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Production of June-bearing Strawberries in Summer under Controlled Day Length and Temperature

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Summary

June-bearing strawberries cannot be produced in summer because they require low temperatures and short days for flower bud formation, and because high air temperatures decrease fruit yield and quality. I tried to produce fruits of June-bearing strawberry in summer by controlling day length and air temperature. Seedlings of three cultivars, ‘Sachinoka’, ‘Benihoppe’, and ‘Marihime’, were transplanted to a greenhouse in autumn 2012 and grown in rockwool culture. In late spring 2014 the growing area was covered with shade cloth having heat-insulating properties. Day length was controlled to 12 h and the air was cooled initially to 28/15°C (initially) and then to 28/10°C in summer. In the control, air temperature was not cooled. In the air-conditioned area, the vapor pressure deficit was always lower and the CO_2 concentration in the dark period was higher than in the control. In control plants, fruit yield after May was very low, and no fruit was harvested in September, while the air-conditioned plants produced similar yield as in winter. Soluble solids content and firmness of fruits in the air-conditioned area in summer were higher than in fruit harvested in winter.

Keywords: Control, Environment, Heat pump, Temperature, Day length, Quality, Strawberry, Yield

1. Introduction

June-bearing strawberry (*Fragaria* × *ananassa* Duch.) requires low temperatures and a short day length to form flower buds[1-3]. Therefore, fruits cannot be harvested in the summer, because flower buds do not initiate under high temperatures and long day lengths. Even if flowers can be induced to bloom and fruits to set by controlling day length or by localized cooling of the crown[4], fruit weight and quality will both be low[5] because of extremely high temperatures in the greenhouse. In Japan, strawberry production is minimal between June and December[6]. In this period, most strawberries are imported, except for the limited production of ever-bearing strawberries. Because ever-bearing strawberries are lower taste than June-bearing ones, the production of quality strawberries in summer is desirable. In this study, I tried to produce strawberry fruits in summer of equal quality to those produced in winter by controlling day length and air temperature.

2. Materials and Methods

2.1 Plant materials

June-bearing strawberry cultivars ‘Sachinoka’, ‘Benihoppe’, and ‘Marihime’ were used in this study. Seedlings were transplanted to containers (W×L×H = 20×65×18.5 cm) filled with rock-wool granules and transferred to elevated benches in the greenhouse on September 10, 2012. Each container had six plants, and the containers were spaced at intervals of 45 cm. Each container had a 40-L tank beneath the bench to supply a quarter-strength Otsuka A nutrient solution to the plants; drainage from the container was returned to the solution tank. The nutrient solution was refreshed monthly. The greenhouse was ventilated by fans when the air temperature exceeded 25°C and was heated to 10°C at night. Supplemental lighting with incandescent lamps was carried out by the method of prolonging day length to 12 h from December to February. Flowers were pollinated by honey bees.

2.2 Growing environment in summer

The experimental area in the greenhouse was divided into two separate blocks (4 m×6 m), each with nine containers (3 replicates per cultivar). The sides of each block were covered with black polyethylene (PE) film. Day length was controlled to 8 h by placing black PE film at about 50 cm above the plants between 18:00 and 10:00, beginning April 8, 2013. After April 26, the PE film was removed and the sides and top of the growing area were covered with shade cloth (Venus raschel shade, Koizumi Jute Mills, Kobe, Japan) that also had heat-insulating properties (Fig. 1). The shade cloth above the growing area was opened at 6:00 and closed at 18:00 by an automatic roll-up system (Kuru-fami AceIII; Seiwa, Kyoto, Japan) to shorten a day length of 12 h. On May 28, the top of the growing area of one block was covered with polyvinyl chloride (PVC) film inside the shade cloth and the air temperature was cooled to 28/15°C

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(light/dark) by a heat pump (LRDYP8C; Daikin, Osaka, Japan). Air from the heat pump flowed to the plants through a PE duct at the center of the bench. The duct had holes (ø=75 mm) at intervals of 45 cm. After June 19, the temperature in the dark period was changed to 10°C. A separate control block was not air conditioned or covered with PVC film.

