, shell color of 65-75% of the fruits was yellow but the fruit had inferior flesh color and taste.

Key Words: Pineapple; Crop season; Environmental factors; Fruit shape; Shell color; Quality

INTRODUCTION

According to Food and Agriculture Organization statistics (Baker, 1990; Anonymous, 2002), the leading pineapple producing countries are Thailand, Philippines and Brazil. The pineapple industry is the largest fruit industry in Thailand. The variety of pineapples used in commercial cultivation for fresh fruits as well as for the processing industry is the Smooth Cayenne or Pattawia (Anupunt *et al.*, 2000). Pineapple fruits are consumed locally and exported, especially to Europe, Singapore, Japan and The Middle East. However, the economic production of pineapple from Thailand for export has been limited by inconsistence in quality. There are few definitive data on the effect on climatic factors on inflorescence or fruit development of pineapple (Bartholomew *et al.*, 1977). The rate of fruit growth over time is determined primarily by temperature. After flowering, fruit size increases with increasing sunlight (Monselise, 1986). In two studies pineapple was planted at different times of the year and fruit development was induced with a growth regulator, but it was slow during cool seasons (Moreau & Moreuil, 1976; Smith, 1977). Smith (1977) reported that in South Africa, fruit which developed during cool months were smaller than fruit on plants of comparable size which developed during warm months.

In Hawaii, for the fresh fruit market, the summer crop was harvested when the eyes were pale green. At this season, sugar content and volatile flavors develop early and steadily over several weeks. For winter crop time maturity was delayed by about 30 days, and the fruits were picked when they were slightly yellow at the base (Morton, 1987). In Taiwan, with clear temperature differences between summer and winter, during winter (monthly average 17 °C), fruits harvested were sour and vice versa for summer fruits (Lin & Chang, 2000).

A crop of pineapples can be grown to maturity at any time of the year, with suitable sized of plants, planting time and flower induction, but the physical characteristics and eating quality vary widely with seasons. Thus, it is necessary to characterize and determine the quality changes of pineapple fruits during maturation and harvesting in different growing seasons of the year. In this first paper of the two part series, we report the morphological attributes of pineapple fruits (Smooth Cayenne) cropped at different seasons in year 2002 and 2003.

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 and April 1- May 21, 2003), rainy season (June 22 – July 11, 2002 and June 2 – July 30, 2003) and in the winter (November 2 – December 22, 2002 and November 9 – December 29, 2003). After harvesting, the fruits were transported immediately to The Postharvest Institute Technology laboratory, Chiang Mai University, and prepared for analysis.

Assessment of morphological and physical properties. Size, shape and weight of the fruits were noted (Table I). Crown weight (g), crown size: crown length (cm), crown diameter (cm), crown shape (1 = elongate, 2 = rosette), and fruit shape (1 = spherical (small), 2 = cylindrical (medium) and 3 = conical (big)) were also recorded. The fruit shape was determined as recommended by Bandith (1997). The harvested pineapple fruits were evaluated for shell color score as follows: CS1 = green, CS2 = breaker, CS3 = 25% yellow, CS4 = 50% yellow, CS5 = 75% yellow and CS6 = 100% yellow.

Statistical analysis. Data were statistically analyzed by analysis of variance (ANOVA) and mean separation was by Duncan's multiple range test at $P<0.05$. A multiple linear regression (MLR) analysis was used, to determine the coefficients of determination (R^2) of the correlation model using 1 to 3 environmental factors.

RESULTS AND DISCUSSION

Fruit weight. Fruit weight increased during the first 2-3 weeks before harvesting (Fig. 1a-e). Bartholomew *et al*. (2003) reported that the growth pattern of pineapple fruit was a sigmoid curve. Nakasone and Paull (1998) showed that after the inflorescence is initiated, the weight of the fruit and its components increase in a sigmoid pattern. There were significant differences in weight of fruit growing in different seasons ($P<0.05$). Growth of the summer fruit continued until the final harvest and had the heaviest fruits (Fig. 1), while growth and ripening of the winter crop took less time and fruits were lightest. During the harvesting period of 50 days between 110-160 DAFB, fruit of rainy season and winter crop reach a final size between 120 and 130 DAFB with average fruit weights of 1,197.93 and 1,207.37 g., whilst the fruit weight of the summer crop, at the final harvest date, increased to an average of 1,766.54 g (Fig 1a, e).

