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Effect of high temperature stress on the reproductive growth of strawberry cvs. 'Nyoho' and 'Toyonoka'

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Abstract

High temperatures are known to reduce fruit size and fruit weight in strawberry, but cultivar differences in the response to high temperature stress during the reproductive stage up to the second inflorescence have not been sufficiently reported. We examined the effect of two day/night temperature regimes on fruit set and fruit growth in two cultivars, 'Nyoho' and 'Toyonoka'. A high day/night temperature of 30/25 °C reduced the number of inflorescences, flowers, and fruits in both cultivars compared with plants grown at 23/18 °C. The percentage of fruit set in 'Nyoho' was not significantly different between the two temperature treatments, while that in 'Toyonoka' was much lower at 30/25 °C than at 23/18 °C. Days to ripening was shorter at 30/25 °C than at 23/18 °C, and no cultivar differences were observed. Fresh weight of primary, secondary, and tertiary fruits was greater at 23/18 °C than at 30/25 °C in both cultivars, and no cultivar differences were observed, except in tertiary fruits. The diameter of fruits from all positions was also reduced at 30/25 °C in both cultivars. Relative growth rates of fruits showed two peaks in both cultivars and in both temperature treatments. Both peaks appeared earlier at 30/25 °C than at 23/18 °C. Percentage of fruit set at 30/25 °C in the second inflorescence was also significantly lower in 'Toyonoka' than in 'Nyoho'. These results indicate that high temperature stress negatively affects the reproductive process in strawberry and that plant response to high temperature stress is cultivar-related in such responses.

Keywords: *Fragaria* × *ananassa*; Reproduction; Inflorescence; Fruit set; Fruit growth; Relative growth rate

1. Introduction

Reproductive development in plants is more sensitive to high temperatures than vegetative growth because plant fertility is considerably reduced as temperatures increase (McKee and Richards, 1998; McWilliam, 1980). Fruit set and fruit growth were shown to decrease significantly at day/night temperatures of 30/25 °C in cherimoya (Higuchi et al., 1998), 33/22 °C in groundnut (Prasad et al., 2000), and 35/15 °C in *Brassica* (Angadi et al., 2000). For heat-sensitive plants such as tomato, no fruit set occurs at day/night temperatures of 35/23 °C (Abdul-Baki and Stommel, 1995). Studies on cowpea (Hall, 1992), common bean (Gross and Kigel, 1994), and peach (Kozai et al., 2004) showed that elevated temperatures during flower development can significantly reduce fruit set. The decrease in fruit set has generally been attributed to low pollen viability and germinability at high temperatures in several crop species such as tomato (Sato et al., 2000), groundnut (Prasad et al., 2001), and bean (Porch and Jahn, 2001). The effect of high temperatures on fruit growth is also well known. Increases in temperature have been shown to accelerate fruit growth rate in passionfruit (Utsunomiya, 1992) and strawberry (Went, 1957), but reductions in fruit size were also observed. Differences in the response to high temperatures among cultivars have also been observed in cotton (Ashraf et al., 1994), *Primula* (McKee and Richards, 1998), and tomato (Nkansah and Ito, 1994; Sato et al., 2004). Such differences have allowed researchers to classify cultivars into either heat-tolerant or heat-sensitive types.

The strawberry is mainly grown in temperate climates because its optimum growth temperature ranges from 10 °C to 26 °C (Strik, 1985). However, it can also be grown commercially in the cooler highlands of tropical countries such as the Philippines where temperatures range from 12 °C to 26 °C (Aspuria et al., 1996). High temperatures above 30 °C are known to reduce fruit size (Wang and Camp, 2000), fruit weight (Kumakura and Shishido, 1994), and overall plant growth (Hellman and Travis, 1988). Mori (1998) found that the number

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of achenes per fruit was lower at a day/night temperature of 32/27 °C than at 24/19 °C and 20/15 °C. However, he did not measure fruit set, fruit growth, and days to maturity.

There are few studies that compare strawberry cultivars in terms of their performance at high temperatures. The oldest report on heat resistance in strawberry was made by Darrow (1966), who found ‘Blakemore’ and ‘Missionary’ to be heat-resistant cultivars. Archbold and Clements (2002) found that at 39 ± 2 °C, *Fragaria virginiana* plants originating from eastern North America were more heat tolerant than those from western North America. Wang and Camp (2000) showed that in ‘Earliglow’ and ‘Kent’ strawberries, fruit weight decreased with increasing temperature, but there were no cultivar differences in the high temperature treatment. Wang and Lin (2006) also found differences in the membrane lipid content of the same cultivars exposed to increasing day/night temperatures. A comparison of the responses of ‘Korona’ and ‘Elsanta’ strawberry plants to increasing photoperiod and day/night temperature combinations showed that in terms of flower production, ‘Korona’ was more sensitive to photoperiod and temperature than ‘Elsanta’ (Verhuel et al., 2007). However, their study did not include fruit development. Ledesma and Sugiyama (2005) reported cultivar differences in the response of pollen germination to high temperature stress of two Japanese strawberry cultivars.

