CHAPTER 3

CHANGE OF MORPHOLOGICAL ATTRIBUTES IN RELATION TO MATURITY AND CROPPING SEASONS OF PINEAPPLE FRUIT

3.1. Introduction

Thailand was blessed with large areas appropoate for pineapple growing. Pineapple is generally produced 3 crops per year. The main crop is harvested during rainy season which harvested from June to July refer to regular season crop. The early and late season crops are harvested during May to April and November to December, respectively. The consumer pointed out that the seasonal variation affects the inconsistent of quality. Seasonal condition and fruit maturity are the factors that play a major role in affecting physico-chemical properties and quality of fruit. There are few definitive data on the effect of climatic factors on inflorescence or fruit development of pineapple (Bartholomew and Kadzimin, 1977). The rate of fruit growth over time apparently is determined primarily by temperature. After flowering, fruit size may increases somewhat with increasing sunlight (Monselise, 1986). In two studies where pineapple was planted at different times of the year and fruit development was forced with a growth regulator. Fruit development was slower during seasons with cool temperatures (Moreau and Moreuil, 1976; Smith, 1977). Smith (1977) reported that in South Africa, fruit which developed during cooler months were smaller than fruit on plants of comparable size which developed during warmer 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 there was a slight yellowing around the base (Morton, 1987). In Taiwan, which is located in the sub-tropics, with clear temperature differences between summer and winter. During winter (monthly average 17°C), harvested fruits were sour and vice versa for summer fruits (Lin and 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 morphological attributes and eating quality vary widely with season. Thus, it is necessary to characterize and determine the changes on morphological attributes of cropping seasons pineapple fruits in the year. The objectives of this study was to determine the morphological attributes of Smooth Cayenne pineapple fruits in cropping seasons for the years 2002 and 2003.

3.2 Materials and methods

(a) Samples

Pineapple cv. Smooth Cayenne was planted in a private farm at Thasadet village, Muang district, Lampang province. The pineapple were planted in 3 crops a year. The flower was initiated by using chemical treatment after planting for 12 months. Flower and fruit developments take place for peroid of 5 and 15–16 weeks, respectively. Five hundred similar inflorescence flowers were selected and tagged after the flower on the top of inflorescences were in full bloom. The fruits of each crop were first harvested at 15 weeks (110 days after full bloom). Forty similar fruits were harvested intervally 6 time at 110, 120, 130, 140, 150 and 160 days after full bloom (DAFB). The time schedule of flower induction, fruit development and harvesting peroid of all 3 crops for the years 2002 and 2003 was shown in Figure 3.1 together with changes in environmental condition in related to each crop. Detail of harvesting date were as follow:

1. Early crop, which is the first crop, flower induction was induced in August 2001 on mother plant which planted in the last August 2000. Due to unsuccess in flower induction therefore flower induction was repeated in September 2001. Flowering peroid was 41 days during September to October 2001. The fruit were developed during winter in December 2001 to February 2002 and harvested in summer during March to April 2002.

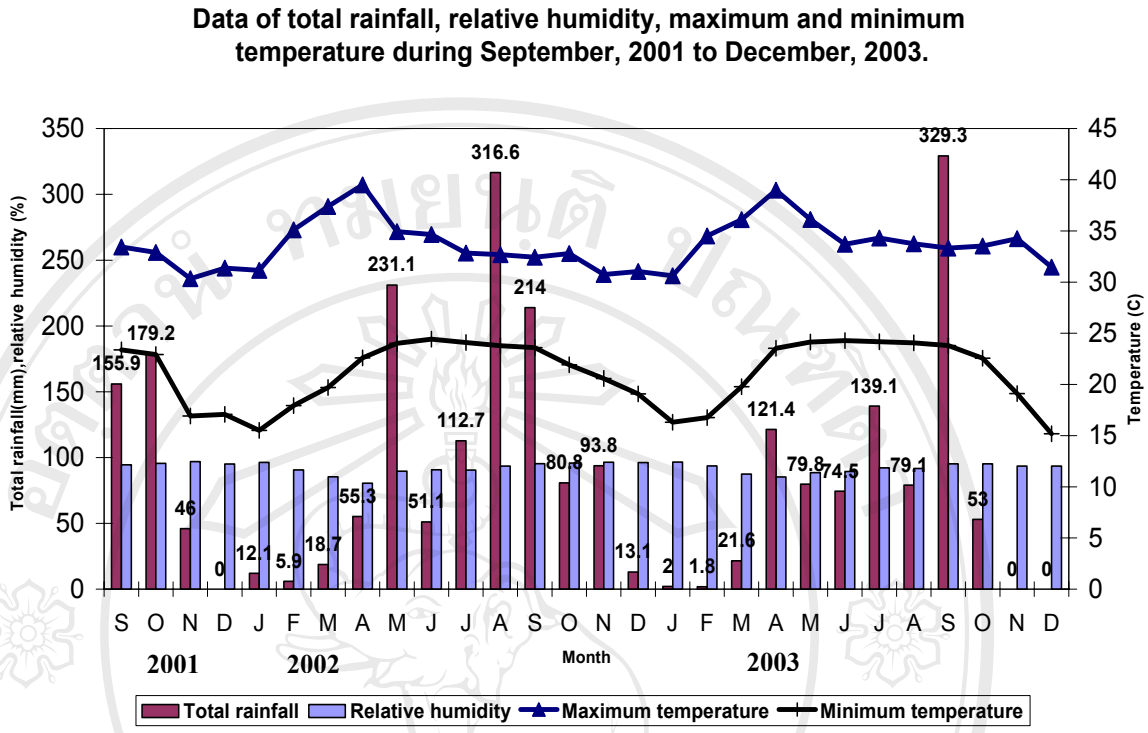
The repeate experiment for early crop in year 2003, flower induction was conducted in the last week of October 2002 on the mother plant which planted in October 2001. Flowering peroid was 42 days during October to November 2002.

The fruit were developed during December 2002 to February 2003 and harvested in summer during April to May 2003.

2. Regular crop, The flower induction was induced in December 2001 and 2002. Flowering peroid were 37 and 39 days during January to February 2002 and 2003, respectively. The fruit were developed during hot season in March to June 2002 and 2003. The fruit were harvested in rainy season during June to July 2002 and 2003.

3. Late crop, The flower induction was induced in May 2002 and 2003. Flowering peroid were 42 and 41 days during May to June 2002 and 2003, respectively. The fruit were developed during rainy in July to September 2002 and 2003. The fruit were harvested in winter during November to December 2002 and 2003.

