Tree growth characteristics and flower bud differentiation of sweet cherry (*Prunus avium* L.) under different climate conditions in China

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Abstract

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The phenological stages, flower characteristics, shoot growth and flower bud differentiation of sweet cherries, cv. Hongdeng and Van, were investigated in different climatic zones in China, subtropical monsoon climatic zone (Shanghai, 31°14'N, 121°29'E) and temperate climatic zone (Qingdao, 37°09'N, 121°20'E). Sweet cherry trees grown in subtropical monsoon climatic zone had earlier phenological stage and longer blooming duration than those grown in temperate climatic zone. Fruit growth periods of Hongdeng and Van in Qingdao were 38 days and 51 days, respectively, but only 29 days and 45 days in Shanghai. Both cultivars showed more abnormal flowers under subtropical monsoon climate. The percentage of fruit set under open pollination in Hongdeng and Van were 31% and 24% in Qingdao, respectively, but only 0.4% and 3.2% in Shanghai. The trees grew more vigorous in Shanghai; flower bud differentiation was delayed by high temperature and superabundant rainfall in subtropical monsoon climate zone and more easily affected by the overlap of current shoot growth.

Keywords: sweet cherry; climate; phenological stage; fruit set; flower characteristics; shoot growth; flower bud differentiation

Sweet cherry is one of the important fruit crop in China and mainly grows in temperate climate zones or higher elevation. According to the data from Chinese Society for Horticultural Science, the commercial production of sweet cherry in China at 2008 reached 70,000 to 80,000 ha. The current main production areas are spread in the temperate regions surrounding Bohai bay (including Shandong province and Liaoning province), and also in the high altitude regions Sichuan province and Shanxi province (Fig. 1). Because of the great market potential and high value of the sweet cheery production, it has started to be commercialized in the regions of south part of Yangzi Rive (mainly Shanghai and Zhejiang province), where the temperature is warmer than that in the traditional regions.

Fruit tree growth and production is heavily influenced by climatic conditions. For example, chilling increased flower size, pedicel length and fruit set (Mahmood et al. 2000). The high temperature hastened sweet cherry blooming and induced small ovule and nucelli (Beppu et al. 1997). Beppu (1999) found that

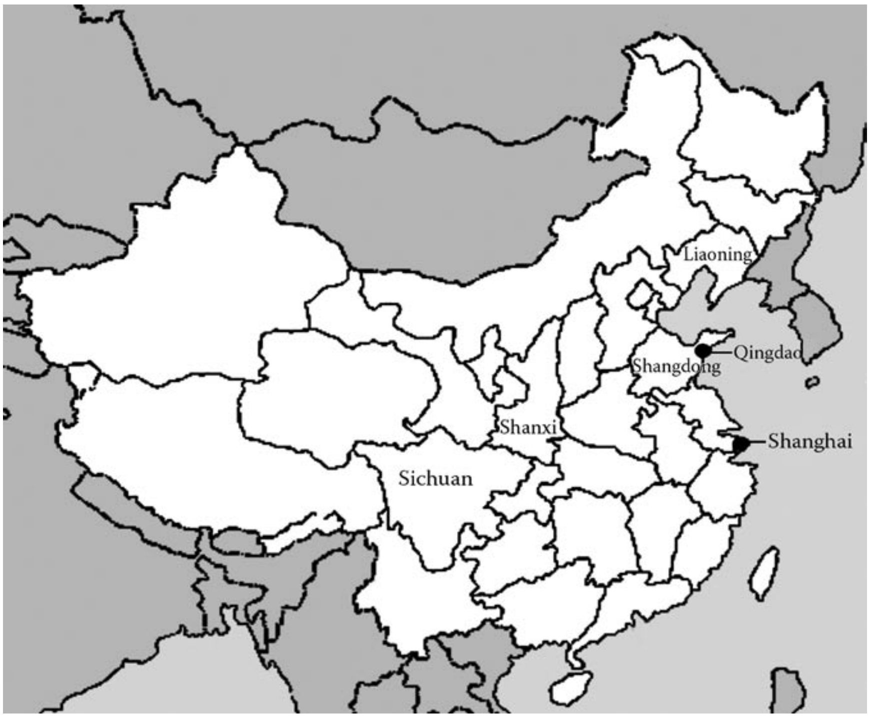

Fig. 1. The location of main production regions of sweet cherry in China

the occurrence of double pistils in Satohnishiki markedly increased when the trees were exposed to high temperatures (above 30°C) throughout the period of flower differentiation (Beppu, Kataoka 1999). It is reported that moderate plant water deficits enhance flowering in many important horticultural and forestry species (Krajewski, Rabe 1995; Stern et al. 1993; Sharp et al. 2009). Light intensity was closed related with the floral development, and plants did not flower in response to low temperature under low-intensity light or in complete darkness (Hisamatsu et al. 2001). Rain and low temperatures influence negatively the activity of pollinating bees and, consequently, the fruit set (Roversi, Ughini 1996). Cultivation in areas with milder temperatures can reduce damages from spring frosts, but result in erratic blooming, malformed fruits and yield reduction (Martinez et al. 1999; Mahmood et al. 2000; Beppu, Ikeda 2001). Recently, attempts have been made to improve the sweet cherry cultivation in south of China in order to harvest the fruits earlier than in the northern major production areas and to supply local markets. In this region, however, the growth characteristics and flower bud differentiation of sweet cherry under such conditions are still not fully understood.

