Effect of Temperature on the Size of Strawberry Fruit

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Summary

Strawberry, *Fragaria × ananassa* Duch. cv. Toyonoka, plants were grown from October onward in two glasshouses where the air temperature was controlled at either 15° or 19 °C night and day. Several days after pollination, the diameter of all the fruits in the first inflorescence (truss) was measured at approximately two-day intervals, and fully red ripe fruits were sampled. The growth of the fruits showed a double sigmoidal curve in all ranks of the inflorescence at both temperatures. The growth was faster in the higher rank fruits that developed earlier and at 19 °C than in the lower rank fruits and at 15 °C. Fresh and dry weight per fruit was larger in the higher rank fruits and at 15 °C (mean of all fruits; 0.879 g DW) than in the lower rank fruits and at 19 °C (mean of all fruits; 0.774 g DW). The total numbers of ripe fruits per inflorescence (plant) were slightly smaller at 19 °C. The values of the total fruit fresh and dry weight per inflorescence (plant) were much lower at 19 °C. The bearing fruit period from the flowering of the first flower to the ripening of the last fruit in the inflorescence was 88 days at 15 °C and 69 days at 19 °C, respectively. The daily dry weight increments of total fruit in the inflorescence (per plant) were 0.170 g at 15 °C and 0.151 g at 19 °C. It was considered that the small size of the fruits at a high temperature like 19 °C was not caused by the increase in the number of fruits, but by the low rate of dry matter accumulation in fruit.

Introduction

In 1957, Went reported that ripe fruits on strawberry plants grown at a high temperature were smaller than those on plants grown at a low temperature, based on the results of experiments where the plants were grown at different temperatures and ripe fruits were sampled and weighed. Similar results have been reported by other researchers (Noguchi and Yamakawa, 1988; Sato and Hiraoka, 1971). However, it remained to be determined whether the decrease in the size of the fruits at a high temperature was caused by the increase in the number of fruits per plant, or by the decrease in the total weight of the fruits per plant. Also the mechanism responsible for the decrease in the size of the fruits had not been elucidated. Therefore more detailed studies are needed to analyze the effect of the temperature on the fruit size. In this experiment, the date of flowering of

the flowers and ripening of the fruits, the size of the fruits, the total fruit weight and the total number of fruits on each plant grown in two glasshouses at different controlled temperatures were determined.

Materials and Methods

Runner plants of the strawberry 'Toyonoka' were set into plastic pots filled with a mixture (600 ml) of sand, rice hull charcoal and fertilizer (N : P₂O₅ : K₂O = 0.15 : 0.24 : 0.09 g/pot) in May 1990, and afterwards the plants were treated with a nutrient solution (N : P₂O₅ : K₂O = 0.02 : 0.02 : 0.02 %, 200 ml/pot) at about ten-day intervals until mid-August. The plants were transplanted into Wagner's pots (1/5000 a. 3 liter) filled with soil and fertilizer (N : P₂O₅ : K₂O = 1.9 : 3.1 : 1.9 g/pot) in September and grown from October onward in two glasshouses, where the air temperature was controlled at either 15° or 19 °C night and day. At about 2-week intervals, they were treated with a nutrient solution (N : P₂O₅ : K₂O = 0.01 : 0.02 : 0.01 %, 200 ml/pot). All the flowers of the first inflorescence were tagged and polli-

Received for publication 24 November 1992.

The outline of this study was presented at the Autumn Meeting of the Japanese Society for Horticultural Science, Sapporo, 1991.

nated at full bloom using a paintbrush. Several days after pollination, the fruit diameter (the smaller diameter in the area corresponding to the maximum circumference) was measured using a caliper at around two-day intervals. Based on the appearance of the inflorescence (truss), a flower (fruit) on a peduncle, flowers (fruits) on primary branches arising from the peduncle, flowers (fruits) on secondary branches arising from primary branches were referred to as a primary flower (fruit), secondary flowers (fruits), and tertiary flowers (fruits), etc. Fruits from the secondary to the quinary ranks were numbered first, second and third fruits, etc., in the calendar order of their bloom. Fully red fruits were sampled, the calyces were removed and the fresh weight was determined. After lyophilizing, the dry weight was also determined. Nine plants were used in the 15 °C glasshouse, and 11 in the 19 °C glasshouse. The changes in the fruit diameter with the growth and development were analyzed based on the data of 6 plants in each treatment. During the experiment no flowers of the second inflorescence opened.