After harvesting, the fruits were transported immediately to The Postharvest Institute Technology laboratory, Chiang Mai University, unloaded and prepared for analysis.



Harvested crop	Year 2001				Year 2002												Year 2003											
	Month																											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Early	*	←→		●	——	●	◆→							*	←→		●	——	●	◆→									
Regular				*	←→		●	——	●	◆→						*	←→		●	——	●	◆→							
Late									*	←→		●	——	●	◆→						*	←→		●	——	●	◆→		

*: **Flower induction**, ←→: **flowering**, ●—● : **fruit growth and developpment**, ◆→ :**harvesting**

Figure 3.1 Time schedule of harvesting and total rainfall (mm.), relative humidity (%), maximum and minimum temperatures (°C) during flowering induction, fruit development and harvesting of pineapple fruit produce in Lampang Province, Northern of Thailand. The fruit were produced 3 crops a year and harvested during summer, rainy season and winter for early, regular and late crop, respectively.

(*b) Assessment of morphological and physical properties*

Size, shape and weight of the fruits were noted (Table 3.1). The pineapple fruits were weighted and measured. 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).

Table 3.1 Fruit shape as determined by ratio of base and top diameters and fruit length

Shape	∅ Base: ∅ Middle: ∅ Top of fruit
Spherical (small)	∅ Middle more than ∅ Base and Top
Cylindrical (medium)	∅ Base, Middle and Top nearly equal
Conical (large)	∅ Base more than ∅ Middle and Top

Conical **Cylindrical** **Spherical**

Figure 3. 2 Fruit shape of pineapple

(c) Statistical analysis

Data were statistically analyzed by analysis of variance (ANOVA) and mean separation was analyzed 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.

3.3 Results and discussion

(a) Influence of cropping seasons on morphological characteristics of pineapple fruit ("set A" samples were harvested in year 2002 and "set B" samples were harvested in year 2003, raw data were given in Appendix A)

3.3.1.1 Fruit weight

Fruit weight increased during the first 2-3 weeks before harvesting (Figure 3.3A-E, Table A3.1-3.2 in Appendix A). Bartholomew *et al*. (2001b) 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 from plants growing in the different seasons ($P < 0.05$). The early crop fruit had the highest fruit weight, while the late crop had the lowest fruit weight (Figure 3.3, Table 3.2). During the harvesting period of 50 days between 110-160 DAFB, fruit of regular and late crop reach a final size between 120 and 130 DAFB with average fruit weights of 1,197.93 and 1,207.37 g, respectively. The fruit weight of the early crop, at the final harvesting date, increased to the average of 1,766.54 g (Figure 3.3A, E and Table 3.2).

Harvesting season in related to fruit weight are shown in Table 3.3. Variation of environmental conditions among the 3 different seasons of years 2002 and 2003 are shown in Figure 3.1 and Table 3.3. In the early crop, during fruit development, the average day and night temperatures were lower (T_{day} 28.7°C, T_{night} 24.1°C) than the other seasons (T_{day} 34°C, T_{night} 26°C) (Table 3.3). This is the main factors for the photosynthesis of pineapple mother plant and affect fruit development, resulting in heavy fruits. For the regular and late crops, the average day and night temperatures during fruit development were higher than the early crop, which may cause decreasing in the accumulation of photosynthesis in the pineapple mother plant. The

cropping season of tropical climate showed that the early harvested crop, fruit developed during the cooler month while the late harvested crop the fruit developed during the highest night and day temperatures (Figure 3.6). This cropping pattern caused the maturity peroid of early crop delay but the late crop the maturity peroid hasten resulting small fruit size. This growth pattern of this different season crops is different from the pineapple grown in South Africa and Hawaii (Smith, 1977; Morton, 1987). The winter pineapples crop are developed during cold temperature and the peroid of maturity was delayed. Friend (1981) reported that plants grown at 30°C night temperature produced smaller fruit than those grown at cooler night temperature. Bartholomew (1982) also showed that growing pineapple plant in controlled environments having night temperature of 26°C or less have greater weights than in environments having 30°C night temperature. Hepton *et al.,* (1993) and Hepton (2001) pointed out that when the temperature is high, pineapple mother plants have increased numbers of leaves, which affect food storage in the stem and causes decreased fruit weight and yield.

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 the root growth which may decrease photosynthesis of pineapple mother plant. According to cropping seasons there are mild rainfall in during fruit development of regular crop and heavy rainfall before harvesting of late crop (Figure 3.1). This raining pattern may cause to reduce fruit size of both regular and late crops.

3.3.1.2 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 (Figure 3.3B, C, F & G). There was no significant increase in both length and diameter of the fruit afterwards. The early crop had the highest fruit weight. Consequently, the crop also had the highest fruit length and fruit diameter compare to other crops.

3.3.1.3 Fruit shape

In both years, the percentage distribution of three types of fruit shape (conical, cylindrical and spherical) was significantly different in all crops. During early crop of years 2002 and 2003, fruit with conical in shape were 61.11% and 48.53% of the total while shape in the regular and late crops were 98.88.%, 61.11% and 67.50%, 89.44% spherical, respectively (Table 3.2, Figure 3.4). The fruits with conical shape showed higher fruit weight than spherical shape. The relationship between fruit weight and shape and distribution of each shape are shown in Figure 3.5.

A cylindrical fruit shape is the dominant character of the Smooth Cayenne variety (Bartholomew, 1977). However, in this experiment, the percentages of fruit with spherical shape were higher than the other shapes in the regular and late crops (Figure 3.4, 3.5). In the regular and late crops during fruit development, the average day and night temperatures were higher than the early crop and light intensity was reduced during the rainy season. These 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 (Figure 3.1), caused all the fruits to develop into a spherical shape with lower fruit weight about 1,500g.

3.3.1.4 Fruitlet number

The total fruitlet number of pineapple fruits was not significantly different in the early, regular, and late crops of both years. The range of fruitlet number was about 99 to 105 per fruit. Fruitlet number per pineapple fruit was established at induction, which thereafter determined fruit growth and final size. The number of florets varied considerably with the variety of pineapple, the size of mother plant at induction, plant population density, and the quality of flowering (Bartholomew, 1977; Wee and Rao, 1979).