In tropical countries, strawberries are harvested from sequentially developing inflorescences of plants for several months; however, the effects of high temperatures on fruit set and fruit growth for long periods have not been studied. The aims of this study were to determine the responses of two strawberry cultivars to high temperature stress in terms of fruit set and fruit growth in and to determine if strawberry cultivars respond differently to high temperature stress.

2. Materials and methods

2.1. Plant growth

Rooted runners of two leading Japanese strawberry cultivars, ‘Nyoho’ and ‘Toyonoka’, were obtained from a nursery in Yamanashi, Japan, in August of 2004 and 2006. To ensure uniform flower emergence, runners were first exposed to a temperature of 10 °C for 3 weeks to induce flowering in a growth chamber with a 10 h photoperiod under artificial lighting (fluorescent tubes, 80–90 μmol s^{-1} m^{-2}). After flower induction, plants were transplanted into 15 cm plastic pots containing a medium of 4:1:1 of soil compost (Soil Mix; Sakata, Yokohama, Japan): granulated soil-derived potting material (Engei-baido; Kureha, Tokyo, Japan): vermiculite and maintained in a vinyl house under natural light conditions from September 1 to 30 in 2004 and 2006. The average day/night temperature was 26/15 °C.

2.2. Temperature treatment

When flower buds became visible during the last week of October in both 2004 and 2006, 10 plants of each cultivar were transferred to two growth chambers kept at either 23/18 °C (control) or 30/25 °C (high) day/night temperatures. A slow-release complete fertilizer (6-10-4; Lilly Miller, CA, USA) was applied to each pot at a rate of 10 g plant^{-1}. Flowers were pollinated with a paintbrush when anthers became dehiscent. Five plants from each treatment were randomly selected for determining the relative growth rate (RGR). The diameter and length of fruits from these five plants were measured with a caliper at two day intervals until they ripened. The RGR was then calculated from the data on fruit diameter as follows: $\mathrm{RGR} = (\ln D_2 - \ln D_1)/(t_2 - t_1)$, where D_1 and D_2 are fruit diameter at times t_1 and t_2, respectively. Days to ripening, fruit weight, the number of flowers and fruits, and the percentage of fruit set were also recorded. Data were collected from the first and second inflorescences. The experiment was concluded on January 31 in 2004 and 2006 when all fruits on the second inflorescence had been harvested.

Due to space limitations in the growth chambers, only 10 plants from each cultivar could be used for the experiment. Hence, the experiment was repeated in 2006 for verification purposes.

3. Results

3.1. Effect of temperature on fruit set and fruit growth

Because results from the two trials were similar, only the 2004 data for RGR and fresh weight of the first inflorescence, as well as the 2004 data for all parameters measured in the second inflorescence are presented since these are from the original experiment.

The number of inflorescences, flowers, and fruits were lower at 30/25 °C than at 23/18 °C in both cultivars (Tables 1 and 2). Results were consistent for both years, although ‘Nyoho’ produced more flowers and fruits in 2006 than in 2004 in both temperature treatments. ‘Nyoho’ produced more inflorescences, flowers, and fruits than ‘Toyonoka’. In ‘Nyoho’, no significant difference was found in the percentage of fruit set between 30/25 °C and 23/18 °C. However, the percentage of fruit set in ‘Toyonoka’ was significantly lower at 30/25 °C than at 23/18 °C in both years. A significant interaction between temperature and cultivar was found in the percentage of fruit set.

Table 1
Mean number of inflorescences on strawberry plant cvs. ‘Nyoho’ and ‘Toyonoka’ grown under two day/night temperature regimes

Cultivar	2004		2006	
	23/18 °C	30/25 °C	23/18 °C	30/25 °C
Nyoho	3.3	2.3	3.1	2.4
Toyonoka	2.4	1.5	2.7	1.3
Significance[a]				
Temperature	**		**	
Cultivar	**		**	
Interaction	N.S.		N.S.	

[a] N.S. and (**) indicate not significant and significant at $P \leq 0.01$, respectively.