Fig. 6 shows variation in the environmental conditions among the 3 different seasons of year 2002/2003. Environmental variables related to fruit weight are shown in Table II. In the summer crop, during fruit development, the average day and night temperatures were lower (T_{day} 33°C, T_{mean} 20°C) than in the other seasons (T_{day} 38°C, T_{mean} 30°C), which is optimum factors for the photosynthesis of pineapple mother plants and affect fruit development, resulting in heavier fruits. In the rainy season and winter crops, the average day and night temperatures were higher than for the summer crop, which may reduce accumulation of photosynthates in the pineapple mother plant. The crop harvested in the summer was developed in cool months and vice versa (Fig. 6). This seasonal pattern caused delayed maturity in the summer crop, while the winter crop ripened quickly but had smaller fruit size. Varying growth pattern in different cropping seasons is different from pineapple cultivation in South Africa and Hawaii (Smith, 1977; Morton, 1987), where the winter pineapple crops developed during cold temperatures shows delayed maturity. Friend (1981) reported that plants grown at 30°C night temperatures were smaller than those grown at cooler night temperatures. Bartholomew (1982) also showed that pineapple plants grown in controlled environments, having night temperature of 26°C or less, are heavier than in environments having 30°C night temperatures. Hepton *et al* (1993) and Hepton (2003) pointed out that where temperatures are high, pineapple mother plants have increased numbers of leaves, which affects food storage in the stem and causes decreased fruit weight and yield.

Table I. The fruit shape was determined by ratio of base and top diameter and fruit length

Shape	*∅Top: ∅Base of fruit*	*Fruit length: ∅Base of fruit*
Spherical (small)	More than 0.965	Less than 1.321
Cylindrical (medium)	More than 0.965	More than 1.321
Conical (big)	Less than 0.965	More than 1.321

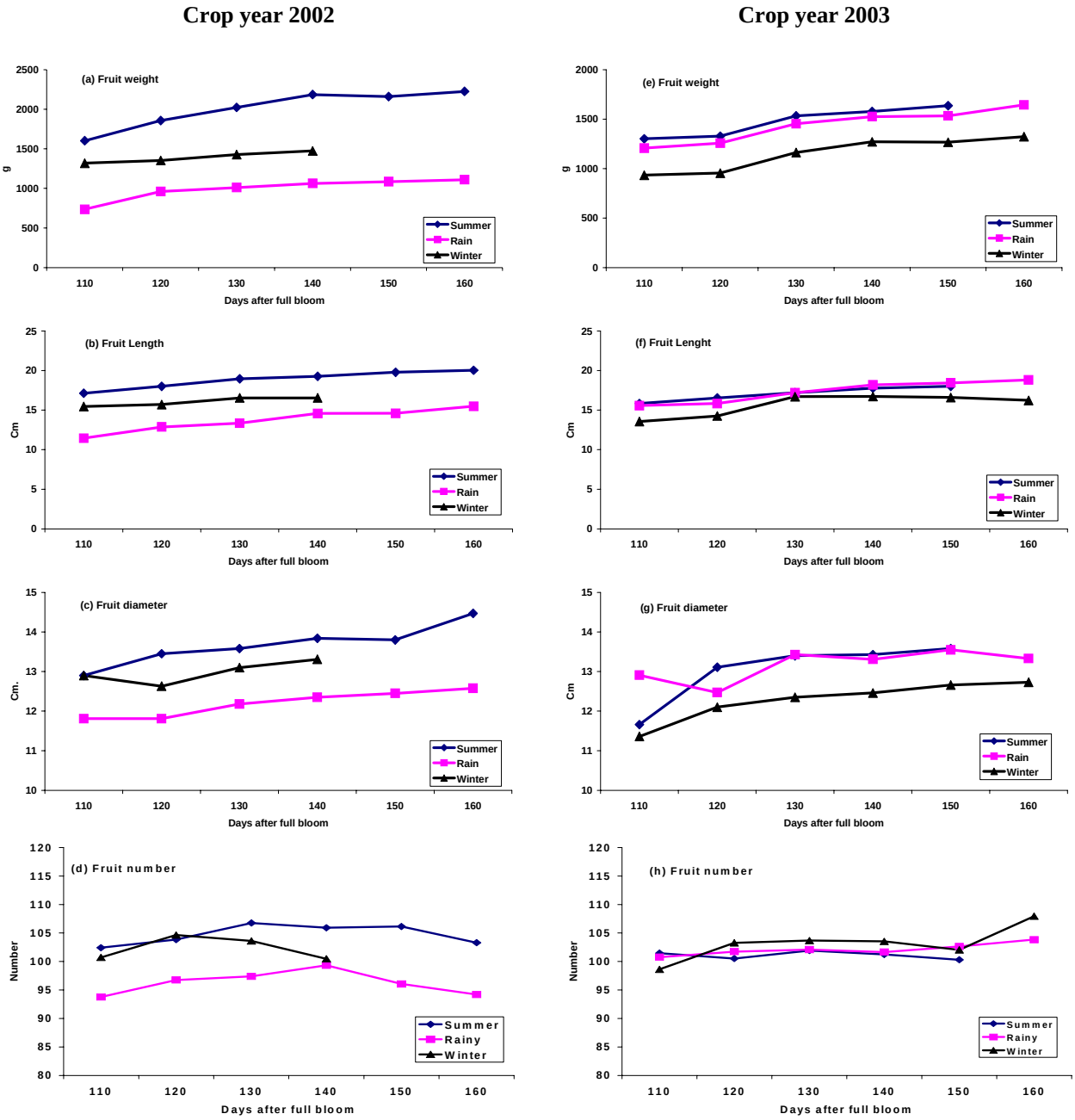
A regression model showed that night temperature showed better correlation than solar radiation and heat unit with fruit weight using a multiple linear regression model between temperatures (Table II). Solar radiation and heat unit variables showed the coefficients of decision (R^2) of 0.442, 0.450 and 0.569 respectively.

