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Effect of root zone cooling on flower development and fruit set of 'Satohnishiki' sweet cherry

Kenji Beppu*, Makito Iino and Ikuo Kataoka

*Faculty of Agriculture, Kagawa University, Miki, Kagawa 761-0795, Japan. * E-mail: beppuk@ag.kagawa-u.ac.jp*

Abstract

The effects of root zone cooling on flower development and fruit set of 'Satohnishiki' sweet cherry were studied. Soil temperature in pots of the tree was maintained at approximately 11°C from bud burst until petal fall, then at about 15°C until harvest by circulating cooled water through a tube coiling the pots. Root cooling did not appreciably affect flower size, pollen germination and pollen tube elongation in pistils. However, the treatment prolonged ovule longevity and markedly increased the fruit set rate. These results suggest the possibility of applying root cooling to improve the fruit set of sweet cherries grown in warm regions.

Key words: Fruit set rate, ovule development, *Prunus avium*, soil cooling

Introduction

Recently, attempts have been made to produce sweet cherries in southwestern Japan to harvest the fruits earlier than in the northern major production areas and to supply local markets. In this region, however, severe yield fluctuation on account of poor fruit set is a serious problem that prevents stable production (Beppu and Kataoka, 2006).

Under controlled conditions, it was demonstrated that the fruit set rate in the 'Satohnishiki' cultivar decreased markedly mainly due to the rapid degeneration of the nucelli and embryo sacs after anthesis when the trees were exposed to high temperatures, above 20°C, from one month before anthesis to petal fall (Beppu *et al.*, 1997). In south-western Japan, temperatures during bud development are high. For example, in Takamatsu City, Kagawa Prefecture, the daily high temperature in April exceeded 20°C for an average 16 days during the past 10 years. These facts imply that cooling the whole tree is a possible method for improving fruit set of sweet cherries grown in warm regions. Unfortunately, the costs involved to cool the entire tree are prohibitive for commercial applications.

However, it has been documented that the poor flower bearing of satsuma mandarin due to high temperature in early forcing culture can be improved by cooling only the root zone (Poerwanto *et al.*, 1989), and this method has already been put to practical use in Japan (Hirose, 2003). Likewise, root zone cooling in sweet cherries grown in warm regions might improve the flower development and the fruit set.

In this study, we examined the effect of root zone cooling in spring on flower development and the fruit set of sweet cherry grown in a warm region.

Materials and methods

Five-year-old 'Satohnishiki' sweet cherry (*Prunus avium* L.) trees, grafted on 'Aobazakura' (*Prunus lannesiana* Wils.), a common rootstock for sweet cherries in Japan, were grown in 7-liter pots filled with a granite soil: bark compost (2 : 1 ; v/v) at the research field of Kagawa University. Four pots of the tree were individually coiled with a vinyl tube, and covered with thermal insulation and aluminium coated polyvinyl chloride film. A filled 100 L water tank was placed below ground level. Water in the tank was cooled with a circulating cooler and pumped to the tube coiling the pots with a portable electric pump. The cooler was set at temperatures of 10°C from April 1 (bud burst) to April 27 (petal fall), then 15°C till May 29 (harvest). Four untreated trees were used as controls. When the soil moisture tension reached 10 kPa, 1 L of water was supplied. Soil temperatures in the pots were measured with thermocouples placed at a depth of 10 cm.

At anthesis, six flowers per tree were collected, the weight of the flower, and the lengths of the peduncles, petals, and pistils were recorded. From these flowers, pollen grains were collected to estimate the germination rate on a medium containing 15% sucrose, 5 ppm boron and 1% agar at 20°C. To evaluate ovule development, six flowers per tree were collected at anthesis and three days after anthesis. The ovaries were fixed in FAA solution and after dehydration, embedded in paraffin wax, and sliced into 16 μm thick longitudinal serial sections which were stained with Mayer's acid-hæmalun. The lengths and widths of ovary, ovule and nucellus were measured with a micrometer under a light microscope, and the developmental stages of the embryo sac and nucellus were observed. Ovules were classified into two groups: normal or abnormal (degenerated embryo sac or nucellus); the developmental stages of the normal ovules were further classified into six categories: no embryo sac, embryo sac mother cell, two-nucleate stage, four-nucleate stage, and eight-nucleate stage with fused or unfused polar nuclei.