Table 3.2 Environmental factors during four months (0–110 days) an the correlation to fruit weight of different crops for the years 2002 and 2003

Harvested crop	Average						Accumulate	
	Fruit weight (g)	Crown weight (g)	Temperature (T) T_{day} (°C)	T_{night} (°C)	T_{mean} (°C)	Sunshine (hrs/day)	Solar radiation $MJm^{-2}day^{-1}$	Heat unit (CDD)	Rainfall (mm)
2002									
Early	2107.4	143.92	28.70 (33.8)*	24.10 (20.9)#	26.40	7.30	15.08	2953.6	276.4
Regular	994.5	345.20	33.0 (38.2)*	28.07 (24.4)#	30.56	7.84	20.38	3455.6	436.0
Late	1393.5	164.11	32.14 (35.6)*	28.96 (26.7)#	30.55	4.88	16.87	3462.1	610.3
2003									
Early	1475.3	76.20	29.45 (34.3)*	24.76 (21.3)#	27.00	7.06	16.66	2874.4	172.5
Regular	1436.9	224.20	32.35 (37.5)*	27.43 (23.8)#	29.89	7.68	19.94	3197.2	233.2
Late	1158.7	266.66	32.44 (30.0)*	29.17 (26.8)#	30.80	5.33	17.31	3784.7	782.6
R^2			0.41	0.32		0.09	0.35	0.18	0.07
Multiple Linear Regression (MLR) of fruit weight	Model 1, $R^2 = 0.411$ (T_{day})								
	Model 2, $R^2 = 0.416$ (T_{day}, $T_{night,}$)								
	Model 3, $R^2 = 0.416$ (T_{day} ,$T_{night,}$, solar radiation)								
	Model 4, $R^2 = 0.615$ (T_{day} ,$T_{night,}$, solar radiation, heat unit)								
	Model 5, $R^2 = 0.615$ (T_{day} ,$T_{night,}$, solar radiation, heat unit, sunshine)								

* = T max

= T min

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≤0.05

Table 3.3 Morphological attributes of pineapple fruits harvested at 130 DAFB from all crops for the years 2002 and 2003.

Morphological Attributes	Crop Season 2002			Crop Season 2003		
	Early	**Regular**	**Late**	**Early**	**Regular**	**Late**
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^{b}	12.18^{a}	13.10^{ab}	13.40^{b}	13.43^{b}	12.35^{a}
Fruit shape (%)						
Spherical (small)	7.77	98.88	67.50	16.66	61.11	89.44
Cylindrical (medium)	31.11	1.11	30.83	35.53	34.44	10.55
Conical (large)	61.11	0.00	1.66	48	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 fruits determinations.

Different letters in the same row indicate significant differences, P∠0.05

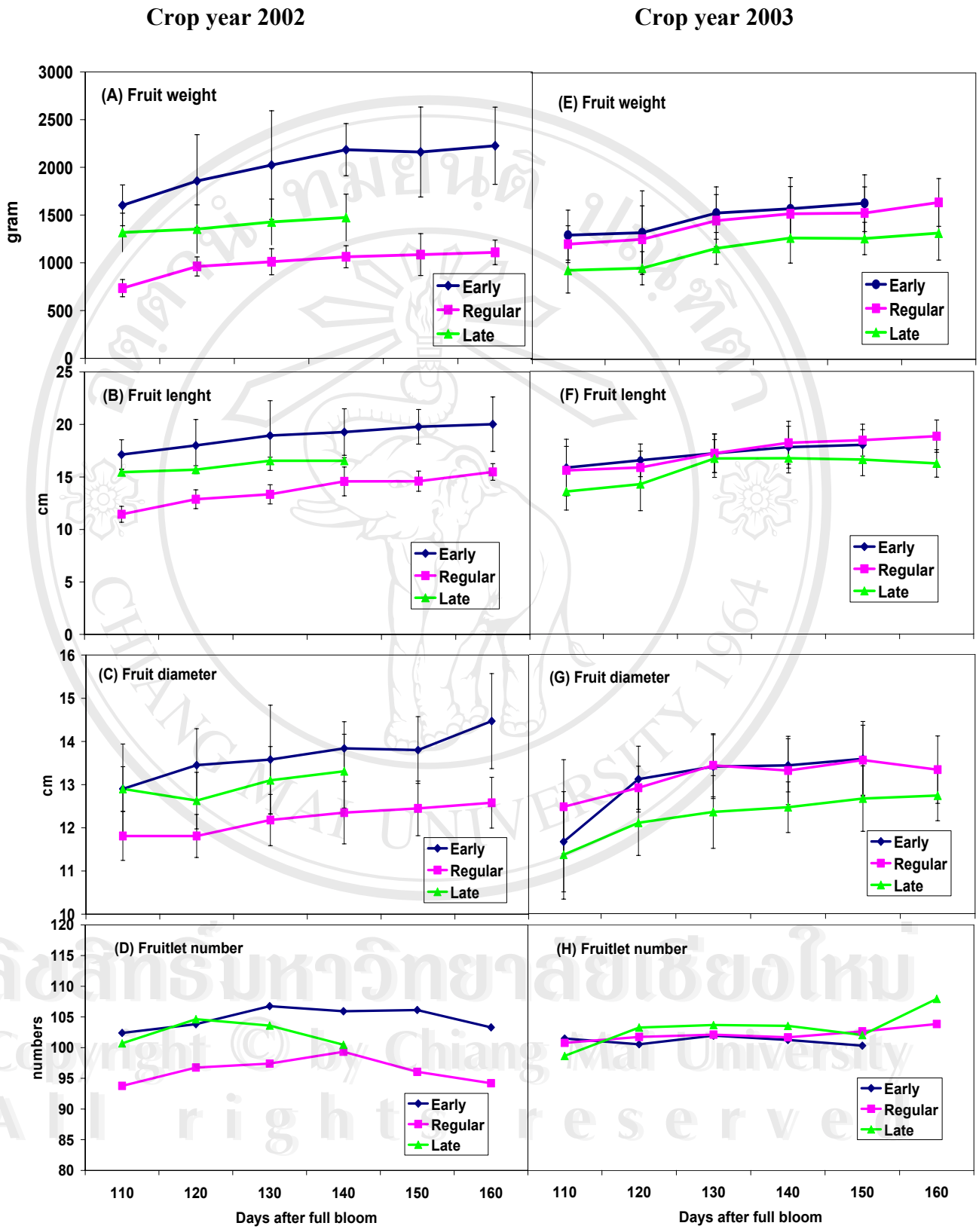


Figure 3.3 Fruit weight, fruit length, fruit diameter and fruitlet number of pineapple fruits harvested in early, regular and late crops for the years 2002 and 2003