The main aim of this study was to evaluate the growth of sweet cherry in South China. Our interest focused on the critical period for bud differentiation in the phenological stages of sweet cherry, trees growth and the change of vegetative buds to generative ones in Shanghai weather conditions. Furthermore, we would pay more attention to the relation between the particular phase of flower bud morphological differentiation and shoot growth under the different climate.

MATERIALS AND METHODS

Plant material

The research was carried out at the farm of Shanghai Jiao Tong University (31°14'N, 121°29'E) and a commercial orchard in Qingdao (37°09'N, 121°20'E), China, during 2007–2008 (Fig. 1). Qingdao is one of the main producing areas of sweet cherry. Six-year-old sweet cherry cv. Hongdeng and Van grafted on *Prunus pseudocerasus* rootstock were selected for the experiment. Spindle trees were planted at 5 x 6 m spacing on a loam soil and fertilized according to the local management recommendation. In this work, we achieved consistent data in two years but only analyzed the representative data of 2007.

Climate record

To evaluate the behavior of sweet cherry under the different climatic conditions, macroclimate data of the two sites including monthly average temperatures and total rainfall of 2007 and 2008 were obtained from the local weather stations. To observe the plant phenology, both sites were visited daily from January 2007 to December 2008. The phenological stages were divided according to Chapman et al. (1976).

Flower characteristics

To calculate the percentage of aborted pistils (non-viable ovule or shorter ovule, AP) and malformed pistils (double pistils, MP), 100 flowers were sampled randomly and the shape was visually examined at the full bloom time. We also counted the flower number per inflorescence at the same time.

Pollen germination and fruit set

Pollen was considered to be germinated when the length of the pollen tube was the same as or greater than the pollen grain diameter. Pollen was scattered in a culture medium containing 10% (w/v) sucrose and 1.0% (w/v) agar, and germinated at 25°C. The number of germinated pollen grains in relation to the total was counted using a Nikon-YS100 light microscope. Percentage of pollen germination was calculated as the number of germinated grains with respect to the total number of evaluated grains. Additionally, the percentage of natural fruit set was recorded 20 days after full bloom.

Current shoot growth

Three Hongdeng trees were selected for shoot growth study in both sites. Ten current shoots in exterior canopy per tree were marked and, the length and basal diameter of current shoots were measured at intervals of 10 to15 days from April 18 to December 31. Tree height, crown width and trunk diameters at 20 cm above the graft union were measured during the dormant season.

The proportion of branch types was investigated and their standards were established according to the following scale:

(1) long shoot – length longer than 60 cm,
(2) medium shoot – length range from 15 to 60 cm,
(3) short shoot – length range from 2 to 15 cm, the internodes can be distinguished,
(4) spur – length shorter than 2 cm, the flower buds are clustered and the internodes cannot be distinguished.

Flower buds differentiation

Three Hongdeng trees were selected in both Shanghai and Qingdao. Thirty spur buds, uniform in size and vigor, were collected around the canopy every 10 to 15 days from post-harvest time to the bud-break time next year. The collected buds were fixed in a FAA solution (formalin, acetic acid, 50% alcohol, 5:5:90, v/v) for at least 24 h. The samples were dehydrated in ethanol series (one time 50%, 70%, and 95% and then twice in 100% for 1 h) then embedded in paraffin and sectioned at thickness of 10 μm. Sections were stained with safranin and fast green according to the method described in apricot (Bartolini, Giorgelli 1994). Slides were then observed through a Nikon-YS100 light microscope with magnifications of 10× and 40×. Six main stages of flower bud differentiation were distinguished according to Diaz et al. (1981).

Data analysis

Experiment data in flowers quality and growth measurement were analyzed by *t*-test and significant levels of differences are represented by $P < 0.05$, $P < 0.01$, and $P < 0.001$ and NS (not significant).

