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Influences of Elevation on Growth and Yield of Strawberry in Thailand

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ABSTRACT

Growth and yield of commercial strawberries (*Fragaria* x *ananassa* Duch.) cvs. Tioga and Tochiotome were compared under different elevations of 340, 720 and 1300 m at Royal Agricultural Research Center (RARC), Phang-da Royal Agricultural Station (PRAS), and Doi Pui Research Station (DPRS) respectively. Vegetative and reproductive growths were of significant differences. At RPAS, Tioga had greater plant fresh and dry weights and number of crown than those in the other locations, whereas DPRS had the longest root. In three elevations, Tochiotome was found to have first blooming before Tioga. At DPRS, Tioga had the highest number of inflorescences, while Tochiotome grown at PRAS had the greater number of runners. In this experiment, Tioga at DPRS produced the greatest fruit number and yield.

Key words: *Fragaria* x *ananassa* Duch., Tioga, Tochiotome, crown, inflorescences, runner

INTRODUCTION

Effects of photoperiod and temperature on the vegetative and reproductive growth of strawberry plants are well documented. A number of components has been shown to influence strawberry growth, including the decrease of vegetative growth (Piringer and Scott, 1964; Heide, 1977; Durner *et al.*, 1984), runner production (Smeets, 1980), and flower induction (Dennis *et al*., 1970; Durner and Poling, 1987). Le Miére *et al*. (1998) found that temperature was positively correlated with the rate of progress to fruiting whereas crown size had no effect. Among the strawberry cultivars introduced and tested for their adaptability in Thailand, Tioga (Pipattanawong, 1996) and Tochiotome (Akagi, 2001) cultivars are produced for processing and fresh fruit production, respectively. There is therefore a need for a study of the influence of elevation on growth and development in these cultivars. The objective of this experiment was to study the adaptability of Tioga and Tochiotome strawberry cultivars to different elevation levels.

MATERIALS AND METHODS

On 15 September 2002, the uniform size runner plants of two Junebearing strawberries (*Fragaria* x *ananassa* Duch.), Tioga and Tochiotome were grown in 3.8 l (18 cm in diameter) plastic pots containing a mixture of soil and natural compost after that they were left in a nursery at Doi Pui Research Station, Chiang Mai province. Observations were made on the cultivars of Tioga and Tochiotome. Runners and old leaves of all plants were removed constantly during the experiment.

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Late October 2002, plants of each cultivar were divided equally into three groups and were moved to Royal Agricultural Research Center (RARC), Royal Phang-da Agricultural Station (RPAS), and also Doi Pui Research Station (DPRS) at elevation levels of 340 m, 720 m, and 1300 m, respectively. A 3 x 2 factorial experiment in a completely randomized design with six replications was used in this study with 8 plants per experimental unit. All plants were placed on the ground and exposed to the natural climate in the experimental areas. During growing season, all plants were watered daily and fertilized biweekly with 50 mg 15N-15P-15K per plant. Insecticides and fungicides were applied as required. A number of leaves, a number of crowns, petiole length, and mean leaf index (length x breadth of the middle leaflet) to estimate leaf area of the third unfolded leaves (counting from the youngest leaf) (Darrow, 1932) were recorded at every two - week intervals. The flowering response of the plants during the experiment was evaluated by counting the total number of flowers and inflorescences per plant. Fruits were harvested at 2-3 day intervals during the growing season, graded, counted, and weighed. At the end of the experiment (30 March 2003), 6 plants per cultivar in each location were randomly selected, washed, and separated into organs. The whole plants were then dried at 80°C for 48 h and the dry weights of separated organ were determined.