Bartholomew and Malezieux (1994) showed that in cases of drought or heavy rainfall during fruit development, pineapple fruit growth decreases. Drought directly causes a decrease in fruitlet enlargement and fruit weight, while heavy rainfall stops root growth, which may decrease photosynthesis of pineapple mother plants. In this study, there was little rainfall during fruit development of the rainy season crop and heavy rainfall before harvesting of the winter crop (Fig. 6). Such precipitation pattern may reduce fruit size of both rainy season and winter crops.

Fruit length and fruit diameter. Fruit length and fruit diameter of pineapple from each crop increased during first and second harvesting dates of 110-120 DAFB (Fig. 1b, c, f & g) and there was no significant increase in length and diameter of the fruit thereafter. The summer season crop had heaviest fruits. Consequently, the crop also had highest fruit length and fruit diameter compare to crops from the other seasons.

Fruit shape. In both years, the shapes of fruit (i.e. conical, cylindrical and spherical) were significantly different in all crop seasons. During summer season of year 2002, fruit with conical shape were 61.1% of the total while shape in the rainy and winter season crops were 100% and 67.5%

Fig. 1. Fruit weight, fruit length, fruit diameter and crown weight of pineapple fruits grown in summer, rain season and winter 2002 and 2003.



spherical respectively (Table III). The fruits with conical shape had higher fruit weight than spherical shape (Fig. 3).

A cylindrical fruit shape is the dominant character of the Smooth Cayenne variety (Bartholomew, 1977).

However, in our experiments, the percentages of fruit with spherical shape were higher than the other shapes in the rainy season and winter crops. In the rainy season and winter crops during fruit development, the average day and night temperature were higher than in other season and light intensity was low during rainy season. This may reduce fruit size and increase the percentage of fruit with a spherical shape. The incidence of heavy rain, during fruit development in May, 2002 caused all the fruits to develops into a spherical shape with lower weights 1,500g (Fig. 6).

Fruitlet number. The total fruitlet number of pineapple fruits was not significantly different in the summer, rainy season, and winter crops of both the years. The range of fruitlet number was about 99 to 105 per fruit. Fruitlet number per fruit was established at induction, which thereafter determined fruit growth and final size. The

Fig. 2. Crown weight, crown length, and crown diameter of pineapple fruits grown in summer, rainy season and winter 2002 and 2003.