RESULTS

Climatic character

Shanghai's climate belongs to subtropical monsoon climate while Qingdao's belongs to temperate monsoon climate. Monthly average temperature and total rainfall during the year of the study in Shanghai and Qingdao were presented in Table 1. Annual average temperature in Shanghai was 15.8°C, which was higher than that in Qingdao (12.2°C). In Shanghai, the highest monthly average temperature (27.8°C) appeared in July, and then August (27.7°C). However, the highest monthly average temperature in Qingdao was just 25.3°C. High temperature period lasted for a long time in Shanghai compared with Qingdao. The total rain-

Table 1. Monthly average temperature (°C) and precipitation (mm) in Shanghai and Qingdao, China (2007)

Site	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	Average temperature (°C)											
Shanghai	3.7	4.4	8.5	14.2	19.2	23.4	27.8	27.7	23.6	18.3	12.3	6.1
Qingdao	–1.4	0.0	4.9	10.7	16.3	20.3	24.4	25.3	21.1	15.5	8.3	1.5
	Precipitation (mm)											
Shanghai	39.4	59.0	81.9	102.4	106.3	152.2	127.9	133.1	155.5	63.3	53.7	35.1
Qingdao	10.6	12.3	20.7	37.5	51.4	80.9	211.4	164.3	96.4	45.1	28.1	9.8

fall in Shanghai was much higher than in Qingdao. There were six months in which the precipitation exceeded 100 mm in Shanghai. However in Qingdao, the precipitation mainly concentrated in July and August.

Phenological stages

As shown in Table 2, both sweet cherry varieties in Shanghai had earlier phenological stages than those in Qingdao. Interestingly, flowering duration of both cultivars in Shanghai lasted longer than in Qingdao. Fruit growth periods of Hongdeng and Van in Qingdao were 38 days and 51 days, respectively, but only 29 days and 45 days in Shanghai. Significant differences were found among the two sites concerning fruit developing period of each cultivar. The sweet cherry began to defoliate in December in Shanghai, whereas defoliation began in November in Qingdao. As we can see, trees planted in Shanghai had a longer growing season than in Qingdao.

Flower characteristics

Results showed that there was a very high percentage of flowers with malformed pistils in Shanghai for the two cultivars (Table 3). The amount of normal flowers of Hongdeng reduced significantly in Shanghai, and the percentage of flowers with aborted pistils was higher than in Qingdao. However, there were no differences between the two sites for Van for the above two aspects. Besides, pollen germination and flower quantity per inflorescence between the two sites of the two cultivars were at the same level. The percentage of the natural fruit set of cvs. Hongdeng and Van were 0.4% and 3.2% in Shanghai, and 31% and 24% in Qingdao, respectively. Differences of fruit setting between the two climates were extremely significant (Table 3).

Tree growth characteristics

Because of earlier phenological development, shoots of Hongdeng in Shanghai were longer than in Qingdao at the beginning of the measurements (April 28). The shoot length increased rapidly before May 31 in Shanghai, and then slowed. However, a month later, the rate of growth became rapid again (Fig. 2). Growth rate of shoots in Qingdao slowed down in July, and recovered in August. Shoot elongation finished at the end of September in Qingdao, while the shoots in Shanghai still kept growing until November. At last, there was a significant difference in shoot length between the two sites.

The proportion of branches type and tree size at the two sites is given in Table 4. The total number of shoots in Shanghai is 430, being larger than in Qingdao. There was a very significant difference for percentage of long shoot, short shoot and spurs between Shanghai and Qingdao. The trunk and crown diameters in Shanghai were 14.2 cm and 450 cm, bigger than trees planted in Qingdao.

Table 2. Phenological stages of sweet cherry in Shanghai and Qingdao, China (2007)

Cultivar	Site	Bud burst	White bud	Full bloom	Petal fall	Harvest	Leaf fall
Hongdeng	Shanghai	March 04	March 21	March 25	April 05	May 04	December 05
	Qingdao	March 25	April 11	April 18	April 20	May 28	November 11
Van	Shanghai	March 05	March 22	March 27	April 03	May 18	December 03
	Qingdao	March 28	April 12	April 15	April 20	June 10	November 15

Table 3. Flower organs quality (2007)

Site	Normal flower	Aborted pistil	Double pistil	Pollen germination rate (%)	Flower number/bud	Fruit set (%)
cv. Hongdeng						
Shanghai	80.5	12.5	7	56.7	2.4	0.4
Qingdao	92.7	6.8	0.5	58.3	2.1	31
Significance	*	*	**	NS	NS	**
cv. Van						
Shanghai	82.8	12.2	5	55	2.8	3.2
Qingdao	88.8	11.2	0	51.7	2.6	24
Significance	NS	NS	**	NS	NS	**

Significant difference at *$P < 0.05$; **$P < 0.01$; NS – not significant

Flower bud differentiation

Under the climate in Shanghai and Qingdao, most of the buds had already formed flower primordia by June 15 (Table 5). At July 1, 83.3% of buds had formed sepal primordia in Shanghai; meanwhile, the proportion of sepal primordia in Qingdao was only 63.3%. Then the speed of differentiation was slightly slower in Shanghai, and 69.7% of the buds in Qingdao had differentiated petal primordia until July 15. At September 1, 96.7% of buds had formed pistil primordial in Qingdao, while pistil primordia were not yet observed in Shanghai. The differentiation process in Shanghai was completed by the end of October.