RESULTS

Tochiotome at RARC had increasing bush height after planting until the end of December 2002 after that bush height decreased. Tochiotome at PRAS had increasing bush height on mid December until the experiment completed. However; Tioga at DPRS had shortest bush height compared with the others treatment. (Figure 1)

On September to December found it was out that every treatment had increasing bush diameter and Tioga at RARC had the greatest most bush diameter (Nov. 29, 02). At the end of December, bush diameter of every treatment decreased; when the experiment completed, both cultivars had bush diameter between 20.6-23.4 cm (Figure 2)

After the end of November, Tioga and Tochiotome increased a number of leaves which Tioga at PRAS had the highest number of leaves per plant. At RARC, it was found that strawberry of both cultivars had less number of leaves (3.5-10.0 leaves) (Figure 3)

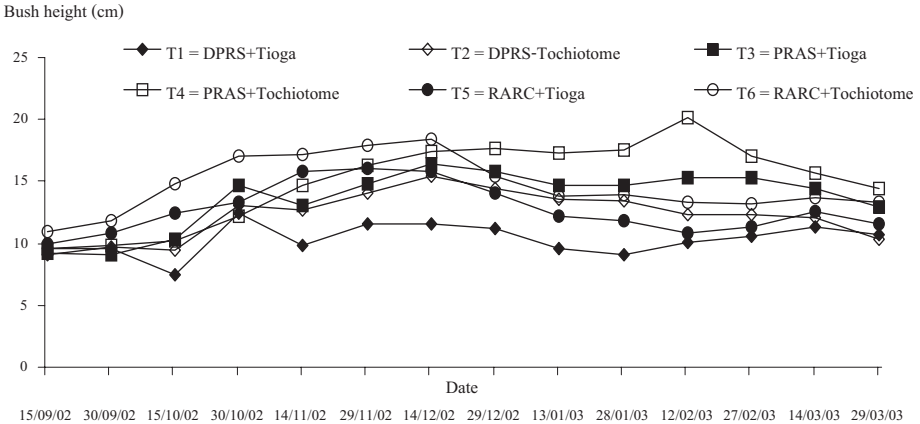

Figure 1 Influences of different elevation on bush height (cm) in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

At the beginning of the experiment, the result showed shown that there was not significant difference in leaf length. On October 30, 2002, Tioga at DPRS was noticed to have the greatest leaf length (7.1 cm) and when the experiment completed Tioga at RARC had shorter leaf length (4.1 cm) (Figure 4)

Every treatment had leaf width between 3.7-8.9 cm but from mid December until the experiment completed the leaf width was found to decreased. Tioga at RARC had the greatest leaf width (4.8 cm) (Figure 5)

Tioga at DPRS was noticed to have the greatest leave area of 380.5 cm^2 while Tioga at RARC had less leave area of 133.5 cm^2 (Figure 6).

At the beginning of the experiment, Tochiotome at DPRS had the greatest petiole length (4.0 cm). However, when the experiment completed, Tioga was the greatest found to have petiole length (8.8 cm) and Tochiotome at RARC had less petiole length (6.4 cm) (Figure 7)

At the end of the experiment, it was found that Tioga had greater fresh and dry weights

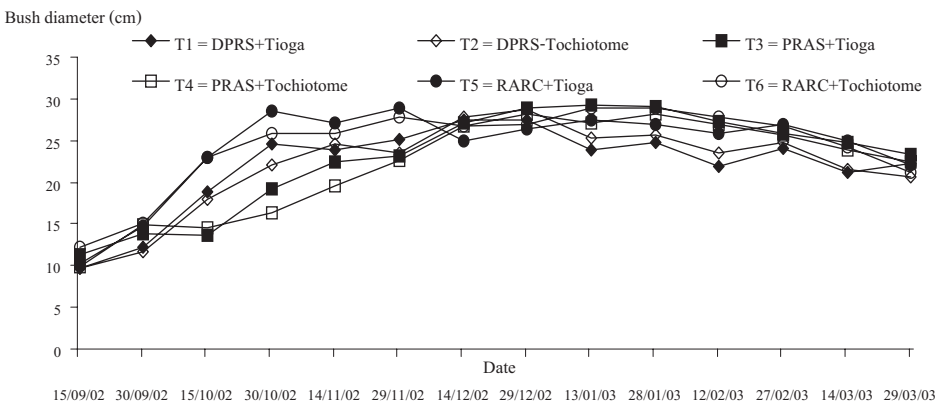

Figure 2 Influences of different elevation on bush diameter (cm) in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