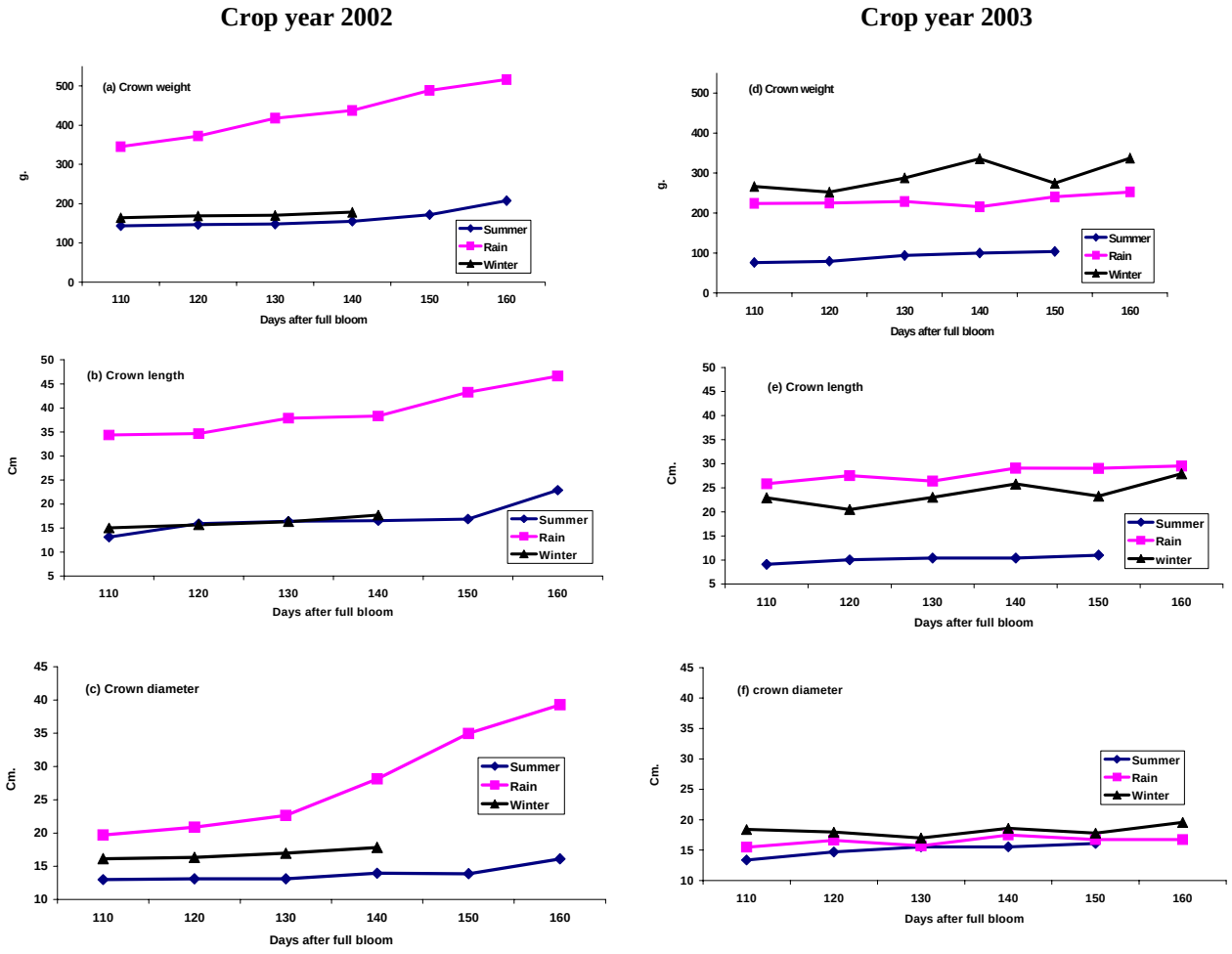
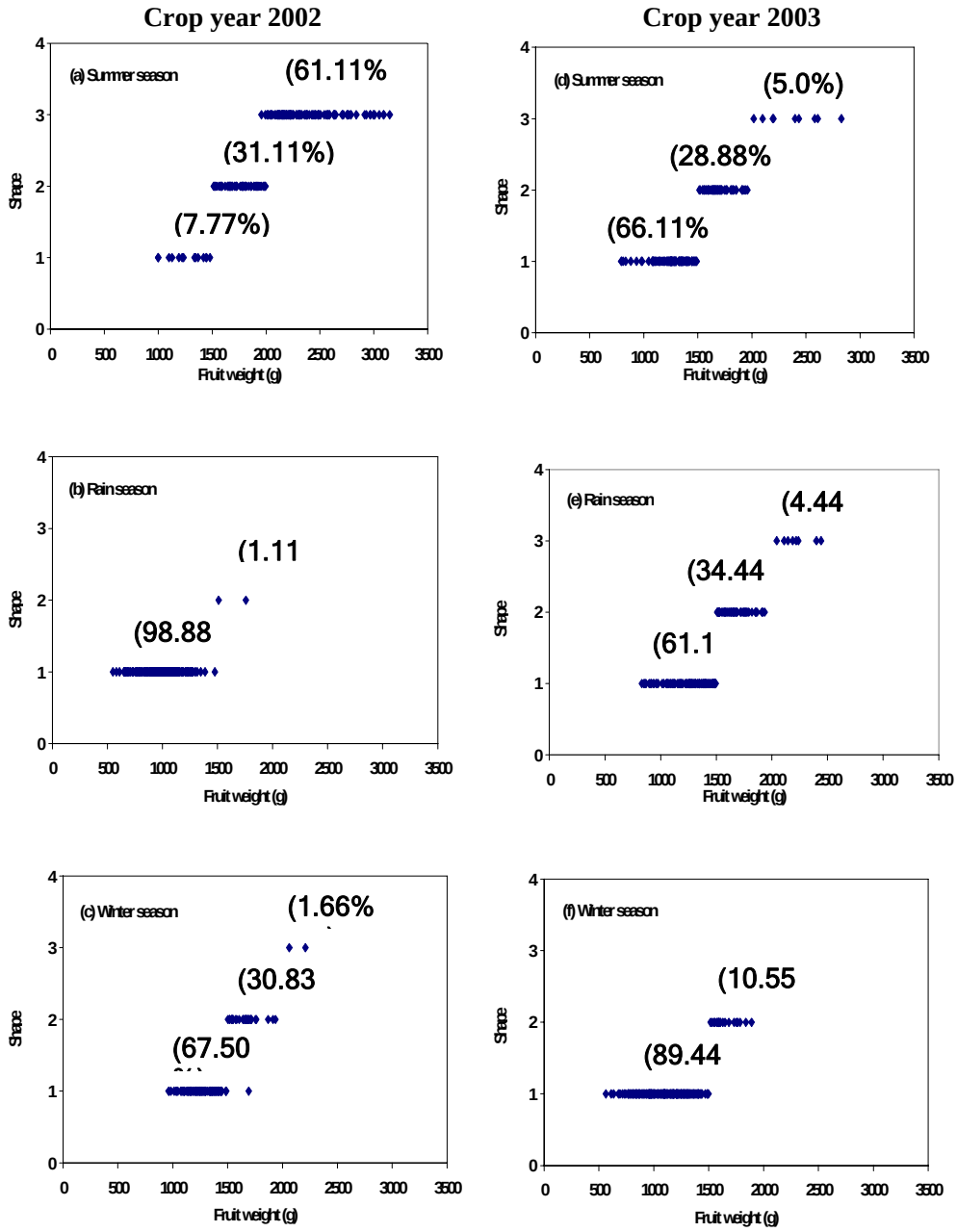