To promote the fruit set, all flowers were hand-pollinated at anthesis with the 'Takasago' pollen which, *in vitro*, had more than a 60% germination rate. The rate of the fruit set was recorded at harvest. To observe the pollen tube growth in the pistils, pistils from hand-pollinated flowers were collected three days after anthesis and preserved in FAA solution. Observations were made using a fluorescence microscope.

Results and discussion

The actual ranges of soil temperature in the pots are shown in Fig. 1. Soil temperature in the root cooling treatment was kept approximately at the above-mentioned set temperatures. The average soil temperature in the treatment, from the onset of the treatment until April 27, was 11.4°C, which was 5.0°C lower than that of the control. It was 15.3°C until May 29, 4.6°C lower than the control. Root cooling lowered the average daily maximum soil temperature during the treatment period by 11.6°C.

Most of the control and root cooling-treated trees began blooming on April 15. Root cooling had no appreciable effect on the size of the flower parts at anthesis (Table 1). Pollen germination rates on the medium were almost 50% in treated and untreated trees. The pollen tubes reached the locules three days after pollination with or without cooling treatment (Data not shown). In a previous study, it was demonstrated that overall temperature did not affect pollen germination or pollen tube growth in pistils (Beppu *et al.*, 1997). Likewise, root zone temperature does not seem to have an influence.

On the other hand, root zone temperature clearly affected the ovule development and fruit set. At anthesis, many embryo sacs were at the four-nucleate stage or earlier, whereas three days after anthesis, the frequencies of ovules with an eight-nucleate stage of embryo sac or with a degenerate embryo sac or nucellus increased dramatically (Table 2). The percentage of embryo sacs at eight-nucleate stage in the root cooling treatment was considerably higher than that in the control. Conversely, the rate of ovules with a degenerated embryo sac or nucellus was lower in the treatment. These results suggest that root cooling prolongs ovule longevity, as the low temperature of the whole-tree does (Beppu *et al.*, 1997). Ovule development is often influenced by plant hormones, especially gibberellin (Komatsu, 1987; Stösser and Anvari, 1982; Takagi, 1980). In a previous study, it was indicated that early ovule degeneration under high temperature is induced by the increased level of endogenous gibberellin (Beppu *et al.*, 2001; 2005). In general, endogenous gibberellins are synthesized in the root apices and young leaves and translocated to other organs (Sembdner *et al.*, 1980). Environmental conditions, such as temperature, affect both gibberellin synthesis and translocation. In satsuma mandarins, the endogenous gibberellin level in leaves decreased when the root and shoot temperature were lowered as low as 15°C (Poerwanto and Inoue, 1990). In grapevines, the activity of gibberellin-like substances in shoots decreased when the root temperature was reduced to as low as 13°C (Kubota *et al.*, 1986). Likewise, in this experiment, the endogenous gibberellin level in above-ground parts may be reduced by root cooling, resulting in prolonged ovule longevity.

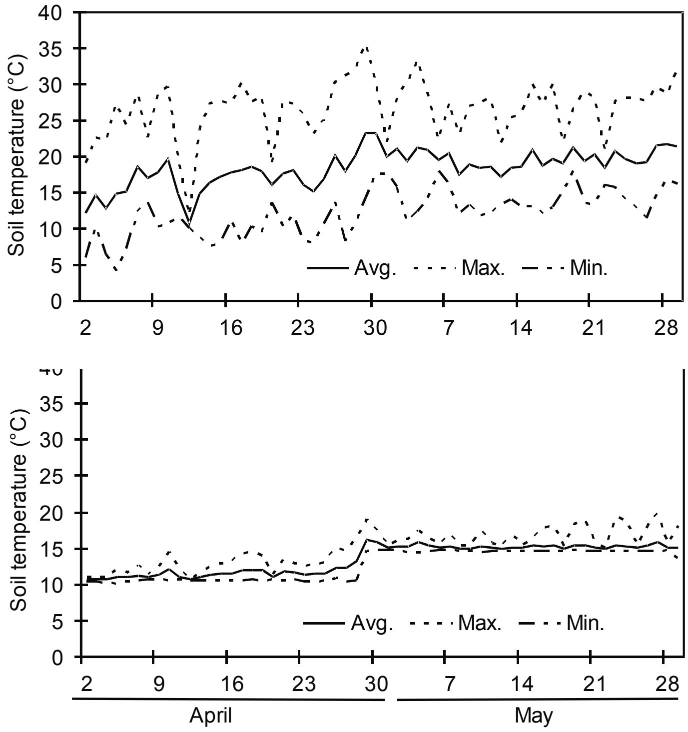

Fig. 1. Daily average, maximum and minimum soil temperatures in the control (above) and in the root cooling treatment (below).