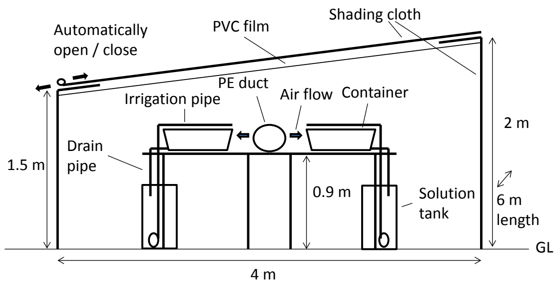

Fig.1 Schematic figure of growing system .

2.3 Environmental measurements

The photosynthetic photon flux density (PPFD) outside the greenhouse was measured using a quantum sensor (LI-190, Li-cor, Lincoln, NE, USA). Air temperature was measured with thermocouples (ø=0.32 mm), relative humidity with humidity sensors (CHS-UPS; TDK, Tokyo, Japan), and CO_2 concentration with CO_2 transmitter (GMT220; Visara , Helsinki, Finland) at the level of the plant canopy in each treatment. Relative humidity was converted to vapor pressure deficit (VPD) using Tetens formula[7]. All data were measured every minute and the 5-min averages were recorded every 5 minutes by a data logger (CR-1000; Campbell Scientific, Logan, UT, USA).

2.4 Evaluation of fruit yield and quality

Matured fruits were harvested twice weekly and individually weighed. From June to September, five fruits per cultivar per treatment were evaluated for firmness and soluble solids content (SSC) monthly. Each fruit was penetrated by a cylindrical plunger (3 mm diam.), and maximum resistance was recorded with a rheometer (Creep Meter RE2-33005B with a CA-3305 automatic analyzer; Yamaden, Ibaraki, Japan). Fruit sap was squeezed by hand and SSC measured with a digital refractometer (PR-101; Atago, Tokyo, Japan).

3. Results and Discussion

PPFD, air temperature, VPD, and CO_2 concentration in the greenhouse overall and in each treatment from August 9–12 are shown in Fig. 2 as representative data of the environmental conditions in summer. Weather during these periods was fine. PPFD outside the greenhouse reached 1,600–1,800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at midday. Maximum and minimum air temperatures in the greenhouse were around 45°C and 27°C, respectively. Air temperatures in the control were similar, while those in the air-conditioned area were around 28°C and 10°C, respectively. VPD in the control (maximum, around 9 hPa; minimum, around 1 hPa) was slightly higher than in the greenhouse overall; in the air-conditioned area it was about 3 hPa at midday and almost saturated in the dark period. CO_2 concentrations in both treatments were almost the same in the light period. However, CO_2 concentrations in the air-conditioned area (500 ppm) were higher than in the control in the dark period.