Table II. Environmental factors affected pineapple fruit crop and it's R^2 of multiple linear regression to fruit weight of different seasons during year 2002/2003

Crops	*Temperature (T)*				*Solar radiation (S)*		*Heat unit*	*Average Rainfall*
	T_{day} (°C)	T_{night} (°C)	T_{mean} (°C)	St* (mm/day)	S_{to}+ ($Jm^{-2}day^{-1}$)	S_{to} ($MJmm^{-3}$)	(CDD)	(mm)
2002Summer	33.8	20.9	26.4	6.20	939.3	2293.5	2953.6	276.4
Rain	38.2	24.4	30.3	8.31	1230.5	3005.1	3455.6	436.0
Winter	35.6	26.7	30.5	6.91	1015.5	2479.9	3462.1	610.3
2003Summer	34.3	21.3	26.9	6.80	973.0	2376.0	2847.4	172.5
Rain	37.5	23.8	29.6	8.14	1147.6	2802.4	3197.2	233.2
Winter	36.0	26.8	30.8	7.09	1127.1	2752.6	3784.7	782.6
Multiple linear regression (MLR) of fruit weight	Model 1, R^2 (T night, solar radiation (s_{to}+) $^{\#}$= (0.442)							
	Model 2, R^2 (T night, solar radiation (s_{to}+), heat unit)$^{\#}$ = (0.450)							
	Model 3, R^2 (T night, solar radiation (s_{to}+)and (St*), heat unit)$^{\#}$ = (0.569)							

T_{day} = 0.5 (T max + T min) + (T max – T min)/3π
T_{night} = 0.25 (T max + 3T min)
T_{mean} = (T day + T night)/2
R^2 = coefficients of determination, # =environmental factors affected the fruit weight
Different letters in the same row indicate significant differences, $P \angle 0.05$

Fig. 3. Relation of fruit weight and fruit shape of pineapple and percentage of fruit shape distribution. Shape 1: sphere (small), 2: cylinder (medium) and 3: conical (large)
(a) summer season, (b) rain season, and (c) winter season of crop year 2002
(d) summer season, (e) rain season, and (f) winter season of crop year 2003



number of florets varied considerably with the variety of pineapple, the size of the pineapple mother plant at induction, plant population density, and the quality of forcing (Bartholomew, 1977; Wee & Rao, 1979).

Crown weight and length.. Crown weight and its length in the summer season crop was significantly lesser than that of rainy season and winter crops (Fig. 2a, b, d & e). Most of all crowns in summer crop were rosette and crown in rain and winter crop were elongated normal (Fig. 5). The crown is composed of a bunch of leaves, which morphologically behaves like vegetative leaves. Growth of the crown follows a sigmoid pattern, the same as in the fruit. Crown growth increases about 30-45 days after fruit growth commences. The crown has been reported to have no direct effect on the

development of the fruit, although crown removal early in fruiting leads to greater fruit weight (Paull, 2000).