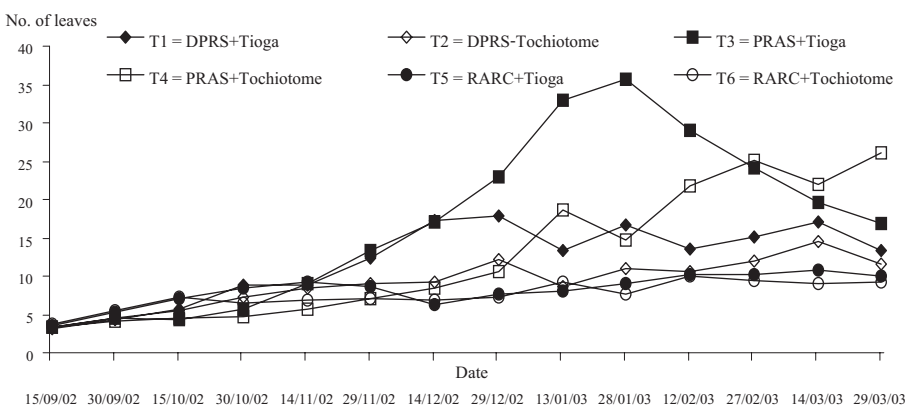

Figure 3 Influences of different elevation on number of leaves in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

of shoot and whole plant than Tochiotome but there was no significant difference between fresh and dry weights of root. Both strawberry cultivars at PRAS had the greatest fresh and dry weights of shoot and whole plant when compared amoung three locations and at RARC these two cultivars had the greatest fresh and dry weights of root of 16.6 and 5.1 g respectively. Tioga at PRAS had the geratest fresh and dry weights of shoot and whole plant while Tioga at RARC had the greatest fresh and dry weight of root which was 18.1 and 5.8 g respectively compared with interaction of cultivars and locations (Table 1).

There were no significant difference between root length and crown size both strawberry cultivars at the end of the experiment. Tioga had more number of crowns than Tochiotome while Tochiotome had more number of runner than Tioga. Both strawberry cultivars at DPRS had the greatest root lengths and crown sizes which were 22.1 cm and 8.8 mm, respectively where as PRAS had the greatest number of crowns and runners. Interaction between cultivars and locations on root length showed no significant

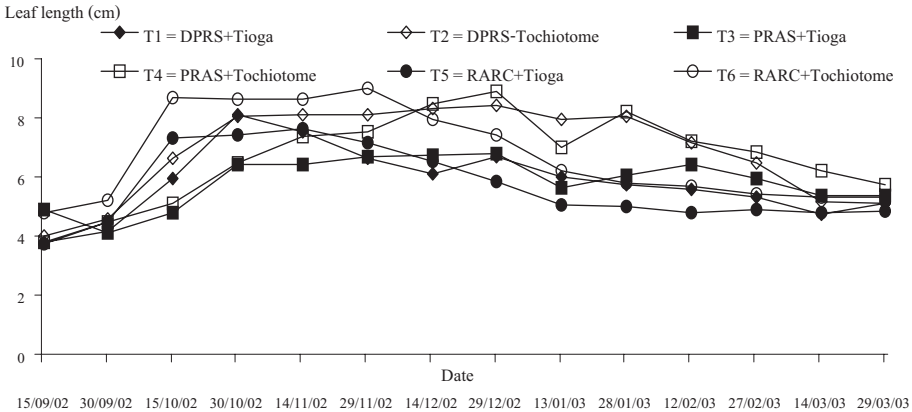

Figure 4 Influences of different elevation on leaf length (cm) in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

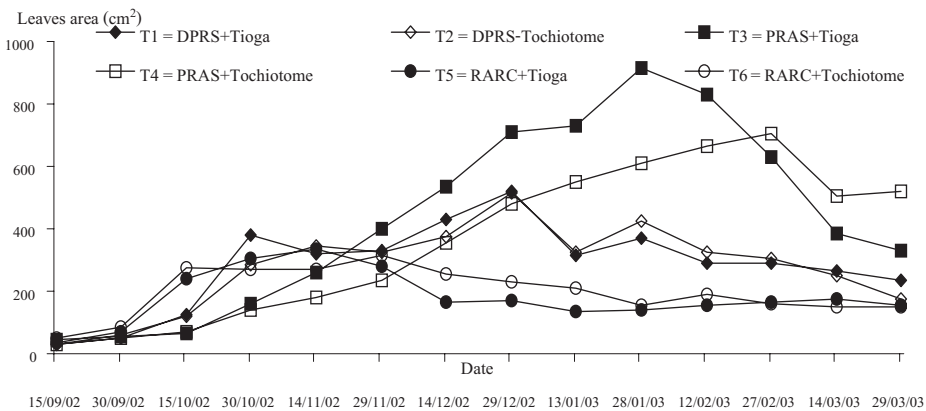

Figure 5 Influences of different elevation on total leaf width (cm) in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