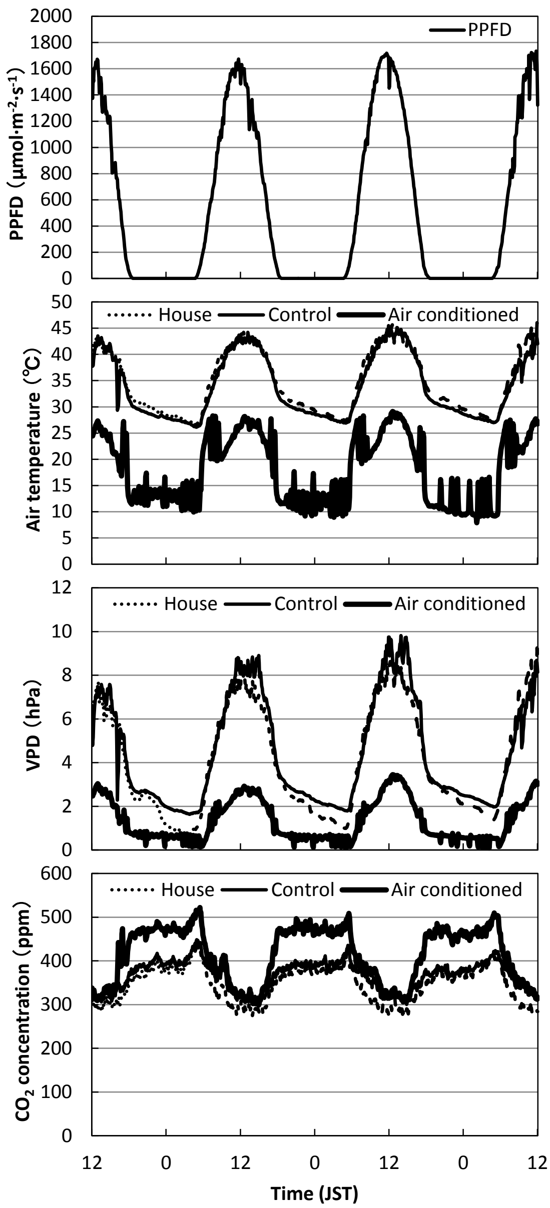

Fig.2 Environmental conditions in the greenhouse in summer. House, outside the growing area; Control, not air conditioned. Value were measured at plant canopy height from August 9–12.

Table 1 Daily maximum and minimum values of climate data on a fine day in August

Climate factor/ Treatment	Maximum	Minimum
Temperature (°C)		
Greenhouse	43.5 ± 1.3 b[y]	25.6 ± 1.4 b
Control	43.9 ± 1.0 b	25.6 ± 1.0 b
Air conditioned	28.9 ± 1.1 a	8.4 ± 0.9 a
VPD[z] (hPa)		
Greenhouse	7.9 ± 0.76 b	1.0 ± 0.28 b
Control	8.0 ± 0.91 b	1.6 ± 0.26 c
Air conditioned	3.1 ± 0.38 a	0.1 ± 0.02 a
CO_2 (ppm)		
Greenhouse	412 ± 14 a	281 ± 9 a
Control	423 ± 15 a	310 ± 7 b
Air conditioned	496 ± 17 b	306 ± 14 b

Values are mean ± s.d. (n=27).
[y] Different letters indicate significant differences (p=0.05) by Tukey–Kramer's HSD test.
[z] VPD, vapor pressure deficit

Table 2 Averaged values of climate data in August

Climate factor/ Treatment	Average	
	Light[x]	Dark
Temperature (°C)		
Greenhouse	34.9 ± 4.4 b[y]	26.5 ± 2.7 b
Control	34.6 ± 4.0 b	26.4 ± 2.2 b
Air conditioned	23.5 ± 0.7 a	12.7 ± 1.2 a
VPD[z] (hPa)		
Greenhouse	4.5 ± 1.58 b	1.4 ± 0.61 b
Control	4.6 ± 1.42 b	1.9 ± 0.46 c
Air conditioned	1.6 ± 0.47 a	0.5 ± 0.08 a
CO_2 (ppm)		
Greenhouse	329 ± 20 a	381 ± 15 a
Control	350 ± 14 b	392 ± 15 b
Air conditioned	364 ± 22 c	459 ± 13 c

Values are mean ± s.d. (n=27).
[x] Light, 6:00–18:00; Dark, 18:00–6:00
[y] Different letters indicate significant differences (p=0.05) by Tukey-Kramer's HSD test.
[z] VPD, vapor pressure deficit