Shell color. The shell color of pineapple fruit changes from green to yellow (color score 1 to 6) during maturation (Fig. 4a, d). Fruit began to change color at 120 DAFB, but the change pattern of shell color depends on growing season. In summer crop, at harvesting date of 120 DAFB, when the fruit is ready for consumption, 85% of fruits still green (Fig. 4b, e). In contrast 40% of fruit of winter crop had changed to color score 3 (two lower row of eyes became yellow). At the optimum harvesting date 130 DAFB (Fig. 4c, f) more than 75% of the summer crops were ripe with green shells (color score 1 and 2), while percentage of winter fruits were yellow (color score 3 – 4) (Fig. 4c, f).

High night temperatures during summer season delayed change in shell color. The night temperature of the summer crop in 2002 and 2003 was as high as 31°C and 23°C respectively, while the winter crop night temperature in those years was on average lower than 23°C and 15°C. Low night temperature especially in year 2003 caused rapid color change of the fruit and most fruits were 75% yellow (color score 5) compared to the year 2002 which show higher night temperature and caused 70% of the fruits to show at the breaker stage (color score 2) at harvesting time (Fig. 4b, c). Smith (1984) reported that the degree of skin yellowness (skin color) present at optimum ripeness varies

Fig. 4. Average shell color score changes during the harvesting period in summer, rainy season and winter crops of year 2002 (a) and 2003 (d) and percentage of pineapple fruit with different color score when harvested at 120 DAFB and at 130 DAFB of year 2002 (b, c) and 2003 (e, f).
Color score (CS): CS1 = green, CS2 = breaker, CS3 = 25% yellow, CS4 = 50% yellow, CS5 = 75%yellow, CS6 = 100% yellow.