difference. At DPRS, Tochiotome had the biggest crown size (9.6 mm) while Tochiotome at RARC had the smallest (7.0 mm). Tioga at PRAS had the greatest number of crowns per plant where as Tochiotome at DPRS had less (Table 2).

Tochiotome had a number of days to first blooming less than Tioga but there was no significant difference when compared between locations. In each location, Tioga had no significantly difference number of days to first blooming compared with interaction between cultivars and locations, whereas Tochiotome at RARC had less number of days to first blooming (38.9 days). Tioga had more number of inflorescences than Tochiotome while at the three locations there were no significant difference between number of inflorescences in both strawberry cultivars. Tioga at DPRS had the greatest number of inflorescencs and Tochiotome at PRAS had less compared between interaction of cultivars and locations (Table 3).

A number of fruits and yields per plant

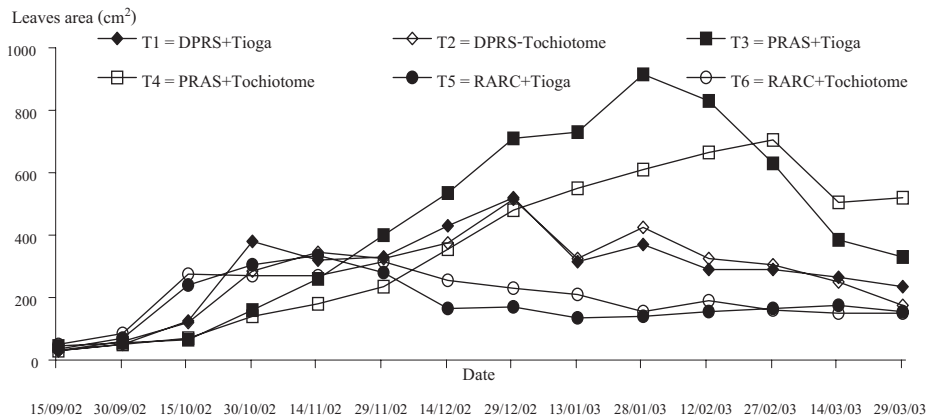

Figure 6 Influences of different elevation on leaf area (cm^2) in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

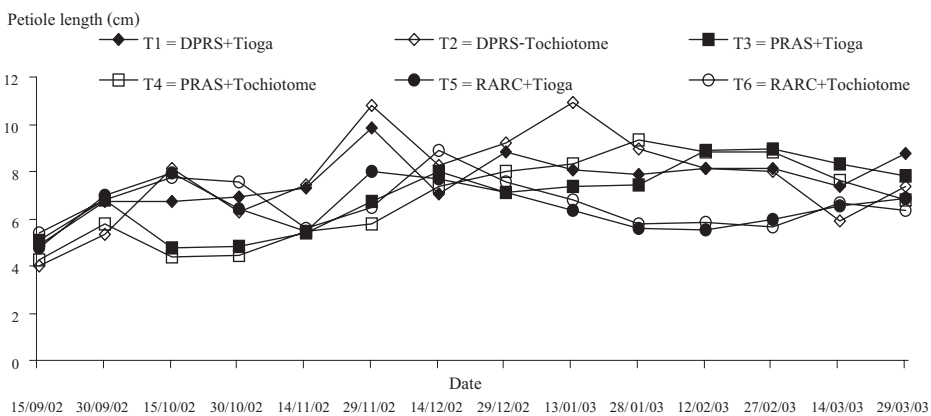

Figure 7 Influences of different elevations on petiole length (cm) in two strawberry cultivars. Treatments 1-6 were Tioga and Tochiotome strawberry cultivars grown at DPRS, PRAS, and RARC, respectively.

of Tioga were greater than those of Tochiotome compared between locations, while at DPRS they had the greatest number of fruit (27.3) and yield (150.4 g). Tioga at DPRS had the greatest number of fruit and yield whereas Tochiotome at PRAS had less compared between interaction of cultivars and locations (Table 3).