Root cooling markedly increased the fruit set rate such that it was 31% compared to 14% in the control (Fig. 2). This may be due to prolonged ovule longevity because of low root zone temperature.

On the other hand, not only phytohormons but also tree nutrition, such as non-structural carbohydrates, are involved in ovule development and fruit set of sweet cherries (Beppu *et al.*, 2003a). High temperatures reduce the carbohydrate accumulation as a result of increase of respiration rate (Beppu *et al.*, 2003b). In apples, it was reported that the root respiration rate per fresh weight was almost of the same level as the shoot, and that it increased in the warm season (Proctor *et al.*, 1976). Thus, in this

Table 1. Effect of root cooling on flower development in 'Satohnishiki' sweet cherry

Treatment	Flower weight (mg)	Length (mm)		
		Peduncle	Petal	Pistil
Control	160.9±10.0[z]	15.9±1.6	13.3±0.5	12.7±0.5
Root cooling	172.2±5.8	14.8±1.5	13.2±0.3	12.9±0.6

[z] SE

Table 2. Effect of root cooling on ovule development in 'Satohnishiki'sweet cherry

Days after anthesis	Treatment	Stage of development							Degenerated embryo sac or nucellus
		Number of embryo sac	Embryo sac mother cell	Two-nucleate	Four-nucleate	Eight-nuleate			
						Unfused polar nuclei	Fused polar nuclei	Total	
0	Control	43.4[z]	14.7	9.4	9.4	6.0	1.8	7.7	15.5
	Root cooling	30.8	10.4	14.8	15.6	13.5	0.0	13.5	14.9
3	Control	8.9	0.0	5.4	0.0	7.1	10.9	18.0	67.7
	Root cooling	6.1	0.0	2.5	3.6	4.3	27.5	31.8	56.1

[z] Percentage of ovules with embryo sac or nucellus at different stages of development

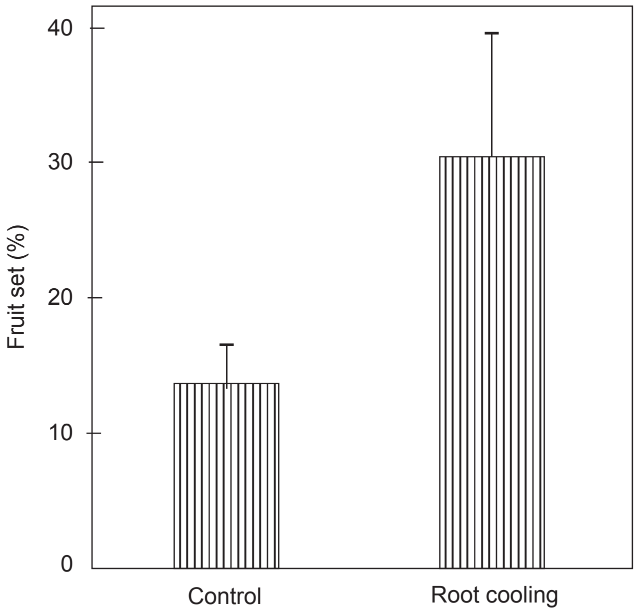

Fig. 2. Effect of root cooling on fruit set in 'Satohnishiki' sweet cherry. Bars indicate SE values

experiment, root cooling could have reduced the carbohydrate consumption through respiration in the root, which might have resulted in a greater supply of the carbohydrate to the reproductive organs resulting in an improvement of the ovule development and fruit set.

Our results indicate that root zone cooling prolongs ovule longevity and consequently increases fruit set of sweet cherries grown in a warm region. For practical application in industry, one should examine a root cooling system in which cooled water circulates through tubes buried in the soil of an orchard, such as the kind of systems already applied in a commercial context in the early forcing culture of the satsuma mandarins (Hirose, 2003).

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