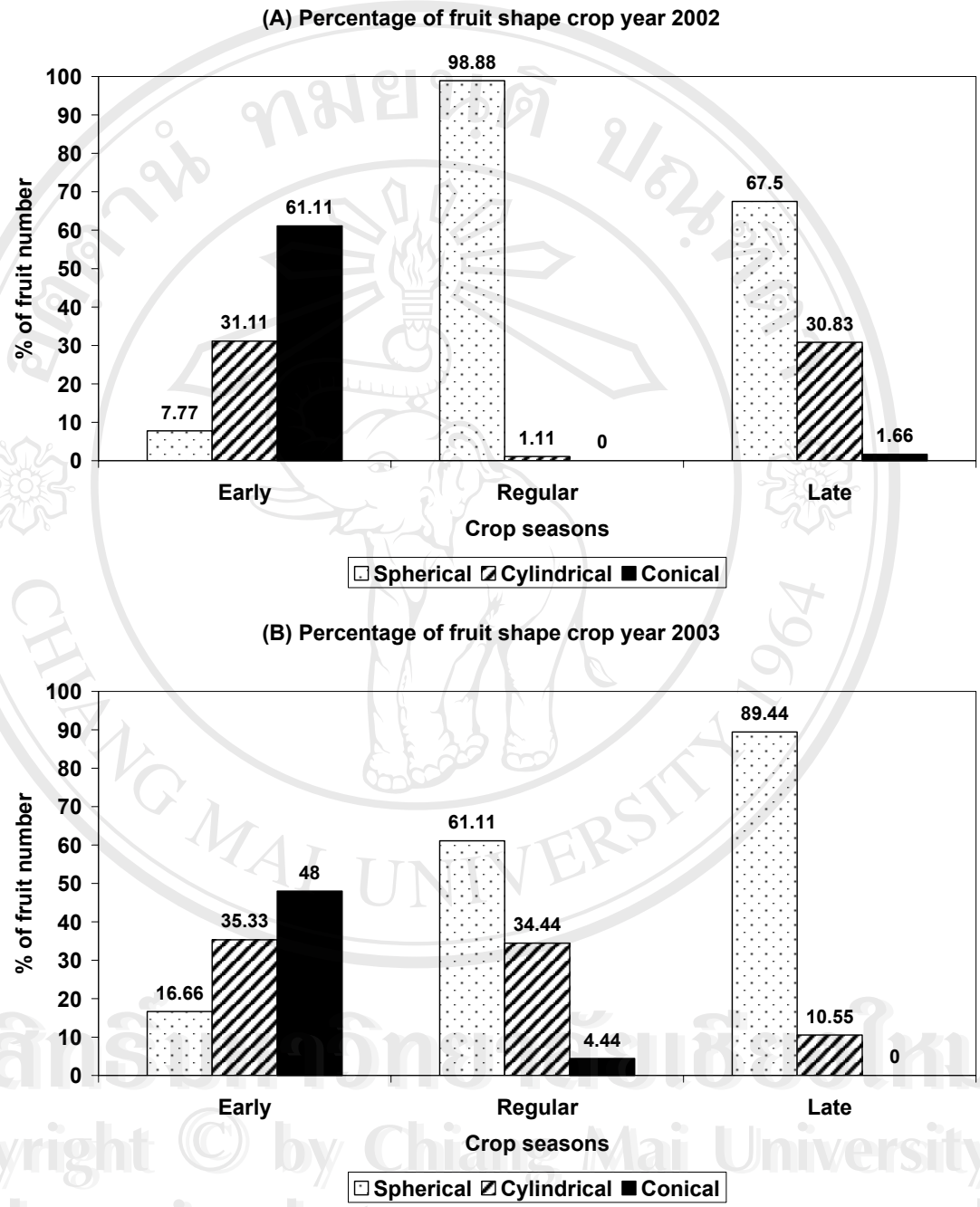


Figure 3.4 Shape distribution of pineapple fruit at different cropping seasons (A) crop year 2002 and (B) crop year 2003.
Early crop, regular crop and late crop were harvested during summer, rainy season and cool season, respectively.