However, when produces were grade-divided according to weight it was found that ….. of both strawberry cultivars had fruit weight less than 7 g. When compared between cultivars, Tochiotome had bigger fruit size than Tioga while at DPRS, Tochiotome had the greatest fruit size comparing between locations. Tochiotome at DPRS had greater number of fruit weight of 15-25 g than the others treatment compared between interaction of cultivars and locations (Table 4).

DISCUSSION

In Junebearing strawberry cultivars, the vegetative and reproductive developments were highly sensitive to climatic variables. Both photoperiod and temperature control the perennial cycle of runnering and flowering (Guttridge, 1985; Le Mière *et al*., 1996), and this sensitivity can be exploited by the growers who produce strawberry runner plants or fruits at defined times of year

Table 1 Influences of different elevation on fresh and dry weights of shoot, root and whole plant in strawberry cvs. Tioga and Tochiotome.

	Fresh weights (g)			Dry weights (g)		
	Shoot	Root	Whole plant	Shoot	Roo	Whole plant
Factor A : Cultivars						
Tioga	51.8 a[1/]	13.6	64.6 a	10.4 a	4.4	14.8 a
Tochiotome	42.7 b	12.8	56.3 b	7.8 b	4.3	12.1 b
F-test	**	ns	**	**	ns	**
Factors B : Locations						
DPRS	45.5 b	11.7 b	57.2 b	9.4 b	4.2 b	13.6 b
PRAS	54.2 a	11.4 b	65.5 a	10.6 a	3.9 b	14.5 a
RARC	42.1 b	16.6 a	58.7 b	7.3 c	5.1 a	12.3 b
F-test	**	**	*	**	*	**
A × B						
Tioga						
DPRS	46.4 b	9.9 d	56.3 bc	9.9 b	3.6 c	13.5 b
PRAS	63.1 a	10.5 d	73.5 a	13.4 a	3.9 bc	17.3 a
RARC	45.9 b	18.1 a	63.9 b	7.8 cd	5.8 a	13.6 b
Tochiotome						
DPRS	44.6 bc	13.5 bc	58.1 bc	8.9 bc	4.9 ab	13.7 b
PRAS	45.3 bc	12.3 cd	57.6 bc	7.8 cd	3.9 bc	11.7 c
RARC	38.4 c	15.1 b	53.4 c	6.8 d	4.3 bc	11.1 c
F-test	*	**	*	**	**	**
C.V.(%)	11.0	15.5	11.6	11.6	21.2	10.6

[1/] Means in the same column followed by the same letters are not significantly different by DMRT at $P = 0.05$ in each factor A,B and A×B.

*, ** significance at $P < 0.05$ and 0.01, respectively

ns nonsignificance

(Le Mière *et al*., 1998). Mean temperatures at DPRS and RARC was recorded form September 2002 to March 2003 which had about 5°C differences in each month, whereas at PRAS mean temperature were between DPRS and RARC (Table 5). Tioga and Tochiotome strawberry plants grown at PRAS had increasing bush sizes, a number of leaves, and leaf areas compared with the others location because of different temperatures in each location. There was a negative relationship between the average growing temperature and leaf sizes in two strawberry cultivars such as at RARC had smallest leaf sizes, leaf areas and petiole lengths resulted from highest temperature. The optimum day/night temperature for the growth of leaf and petiole was 25/12°C but height temperature would limit canopy development in strawberry (Le Mière *et al*., 1998; Wang and Camp, 2000)

There was evidence from the data of fresh and dry weights of shoot and whole plant in Tioga grown at PRAS which indicated that the plants gave much higher crown production at this elevation. Tochiotome at DPRS had the biggest crown size. Mason (1987) found that temperature affected on crown diameter. However, runner removal can be stimulate and hasten branch crown development in both short-day and day-neutral strawberry types (Hancock, 1999). Thus, there is

Table 2 Influences of different elevation on root length, crown size, a number of crowns and a number of runners in two strawberry cultivars.