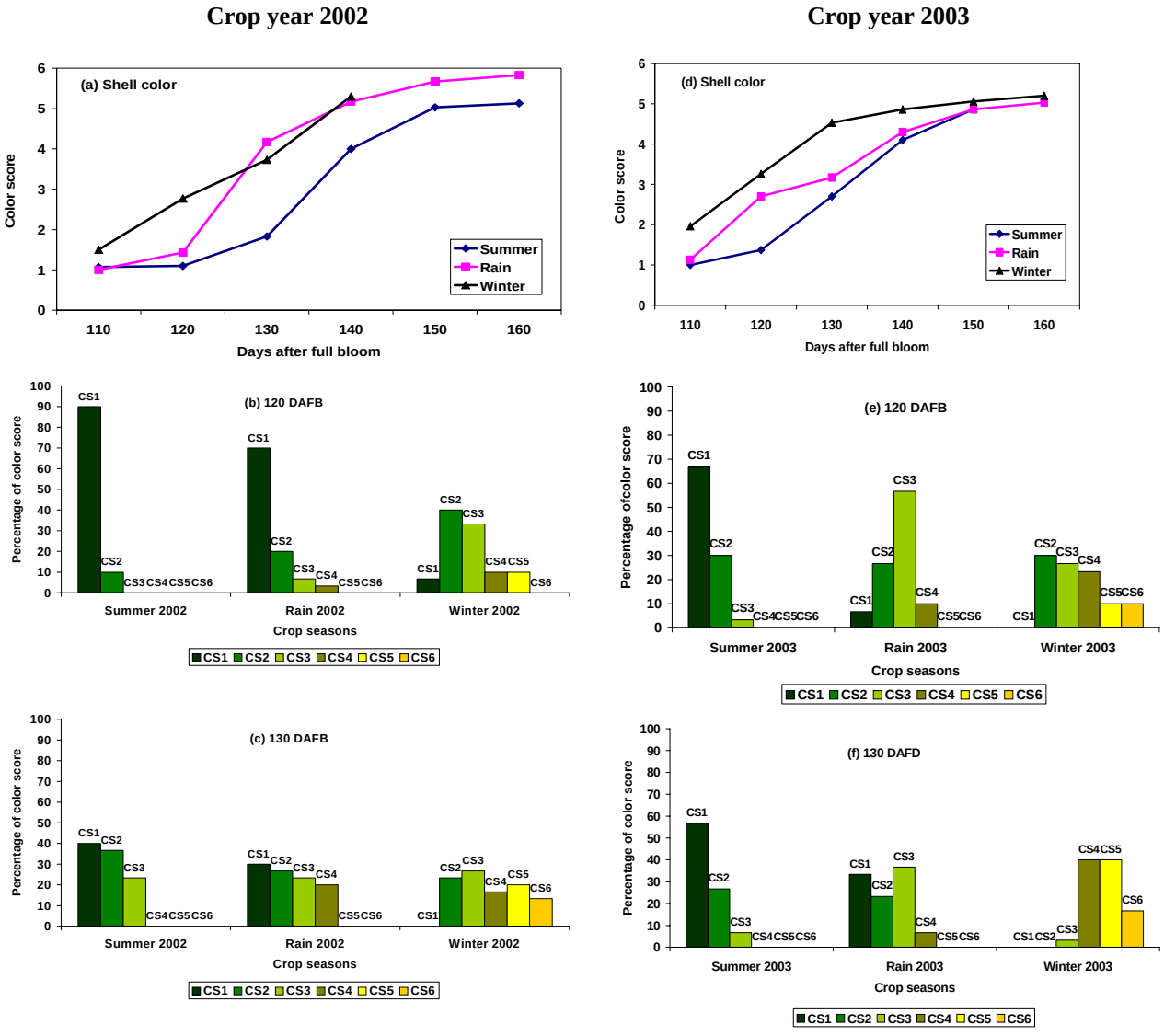


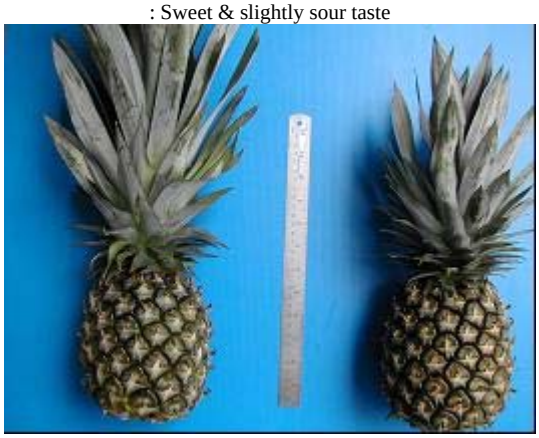
Fig. 5. Characteristics of pineapple fruit of cropping seasons.

(A) Summer crop

: Conical shape
: Rosette crown
: Green shell, light yellow flesh
: TSS 11.16- 13.45 ° Brix
: Low acid, high pH
: Slight sweet taste

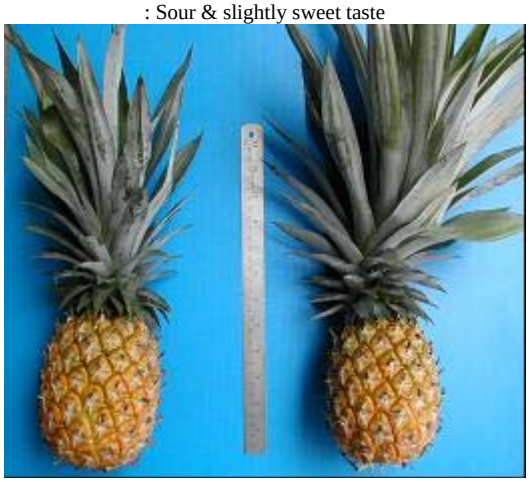
(B) Rain crop

: Cylindrical shape
: Elongate crown
: Green shell, yellow flesh
: TSS 9.99 – 15.44° Brix
: High acid, low pH
: Sweet & slightly sour taste



(C) Winter crop

: Spherical shape
: Elongate crown
: Yellow shell, pale yellow flesh
: TSS 13.35 – 15.72° Brix
: High acid, low pH
: Sour & slightly sweet taste



with season, rainfall, microclimate and field aspect. At various times of the year, the flesh of fruits with a dark green skin can be over-ripe, and at other times completely yellow fruits can be underripe.

Fig. 4 shows the pattern of shell color change in the second year (2003). Comparing the rate of color change of winter crop season year 2002 and 2003, the winter crop 2003 changed color more rapidly than the previous year. Incidence of rain during harvesting period may be the cause of delay in color change of first year winter crop. Although most of the winter crop change the shell color at harvesting, but the flesh quality was not developed (Table III). The flesh of winter crop showed inferior quality when ripe. Their flesh was pale yellow and had sour-sweet taste (Fig. 5c). At the same time rainy crop showed the best flesh quality by showing intense yellow flesh and sweet taste (Fig. 5b), although there were no significant difference in TSS among different season crops, the summer crop also showed inferior flesh quality because the fruit had light sweet taste and low acid content (Fig. 5a).

Fig. 6. Total rainfall (mm.), relative humidity (%), maximum and minimum temperature (°C) during flowering induction, fruit development and harvesting of summer, rain, and winter crop during year 2002 and 2003.