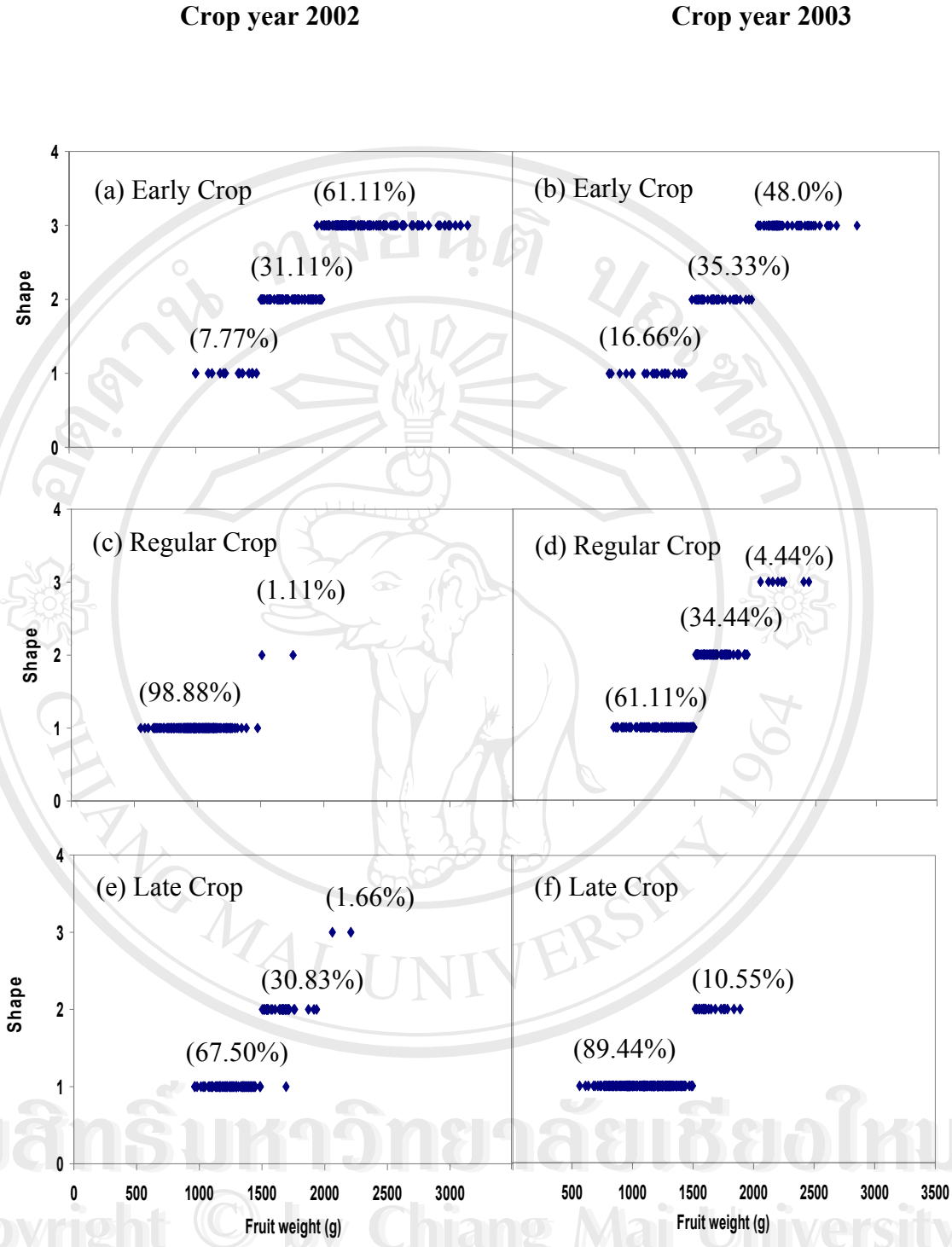
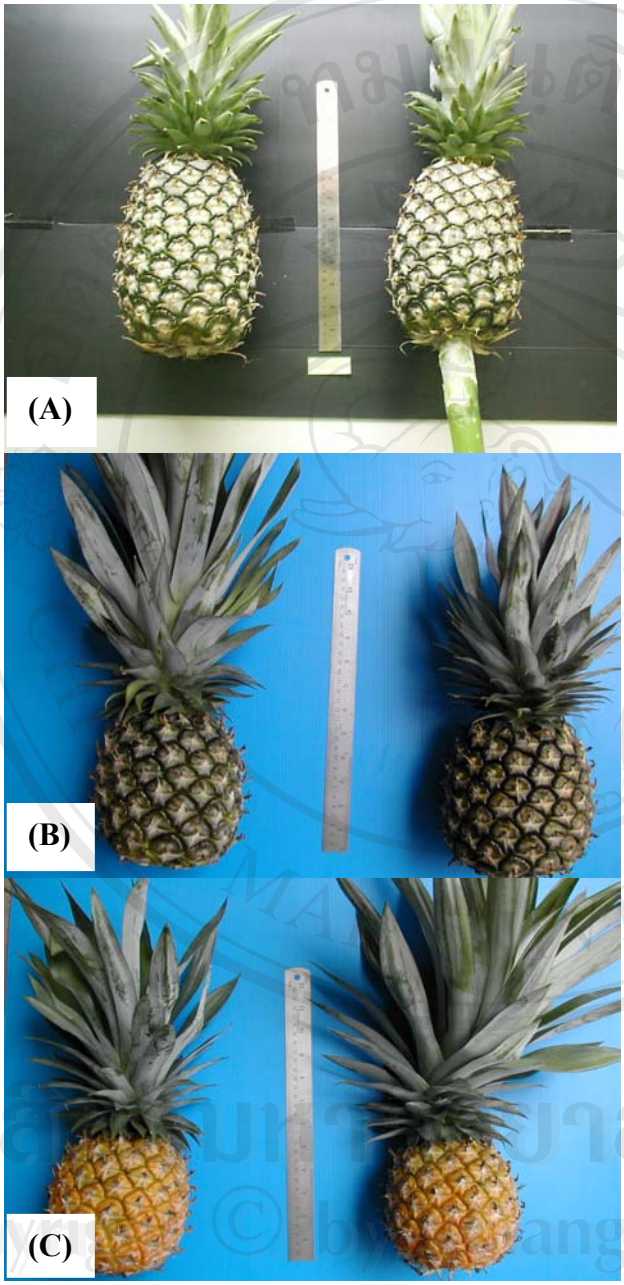


Figure 3.5 Relations between fruit weight and shape distribution of each shape. (a), (b) early crop, (c), (d) regular crop, and (e), (f) late crop for the years 2002 and 2003.

Shape 1: sphere (small), 2: cylinder (medium) and 3: conical (large)



(A) Early crop
(Harvested during summer)
: Conical shape
: Rosette crown
: Green shell, light yellow flesh
: TSS average 12.48%
: TA average 0.48
: pH average 4.15
: Slight sweet taste

(B) Regular crop
(Harvested during rainy season)
: Spherical shape
: Elongate crown
: Green shell, yellow flesh
: TSS average 13.56%
: TA average 0.50
: pH average 3.66
: Sweet & slightly sour taste

(C) Late crop
(Harvested during cool season)
: Spherical shape
: Elongate crown
: Yellow shell, pale yellow flesh
: TSS average 14.95%
: TA average 0.66
: pH average 3.49
: Sour & slightly sweet taste

Figure 3.6 Characteristics of pineapple fruit of different cropping seasons harvested at 130 DAFB.

3.3.1.5 Crown weight and crown length

The crown weight and crown length were significantly differences among the fruits from different seasons and increased with maturity stage. Crown weight of the early crop was lower than the regular and late crops. Crown length of the early crop was shorter than other crops (Figure 3.7A, C, D & F). Most of all crowns in the early crop were small rosette form and the crown in regular and late crops were large elongated form (Figure 3.6).

The crown is made up of a bunch of crown leaves, which morphologically behaves like vegetative leaves. The crown growth follows a sigmoid pattern and 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).

3.3.1.6 Relation of fruit weight and crown weight

The highest fruit weight occurred in April and May (early crop, small crowns) in crop year 2002 (Figure 3.8) and year 2003 (Figure 3.9). The lowest fruit weight occurred in July to August (regular crop, large crown) in crop year 2002 and in June to July and November to December (regular and late crop, large crowns) in crop year 2003 (Figure 3.9). Fruit weight varied from about 1,475 g to 2,110 g, 994.5 g to 1,430 g and 1,150 g to 1,400 g in crop harvested in early, regular and late crops, respectively.