	Root length (cm)	Crown size (mm)	Number of crowns/plant	Number of Runner/plant
Factor A : Cultivars				
Tioga	21.1	8.3	7.1 a	3.9 b
Tochiotome	20.4	8.3	4.5 b	7.0 a
F-test	ns	ns	**	**
Factors B : Locations				
DPRS	22.1 a[1/]	8.8 a	4.6 b	5.9 b
PRAS	19.6 b	8.3 ab	6.5 a	6.7 a
RARC	20.5 ab	7.7 b	6.3 a	3.7 c
F-test	*	*	**	**
A × B				
Tioga				
DPRS	22.2 a	8.1 bc	5.6 b	2.8 c
PRAS	19.7 bc	8.3 b	8.0 a	4.2 b
RARC	21.3 abc	8.5 ab	7.6 a	4.7 b
Tochiotome				
DPRS	22.1 ab	9.6 a	3.5 c	9.1 a
PRAS	19.6 c	8.3 b	5.1 b	9.3 a
RARC	19.6 c	7.0 c	5.0 b	2.8 c
F-test	*	**	**	*
C.V.(%)	9.9	11.2	16.8	3.9

[1/] Means in the same column followed by the same letters are not significantly different by DMRT at $P = 0.05$ in each factor A,B and A×B.

*, ** significance at $P < 0.05$ and 0.01, respectively

ns nonsignificance

need to study about the influence of environment factors on strawberry growth.

Low temperature at DPRS and PRAS produced more runners in this study but high temperature at RARC produced lowest number of runner. Apparently the lower temperature enables to produce adequate runner, especially Tioga. In addition, Durner *et al*. (1984) reported that the runners of short-day strawberry plants were produced after flowering at the base of new leaves, and were formed most readily during long days (> 10 h) when temperatures were in the ranges of 21-30 °C.

The short-day strawberry types actually initiate flower buds either under short-day conditions (< 14 h) or when temperatures are less than 15 °C (Guttridge, 1985; Larson, 1994). In this study, all Tochiotome plants grown at three elevations had no differences of days to first blooming within 40-50 days after transplanting, while Tioga plants required 68 or more days. The results indicated that Tochiotome was the earlier variety due to an earlier season compared with Tioga. However Tioga cultivar is widely planted in Thailand because of its greater size, attractiveness, firmness, productivity, as well as good adaptation (Pipattanawong, 2000).

The strawberry plants used in this study received the low temperature at DPRS and already formed flower bud before the beginning of

Table 3 Influences of different elevation on day to first blooming, a number of inflorescences, a number of fruits and yields per plant during reproductive growth in two strawberry cultivars.

	Days to first blooming	A number of inflorescences	A number of fruits/plant	Yield/plant (g)
Factor A : Cultivars				
Tioga	72.0 a [1/]	8.4 a	23.3 a [1/]	118.1 a
Tochiotome	41.0 b	7.2 b	16.3 b	92.0 b
F-test	**	**	**	**
Factors B : Locations				
DPRS	55.9	9.2 a	27.3 a	150.4 a
PRAS	57.8	6.7 b	14.0 c	85.9 b
RARC	55.7	7.5 b	18.1 b	79.0 b
F-test	ns	**	**	**
A × B				
Tioga				
DPRS	71.2 a	10.9 a	32.8 a	178.1 a
PRAS	72.3 a	8.6 bc	16.3 cd	95.1 c
RARC	72.4 a	5.7 d	20.9 bc	81.2 c
Tochiotome				
DPRS	40.6 b	7.4 c	21.9 b	122.7 b
PRAS	43.3 b	4.9 d	11.6 d	76.7 c
RARC	38.9 b	9.2 b	15.3 d	76.8 c
F-test	*	**	**	**
C.V.(%)	11.1	14.0	19.7	16.8

[1/] Means in the same column followed by the same letters are not significantly different by DMRT at $P = 0.05$ in each factor A,B and A×B.

*, ** significance at $P < 0.05$ and 0.01, respectively

ns nonsignificance

experiment. The duration of cropping was also longer at lower temperatures, so plants grown at lower temperatures would have longer produce and transport assimilates to the fruit (Le Mière *et al*. 1998). The reason was that the plants grown at DPRS tended to increase their productivity, especially Tioga cultivar. While high temperature was non-significant to a number of fruits but there

Table 4 A number of fruits of grade divided produces according to fruit weight.