Results and Discussion

The primary fruit and the first secondary, tertiary and quaternary fruits (Fig. 1) grew fast in the early and late stages of fruit development, assuming a double sigmoidal curve. Miura et al. (1990) have reported that the growth pattern of

strawberry fruit does not follow a single sigmoidal curve as considered formerly, but a double one. The growth of the first quinary fruits showed the same pattern, although the data were omitted from Fig. 1.

Generally growth was faster in the upper rank fruits, that is, the fruits which developed earlier, than in the lower rank fruits, and at 19° than at 15 °C.

Fresh weight value per fruit at both temperatures (Table 1) was the largest in the primary fruit and decreased with the lowering of the fruit rank. Relative fresh weight per fruit in the primary, secondary, tertiary, quaternary and quinary fruits was 100, 70, 37, 21 and 15 % at 15 °C, and 100, 72, 42, 25 and 25 % at 19 °C, respectively. It has already been reported that the size of ripe fruits in an inflorescence decreases with the lowering of the rank (Darrow, 1929) associated with the decrease of the number of achenes per fruit (Janick and Eggert, 1968; Webb et al., 1974, 1978).

As for the effect of the temperature on the fruit size, the fresh weight value of the primary, secondary, tertiary and quaternary fruits was smaller (13–29 %) at 19° than at 15 °C. Only the weight of the quinary fruits was larger at 19° than at 15 °C. However, the mean fresh weight value of all the fruits was smaller (11 %) at 19° and 15 °C. Went (1957) and Sato and Hiraoka (1971) grew straw-

Fig. 1. Effect of temperature on growth of fruits from primary to tertiary fruits.

Figure in Fig. 2-1, for example, indicates the first fruit of secondary fruits.

Table 1. Effect of temperature on flower opening and ripening and size of fruits from primary to quinary ranks.

Characteristic Treatment	Rank in the first inflorescence					Total value per plant	Mean value of all fruits
	Primary	Secondary	Tertiary	Quaternary	Quinary		
	 Mean/plant						
Number of flowers							
15 °C	1.0 (0.0) ²	2.7 (0.2)	5.3 (0.3)	8.0 (0.5)	3.6 (0.8)	20.6 (1.4)	—
19 °C	1.0 (0.0)	3.0 (0.0)	5.9 (0.1)	7.5 (0.5)	2.3 (0.6)	19.7 (1.1)	—
Number of ripe fruits							
15 °C	1.0 (0.0)	2.7 (0.2)	5.3 (0.3)	6.8 (0.5)	1.6 (0.5)	17.3 (0.8)	—
19 °C	1.0 (0.0)	3.0 (0.0)	5.7 (0.1)	3.6 (0.5)	0.4 (0.2)	13.7 (0.7)	—
	 Mean/fruit						
Number of days from flowering to ripening							
15 °C	37.2 (0.9)	40.5 (0.5)	43.6 (0.3)	46.2 (0.5)	46.2 (0.7)	—	44.0 (0.3)
19 °C	28.2 (0.2)	29.3 (0.3)	32.6 (0.3)	35.0 (0.4)	30.0 (2.0)	—	32.1 (0.3)
Fresh weight of ripe fruit (g)							
15 °C	21.8 (1.2)	15.3 (0.7)	8.1 (0.3)	4.5 (0.2)	3.3 (0.2)	141.5 (5.0)	8.2 (0.4)
19 °C	15.4 (1.0)	11.1 (0.5)	6.4 (0.3)	3.9 (0.2)	3.9 (0.4)	100.4 (5.5)	7.3 (0.3)
Dry weight of ripe fruit (g)							
15 °C	2.343 (0.123)	1.546 (0.082)	0.855 (0.034)	0.527 (0.021)	0.413 (0.030)	15.237 (0.682)	0.879 (0.045)
19 °C	1.667 (0.109)	1.101 (0.049)	0.682 (0.028)	0.441 (0.020)	0.398 (0.030)	10.623 (0.598)	0.774 (0.033)

² SE.

berries under controlled day and night air temperatures and heating at night, respectively. Noguchi and Yamakawa (1988) examined the relation between the mean temperature during the period from the beginning of bloom to the beginning of harvesting and mean fruit weight of several cultivars differing in the area, date and year of planting. The results of these experiments which indicated that the fruits grown at higher temperatures were smaller, agreed with the findings obtained in this paper.