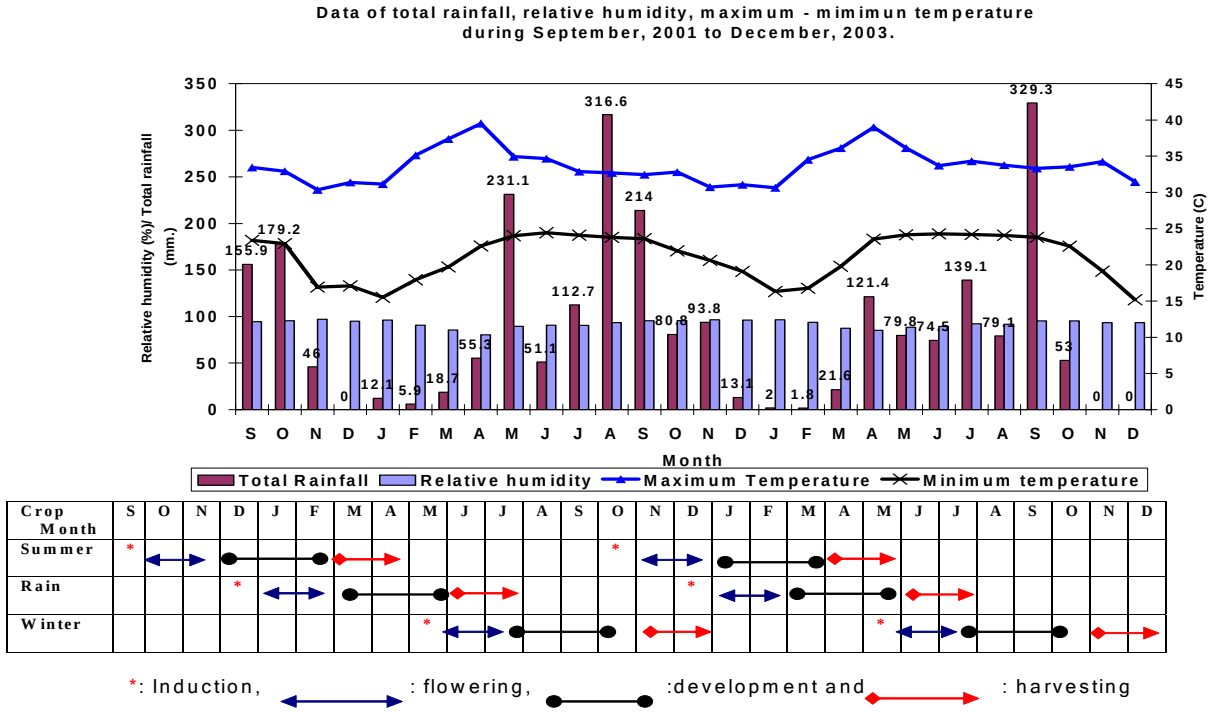


Table III. Morphological attributes of pineapple fruit

Morphological Attributes	Season 2002			Season 2003		
	Summer	**Rain**	**Winter**	**Summer**	**Rain**	**Winter**
Fruit weight (g) (without crown)	2023.46^{c}	1010.99^{a}	1427.71^{b}	1533.40^{b}	1453.73^{b}	1162.75^{a}
Crown weight (g)	148.00^{ab}	417.54^{d}	170.31^{b}	93.90^{a}	229.00^{bc}	287.97^{c}
Fruit length (cm)	18.95^{c}	13.35^{a}	16.55^{b}	17.20^{b}	17.20^{b}	16.70^{b}
Fruit diameter (cm)	13.58	12.18	13.10	13.40	13.43	12.35
Fruit shape (%)						
Spherical (small)	7.77	98.88	67.50	61.11	61.11	89.44
Cylindrical (medium)	31.11	1.11	30.83	28.88	34.44	10.55
Conical (large)	61.11	0.00	1.66	5.0	4.44	0.00
Shell color	Green	Yellow -green	Yellow	Green	Yellow –green	Yellow
Flesh color	Light yellow	Yellow	Pale Yellow	Light yellow	Yellow	Pale Yellow
Taste	Slight sweet	Sweet & Slightly sour	Sour & slightly sweet	Slight sweet	Sweet & Slightly sour	Sour & slightly sweet

Mean value of at least 180 determinations.

Different letters in the same row indicate significant differences, $P \angle 0.05$

CONCLUSION

Development of external morphological attributes was modified by variation in environmental factors during the different crop growing seasons. Although the out season summer crop had the largest and heaviest fruits with highest yield canning factories pay per kilogram of fruit, because the fruit were oversized and conical shape rendered them unsuitable for canning. However, the high yield of the out season summer crop provided high profit returns for the fresh consumption market. The in-season, rainy season crop had superior flesh color and taste and fruits were cylindrical in shape. Therefore, it was suitable for both fresh consumption and canning. The winter crop was more appropriate for canning because fruit had a spherical shape, with big crowns, sour taste and pale flesh color.

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