	Graded					
	>25	15-25	11-15	9-11	7-9	<7
Factor A : Cultivars						
Tioga	0.0 b[1/]	0.2 b	0.6	1.2 a	3.2	18.3 a
Tochiotome	0.1 a	0.4 a	0.6	0.9 b	2.8	11.5 b
F-test	*	**	ns	*	ns	**
Factors B : Locations						
DPRS	0.0 b	0.6 a	1.3 a	1.9 a	4.8 a	18.9 a
PRAS	0.0 b	0.1 b	0.3 b	1.1 b	3.0 b	9.4 b
RARC	0.1 a	0.1 b	0.2 b	0.2 c	1.2 c	16.4 a
F-test	**	**	**	**	**	**
A × B						
Tioga						
DPRS	0.0 b	0.4 b	1.3 a	2.2 a	5.8 a	23.3 a
PRAS	0.0 b	0.0 c	0.3 b	1.3 bc	2.9 b	11.8 b
RARC	0.0 b	0.0 c	0.1 b	0.2 d	0.9 c	19.7 a
Tochiotome						
DPRS	0.0 b	0.8 a	1.2 a	1.6 b	3.8 b	14.5 b
PRAS	0.0 b	0.1 c	0.3 b	0.9 c	3.2 b	7.1 c
F-test	*	*	*	**	**	**
C.V.(%)	20.8	30.6	18.9	20.6	27.6	24.2

[1/] Means in the same column followed by the same letters are not significantly different by DMRT at $P = 0.05$ in each factor A,B and A×B.

*, ** significance at $P < 0.05$ and 0.01, respectively

ns nonsignificance

Table 5 Maximum, minimum and mean temperatures (°C) at DPRS, RPAS and RARC from 15 Sep 2002 to 31 Mar 2003.

Months	Temp. (°C)								
	Maximum			Minimum			Means		
	DPRS	PRAS	RARC	DPRS	PRAS	RARC	DPRS	PRAS	RARC
Sept.	22.0	26.1	27.7	19.1	22.1	21.1	20.8	24.2	25.6
Oct.	22.6	26.4	28.5	18.7	20.8	23.4	20.4	24.1	26.1
Nov.	21.5	25.6	27.0	13.9	17.9	20.5	18.7	22.4	24.2
Dec.	21.2	24.7	25.8	14.7	17.1	19.1	17.9	21.5	23.0
Jan.	17.8	22.6	24.0	14.6	17.5	19.1	16.4	19.4	21.2
Feb.	21.9	23.3	25.0	13.6	18.8	20.3	19.5	20.9	23.0
Mar.	22.8	24.5	29.1	18.6	20.3	22.8	21.2	22.8	26.2

Table 6 Maximum, minimum and mean relative humidity (%) at DPRS, RPAS and RARC from 15 Sep 2002 to 31 Mar 2003.

Months	%RH								
	Maximum			Minimum			Means		
	DPRS	PRAS	RARC	DPRS	PRAS	RARC	DPRS	PRAS	RARC
Sept.	93.4	98.1	91.3	76.5	84	80.7	85.9	90.3	84
Oct.	99	91.6	84.3	60.2	65.4	75.3	86.7	76.4	81.5
Nov.	99	93.1	98.4	72.5	72.7	75.3	88	79.5	84.8
Dec.	99	83.3	94.5	61.2	64	77.4	87.1	75.5	85.8
Jan.	99	91.1	98.9	66.4	63	76.5	85.2	72.9	83.9
Feb.	87.4	72.5	85.1	39.6	52.9	60.1	65.5	63.1	68.9
Mar.	96.7	86.2	77.6	38.2	56.3	44.4	69.6	66.7	58.5

were small fruit size were produced. This may be due to the effects of lower night temperature at DPRS and higher day temperature at PRAS and RARC which reduced pollination and fruit development.

CONCLUSION

The study resulted in the understanding of physiology and development of two strawberry cultivars grown in the different elevations to benefit strawberry growers in Thailand.

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