Crown weight tends to be small on fruit that develop in the tropics (Py *et al.*, 1987), and this effect was attributed to the relatively short interval between induction and fruit harvest. Crown weight varies considerably throughout the year in Hawaii. Bartholomew *et al*. (2001a) reported that fruit initiated in winter tend to be small relative plant weight. These relatively small fruit mature in summer, when irradiance and temperature are high, and tend to have large crowns. Plants that bear a small fruit during summer would probably produce a surplus of carbohydrate in the warm temperatures that could be allocated to the developing crown before it becomes autotropic. Surplus carbohydrate, warm temperatures and high irradiance would speed crowm growth and presumably result in a large and heavy crown at harvesting time.

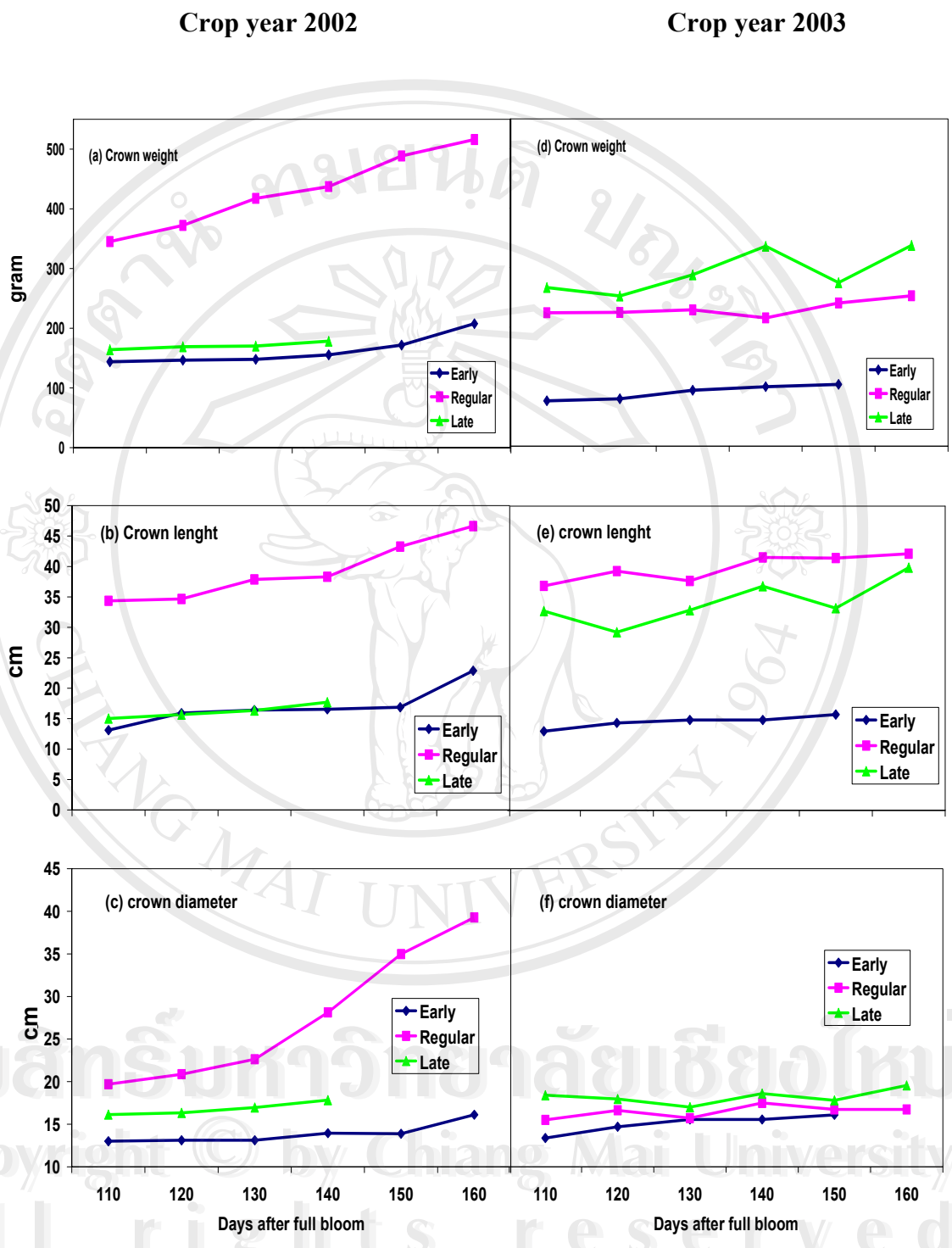


Figure 3.7 Crown weight, crown length, and crown diameter of pineapple fruits harvested in the early, regular and late crops for the years 2002 and 2003.