The first inflorescence of the plants used in this experiment is illustrated in Figs. 2 and 3. All the plants grown at 19 °C and most of the plants (67 %) grown at 15 °C belonged to the type shown in Fig. 2, or displayed three secondary flowers in the first inflorescence. However the numbers of flowers per inflorescence (Table 1) at 15° and 19°C were not significantly different, i.e., 21 and 20, re-

spectively.

It has been reported that the strawberry inflorescence is basically a dichasium, as shown in Fig. 3, but that some cultivars under certain environmental conditions exhibit a high frequency of inflorescences with more than two secondary flowers (Darrow, 1929; Janick and Eggert, 1968; Anderson and Guttridge, 1982). Studies on the modification of the structure of the inflorescence associated with environmental conditions are in progress.

The total numbers of ripe fruits per inflorescence (per plant) were 17 at 15 °C and slightly lower at 19 °C (14), due to the smaller number of quaternary and quinary fruits at 19 °C. Evidently the decrease in the fruit size at 19 °C did not depend on the increase in the number of fruits.

The total fruit weight per inflorescence was 142 g at 15 °C and 100 g at 19 °C. The total dry

Fig. 2. Flower position and order of flowering in the first inflorescence (type one at 15 °C). Figures in and out circles show the order of anthesis and rank of flowers, respectively. 2-3, for example, indicates third flower of secondary flowers.

Fig. 3. Flower position and order of flowering in the first inflorescence (type two at 15 °C).

weight per inflorescence showed also the same pattern as the fresh weight, namely the weight was 15 g at 15 °C and 11 g at 19 °C.

Consequently, it was concluded that the decrease in the fruit size at 19 °C was associated with the decrease in the total fruit weight.

The duration of the ripening period (Table 1), or the number of days from full bloom of flower to red ripening of fruit, was shorter in the higher rank fruits except for the quinary fruits. The duration of the ripening period of the quaternary fruit was 124 % of that of the primary fruit at both temperatures. The duration of the fruit ripening from the primary to quinary ranks was 24 ~ 35 % shorter at 19 ° than at 15 °C. The averages of all the fruits in an inflorescence were 44 days at 15 °C and 32 days at 19 °C.

In Table 1, the fresh and dry weights per fruit and the duration of the ripening period indicate the means of values for each fruit rank including

different sub-rank fruits, except for the primary fruit. Tables 2 and 3 show the values of each fruit within the secondary, tertiary and quaternary ranks. Within the secondary to quaternary ranks, the weight per fruit was smaller, but the duration of the ripening period was longer in the lower rank fruits that developed later. The fruits within the secondary to quaternary ranks showed generally a heavier weight, and a longer duration of the ripening period at 15 ° than 19 °C. In the quinary rank no distinct relationship was observed because the number of fruits was smaller.

It is recognized that the total fruit weight (Table 1) on a plant is attained during the bearing fruit period from the flowering of the first flower to the ripening of the last fruit. The bearing fruit periods (Table 4) were 88 days at 15 °C and 69 days at 19 °C.

To estimate the daily dry weight increment of the total number of fruits on a plant, the receptacle in each rank at full bloom on plants grown in the field was weighed and used as a value of the

Table 2. Effect of temperature on ripening and size of fruits within secondary and tertiary ranks.

Characteristic Treatment	Rank in the first inflorescence (mean/fruit)								
	Secondary			Tertiary					
	First	Second	Third	First	Second	Third	Fourth	Fifth	Sixth
Number of days from flowering to ripening									
15 °C	39.0 (0.6) ^z	41.0 (0.8)	41.8 (1.0)	42.0 (0.5)	42.7 (0.5)	43.4 (0.7)	44.2 (0.5)	46.0 (1.4)	44.5 (0.6)
19 °C	28.5 (0.4)	29.6 (0.5)	29.8 (0.6)	31.1 (0.5)	32.2 (0.6)	32.5 (0.4)	33.2 (0.6)	33.2 (0.6)	33.8 (0.8)
Fresh weight of ripe fruit (g)									
15 °C	16.9 (1.2)	14.1 (1.1)	14.5 (0.9)	10.1 (0.5)	9.4 (0.5)	8.6 (0.7)	7.3 (0.6)	6.0 (0.7)	5.7 (0.5)
19 °C	12.1 (0.9)	10.7 (0.8)	10.4 (0.5)	8.5 (0.7)	7.4 (0.5)	6.7 (0.4)	5.6 (0.4)	5.2 (0.4)	4.3 (0.6)
Dry weight of ripe fruit (g)									
15 °C	1.728 (0.149)	1.421 (0.135)	1.462 (0.104)	1.044 (0.062)	1.005 (0.059)	0.882 (0.072)	0.771 (0.063)	0.653 (0.084)	0.633 (0.051)
19 °C	1.221 (0.102)	1.040 (0.095)	1.041 (0.037)	0.894 (0.085)	0.769 (0.057)	0.687 (0.050)	0.610 (0.052)	0.575 (0.043)	0.512 (0.051)