Average daily maximum and minimum values of climate data on a fine day in August are shown in Table 1, and averages of daily averaged values are shown in Table 2. In the control, minimum values of VPD and CO_2 concentration were significantly higher than in the greenhouse overall. Averaged values of VPD in the dark period and CO_2 concentration in both light and dark periods were also higher. Water was sometimes sprayed in passages in the greenhouse to cool it, although the area around the experimental block was not sprayed; this may have caused the lower VPD in the greenhouse than in the control. However, I cannot explain why the CO_2 concentration was higher in the control. The air-conditioned area was characterized by lower VPD and higher CO_2 concentrations, especially in the dark period. This area was covered by PVC film all day. The lower VPD may have been caused by the accumulation of vapor transpired by plants. Although CO_2 starvation was a concern because CO_2 fertilization was not done in this experiment, the CO_2 concentration in the air-conditioned area was high enough. Because the shade cloth used in this experiment was slightly permeable to air, I assumed the air ventilated naturally. However, the higher CO_2 concentrations cannot be explained by natural ventilation. One hypothesis explaining the CO_2 levels is soil respiration. The ground in the experimental area was soil covered with an air-permeable fabric sheet. Perhaps the higher CO_2 concentrations during the dark period were caused by low air temperatures, because cool air is more dense. Further research is needed to clarify why CO_2 concentrations were higher in the air-conditioned area.

Fruit yield in the control was less than 50 g/plant in July, and no fruit was harvested in September from any cultivar (Fig. 3). Flower bud differentiation of June-bearing strawberry requires a short day length and low air temperatures. In particular, the air temperature in the dark period must be less than 15°C[1)]. Although the day length in the control was short enough (12 h), the air in the dark period was warmer than 25°C, so I believe that the flower buds did not differentiate.

In the air-conditioned area fruits were harvested throughout the summer. Monthly averaged yields of 'Benihoppe', 'Marihime', and 'Sachinoka' from January to May, the main harvesting period of commercial strawberries, were 117, 102, and 76 g/plant in this experiment, respectively, while the monthly averaged yields from June to September were 103, 73, and 59 g/plant, respectively. Lower yields in summer were caused by lower yields in June and July, which were probably due to the delay in beginning the day length and temperature treatments. The day length on April 8, when the short-day treatment began, was about 13 h. The minimum air temperature around May 28, when the air-conditioning started, often exceeded 20°C. Those conditions could delay the formation and development of flower buds. 'Benihoppe' is a high-yield cultivar[8-9)], and one of its parents, 'Akihime', favors higher root temperatures[10-11)]. Based on these results, I inferred that 'Benihoppe' can achieve high yields in summer.

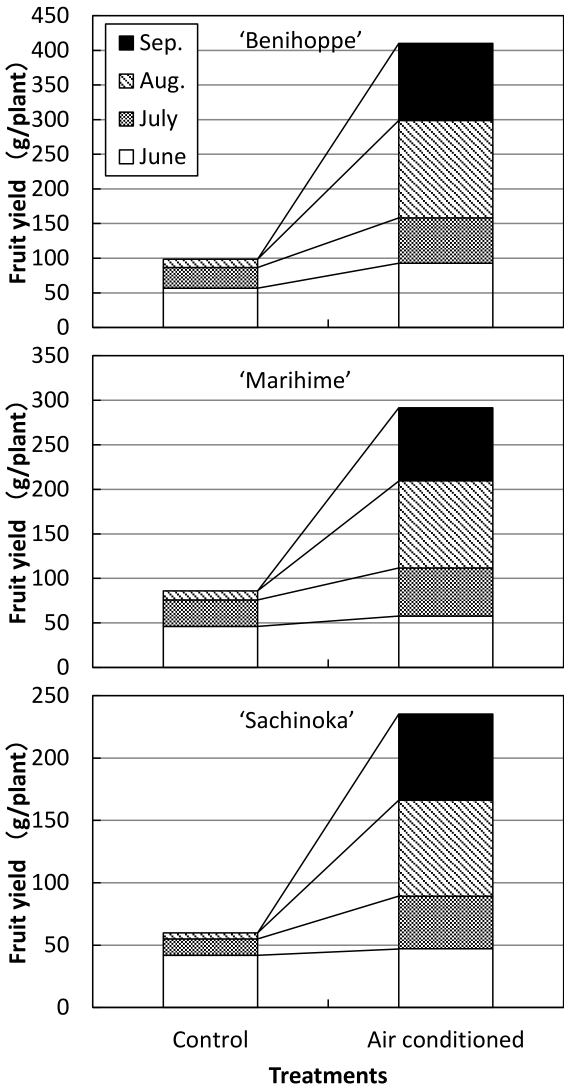

Fig.2 Monthly fruit yield in summer

Table 3 Averaged fruit weight in summer

Cultivar	Treatments	July	Aug.	Sep.
Benihoppe	Control	5.7	3.4	—
	Air conditioned	11.8	15.6	14.6
Marihime	Control	6.1	3.7	—
	Air conditioned	9.1	11.9	10.9
Sachinoka	Control	4.8	4.2	—
	Air conditioned	11.0	12.5	9.7