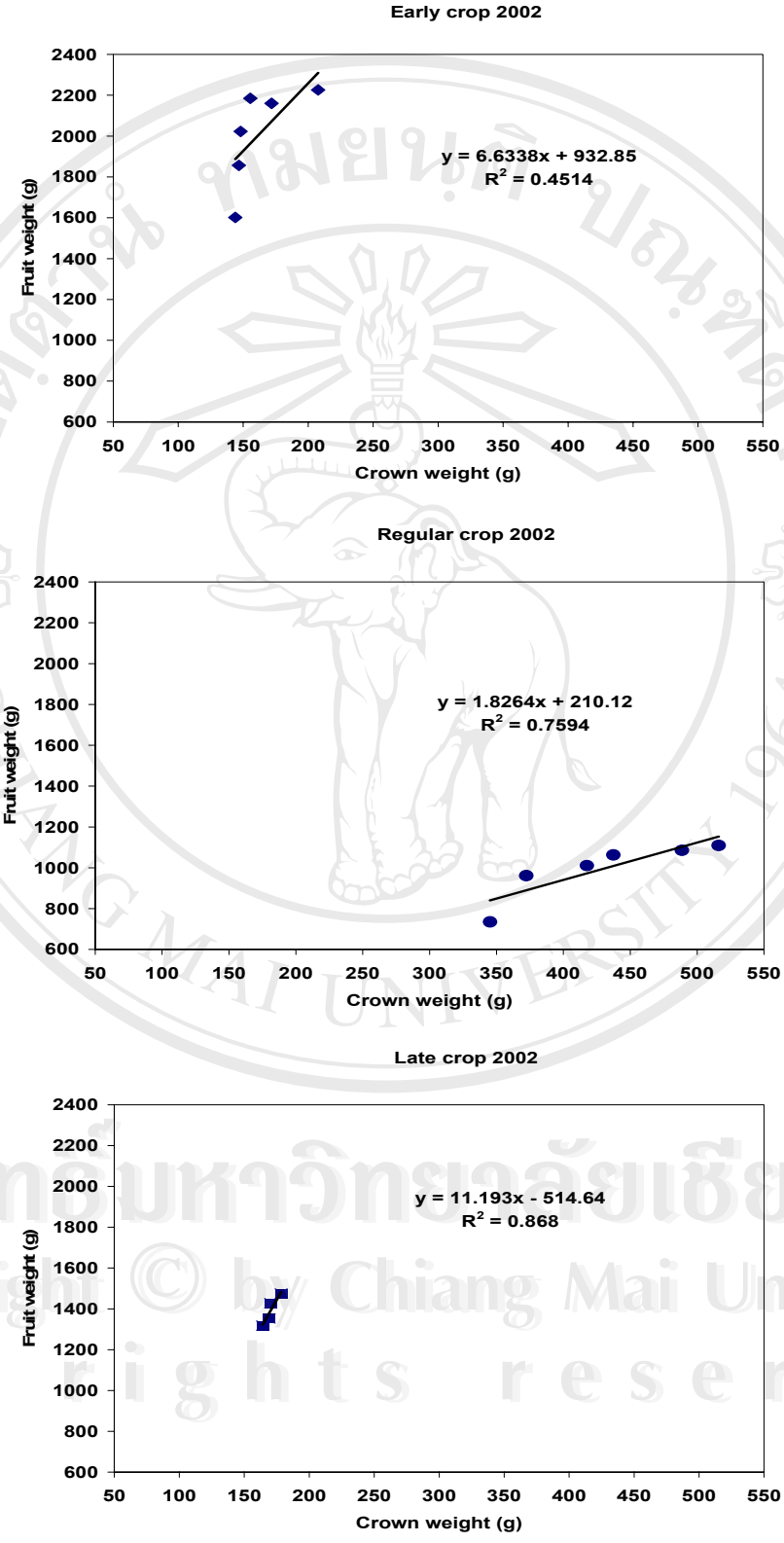


Figure 3.8 Relationship of fruit and crown weights in all crops for the year 2002.

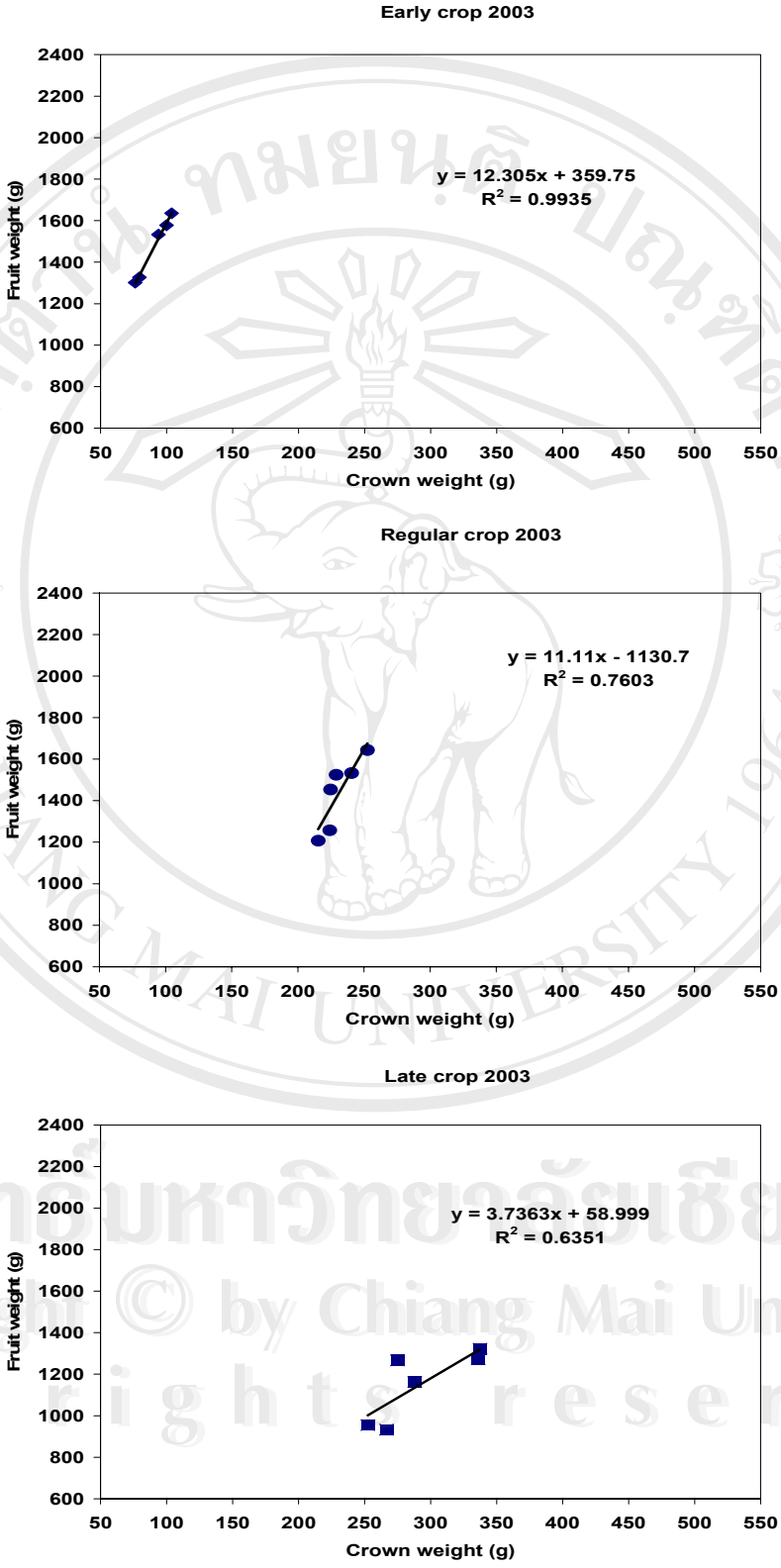


Figure 3.9 Relationship of fruit and crown weights in all crops for the year 2003.