^z SE.**Table 3.** Effect of temperature on ripening and size of fruits within the quaternary rank.

Characteristic Treatment	Rank within the quaternary fruits (mean/fruits)								
	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
Number of days from flowering to ripening									
15 °C	44.8 (0.9) ^z	44.6 (0.5)	46.1 (1.3)	45.6 (1.1)	47.4 (1.6)	48.0 (2.3)	49.0 (2.8)	46.0 (0.6)	47.0 (—)
19 °C	33.8 (0.6)	34.4 (0.7)	35.1 (1.0)	36.0 (1.5)	36.5 (1.7)	36.0 (2.0)	36.0 (1.0)	37.0 (—)	—
Fresh weight of ripe fruit (g)									
15 °C	6.0 (0.4)	5.5 (0.4)	4.8 (0.5)	4.3 (0.4)	3.6 (0.4)	4.3 (0.4)	3.1 (0.6)	3.9 (0.3)	2.4 (—)
19 °C	4.4 (0.3)	3.9 (0.4)	4.0 (0.6)	3.4 (0.6)	2.8 (0.3)	3.3 (0.4)	3.5 (0.0)	3.6 (—)	—
Dry weight of ripe fruit (g)									
15 °C	0.664 (0.056)	0.625 (0.042)	0.547 (0.055)	0.524 (0.041)	0.416 (0.047)	0.501 (0.059)	0.385 (0.080)	0.489 (0.023)	0.311 (—)
19 °C	0.500 (0.032)	0.454 (0.044)	0.453 (0.068)	0.388 (0.076)	0.342 (0.033)	0.380 (0.082)	0.390 (0.003)	0.402 (—)	—

^z SE.**Table 4.** Estimation of daily increment of total fruit dry weight per plant.

Treatment	Bearing fruit period (days)	Daily increment of fruit dry weight (g/day)
15 °C	88.1 (2.1) ^z	0.170
19 °C	68.5 (7.3)	0.151

^z SE.

date of full bloom in this experiment. Dry weight increment of the total number of fruits per plant was 14.966 g at 15 °C and 10.367 g at 19 °C, with a daily dry weight increment of 0.170 g at 15 °C and 0.151 g at 19 °C.

Consequently, the small size of the fruits at a high temperature like 19 °C was considered to be associated with the decrease in the total weight of fruit due to the low rate of dry matter accumula-

tion in fruit.

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イチゴ果実の大きさに及ぼす温度の影響

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摘 要

イチゴ‘とよのか’を10月から昼夜とも15℃あるいは19℃に制御したガラス室内で育てた。受粉数日後から第1果房すべての果実(1番果～5番果)の直径を約1日おきに計測し、全体が着色した果実を採取し、重さを調査した。果実の短径の推移から見た生長は、両区のいずれのランクの果実も前期と後期の二回急速であり、二重S字型曲線を取り、早期に発達した上位ランクの果実ほど、また15℃区より19℃区の方が急速であった。全果実の平均重量は新鮮重、乾物重とも両区で上位ランクの果実ほど大きく、両区を比較すると15℃区の方が19℃区より大きく、乾物

重ではそれぞれ0.879gおよび0.774gであった。株当たり果実数は19℃区でわずかに少なく、総果実重量は新鮮重、乾物重とも19℃区で著しく小さかった。1株における、最初の花の開花から最後の果実の着色までの日数は15℃区で88日、19℃区で69日であり、その期間中の1日当たり乾物重増加量を推定したところ、15℃区で0.170g、19℃区で0.151gであった。以上の結果から、高温の19℃区で成熟果実のサイズが小さかったのは着果数の増加によるのではなく、果実における乾物の蓄積が遅いことによるものと考えられた。