Values are in g/fruit.
—, no data because not enough fruits were harvested

Fruit weight in the control was very low in all cultivars, and most fruits in July were too small to be marketable (Table 3). Fruit weights in the air-conditioned area were high enough in all cultivars. Averaged fruit weights from December to May were 13.8, 12.3, and 11.0 g in 'Benihoppe', 'Marihime' and 'Sachinoka', respectively, while in the air-conditioned area in the summer they were 14.0, 10.7, and 11.4 g, respectively. Fruit weights were slightly lower than in winter in July for 'Benihoppe' and in September for 'Marihime' and 'Sachinoka'. The fruit weight of 'Marihime' was lower than in winter, while in the other cultivars, fruit weights in summer and winter did not differ.

In March, SSCs were 7.8, 6.7, and 7.4 °Brix and fruit firmness were 1.5, 1.2, and 1.3 N in 'Benihoppe', 'Marihime', and 'Sachinoka', respectively. In summer, both SSC and fruit firmness were higher than in March in all cultivars, except for the SSC of 'Sachinoka' in September (Tables 4–5). In the control, not enough fruits could be harvested in August and September to evaluate fruit quality. SSC and fruit firmness are reported to increase at lower temperatures[12-13]; thus, cooling the air in summer, when solar radiation is higher than in winter, could improve fruit quality.

Table 4 Soluble solid content of fruit in summer

Cultivar	Treatment	July	Aug.	Sep.
Benihoppe	Control	9.9	—	—
	Air conditioned	12.2	10.3	8.2
Marihime	Control	9.1	—	—
	Air conditioned	11.1	10.4	7.3
Sachinoka	Control	9.2	—	—
	Air conditioned	10.8	9.9	6.7

Value are means of 5 fruits and given in °Brix.
—, no data because not enough fruits were harvested

Table 5 Fruit firmness in summer

Cultivar	Treatments	July	Aug.	Sep.
Benihoppe	Control	2.2	-	-
	Air conditioned	2.6	2.3	2.2
Marihime	Control	1.3	-	-
	Air conditioned	2.0	2.0	1.6
Sachinoka	Control	2.1	-	-
	Air conditioned	3.2	2.2	1.9

Values are means of 5 fruits and given in N.
—, no data because not enough fruits were harvested

This study demonstrated that strawberry fruits with high quality and sufficient yield could be harvested in a greenhouse in summer if both day length and air temperature were controlled. In this experiment, the day length was 12 h and air temperature was 28/10°C (light/dark). In general, the optimum temperature for photosynthesis of strawberry plants is 20–23°C[14], while nighttime temperatures below 15°C are needed to induce flower buds[15]. Ikeda et al.[16] reported higher strawberry fruit quality when the dark-period temperature was 7°C than when it was 12°C. The air temperature used in this experiment might not be optimum for photosynthesis and fruit quality of strawberry. However, fruit yield and quality are not the only considerations; the costs of materials, labor, and energy consumption are very important to commercial production of strawberry fruits in summer. To save energy for cooling, other methods such as pad-and-fan systems and spot cooling of the crown may need to be combined with air conditioning. Further study is needed to determine the optimum temperature regime and cooling system.

4. Concluding Remarks

Strawberry fruits with high quality and sufficient yield could be harvested in a greenhouse in summer if not only day length but also air temperature were controlled. In this experiment, the day length was 12 h and air temperature was 28/10°C (light/dark). Further study is needed to determine the optimum temperature regime and cooling system with considering the plant physiology and the costs of materials, labor, and energy consumption.

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