When fruit develop and mature during winter season, the environment temperatures are cool and irradiance is low. Such fruit generally have small crown, presumably because plant bearing relatively large fruit during winter would have a more limited supply of photosynthesis to allocate to the strongest sink. There would probably be little surplus carbohydrate available to developing crown, so crown development would be delayed by lack of substrate and by low temperatures and irradiance (Bartholomew *et al.,* 2001a)

3.3.1.7 Regression analysis on relation of environmental variables to fruit weight.

A regression of correlation between fruit weight and crown weight and environmental variables during fruit development was shown in Figure 3.10. Equation of regression between T_{day}, T_{night} temperatures and solar radiation with fruit weight showed a negative direction while the crown weight showed positive direction. This results indicate the competitive growth between the fruit and the crown also the final size of fruit are directly affect by photosynthesis capacity of mother plant. Therefore, the environmental conditions during mother plant development which directly affect the size of mother plant may indirectly effect the size of the fruit rather than the environmental conditions that occur during fruit development. The growth interaction between mother plant, the fruit and the crown could be described as follow:

(1) Early crop, the mother plant grown in September – August during rainy season with high day and night temperature may cause the D-leaf to become green and broad with dense and less erect leaf canopy. This mother plant produce fruit with large size. The fruit developed at lower night temperature about 14–16°C and day temperature is not too high (30°C) promote better fruit growth. The crown developed during dry season and the temperature os low which suppressed the crown growth and gave small crown.

(2) Regular crop, growth of mother plant was developed the end of rainy season during October – December and due to the active growth of crown, the fruit are mostly spherical and cylindrical shapes with large crown.

(3) Late crop, the D-leaf of mother plant developed in dry with hot day temperature and cool night during November – December gave narrow pale green erect leaf with thin canopy may have less potential to promote fruit growth compare

to early mother plant. The fruit harvested during dry and cool months (November – December) fruit are small and spherical shape.

A regression model showed that temperature of T_{day} gave higher correlation than T_{night} and solar radiation (Table 3.3) with fruit weight. Using a multiple linear regression model between temperature of T_{day}, T_{night} and solar radiation variables showed the coefficients of decision (R^2) of 0.411, 0.416 and 0.416, respectively.

3.4 Conclusion

Development of external morphological attributes was modified by variation in environmental factors during the different crop growing seasons. The early fruit crop had the highest fruit weights, while the late crop had the lowest fruit weights. Although the early crop gave the highest fruit weight and size and provide more yield but the canning factory pay less prize per weight of fruit because the fruit were over size and their conical shape were not suitable for canning. However, the high yield of the early crop gave good cost profit return for fresh consumption market. The regular crop had superior flesh color and taste and cylindrical shape. Therefore, it was suitable for both fresh consumption and canning. For late crop due to its spherical shape, big crown, sour taste and pale flesh color, they were more appropriate for canning. Regression analysis showed that differences in fruit weights, among seasons were correlated to temperatures of T_{day}, T_{night} and solar radiation.

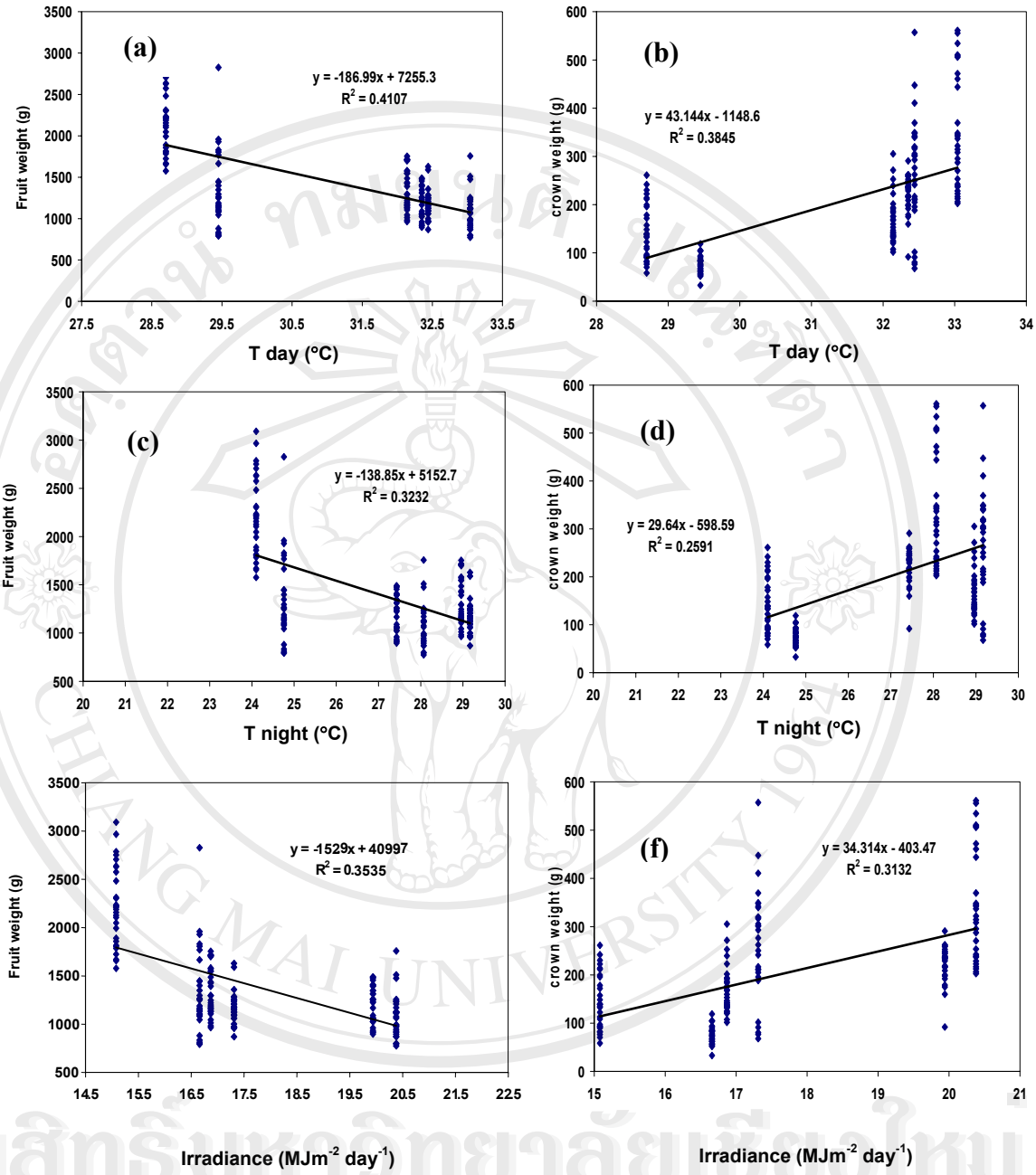


Figure 3.10 Regression of fruit and crown weight in relation to solar radiation and temperatures (T day, T night).

T_{day} = 0.5 (T max + T min) + (T max – T min)/3π), T_{night} = 0.25 (T max + 3T min).