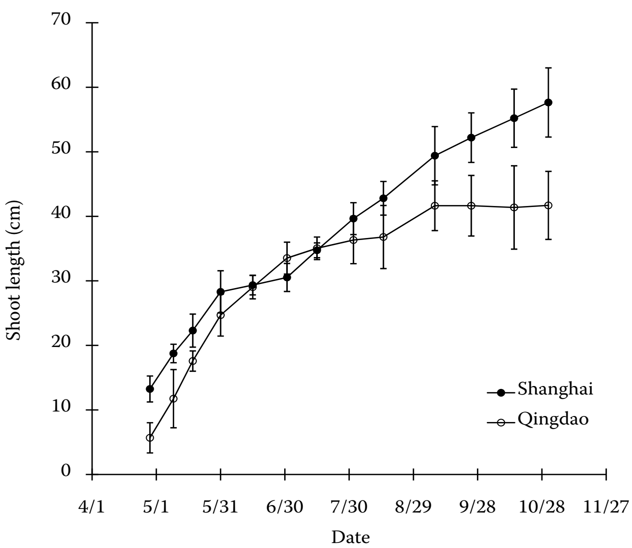

Fig. 2. Current shoot growth of sweet cherry cv. Hongdeng in Shanghai and Qingdao, 2007. Vertical bars indicate SD.

DISCUSSION

With higher monthly temperature in Shanghai, the growth of sweet cherry began earlier than in Qingdao (Table 2). Observation of blooming periods throughout the experiment showed that the flowering duration of Hongdeng and Van in Shanghai were 15d and 11d, respectively, lasting longer than those in Qingdao. The same phenomena were observed in other sweet cherry cultivars and other species cultured in milder winter areas, which resulted from a low accumulation of winter chilling and could be overcome by application of HC (hydrogen cyanamide) for some specific cultivars, like Bing, Van, Brooks, Somerset, Lapins, Sunburst, Garnet, Newstar, Ruby, Rainier, Early Burlat and Stella (Predieri et al. 2003). A difference in the fruit development period was observed between the two sites. The shorter fruit development period might be due to the more thermal accumulation in spring of Shanghai.

Beppu and Kataoka (1999) reported that sweet cherry buds are the most sensitive to the induction of abnormal flower primordia at high temperatures at the transition stage from sepal to petal differentiation. Our study found that the proportion of malformed flowers in Shanghai was higher than that in Qingdao (Table 3). From Table 5, we could see that the time from sepal to petal differentiation just occurred from the end July to early August: when the monthly temperature was the highest in Shanghai. It is reported that abnormalities in differentiation were also observed in anthers and pollen under Mediterranean climatic conditions (Oukabli, Mahhou 2007). However, pollen germination in Shanghai did not decrease compared with that in Qingdao. Thus, we considered that the pollen degradation would not happen or the proportion of degradation might be

Table 4. Branch type and growth vigor of cv. Hongdeng in different sites (2007)

Site	Total shoots number	Long shoot	Medium shoot	Short shoot	Spur	Tree height	Trunk diameter	Crown diameter
		(%)				(cm)		
Shanghai	430	38.79	40.61	9.39	11.21	435	14.2	450
Qingdao	331.7	7.22	48.19	24.52	20.43	345.5	9.9	315.6
Significance	*	**	NS	**	**	*	*	*

Significant difference at *P < 0.05; **P < 0.01; NS – not significant

smaller under the climate of Shanghai. Other works studied the effect of climatic conditions, especially temperature, on the ovule viability and pollen performance (Cerovic et al. 2000; Rodrigo, Herrero 2002). It is believed that high temperatures accelerated ovule degeneration and pollen tube growth rate but also reduced the number of growing pollen tubes along the style (Hedlhly et al. 2007). Additionally, the loss of embryo sac viability in some sweet cherry cultivars is much quicker, starting 2 day after full bloom (Cerović, Mićić 1999). In our studies, we thought warm temperatures during the bloom period in Shanghai would reduce fruit set in sweet cherry as previous experiments had shown in the similar climate. Anyway, for the two cultivars, fruit set was too low to be put into commercial production if without any additional practice.

The cherry shoot elongation had a double-sigmoid growth curve in two sides (Fig. 2), divided into three stages: stage I – rapid growth; stage II – slow growth, and stage III – second rapid growth. The early rise of temperature during early spring in Shanghai led to larger elongation growth of sweet cherry shoots. Then, trees in Shanghai entered stage II after May 31, while the trees in Qingdao were still in the stage I. The duration of stage II in Shanghai was shorter than in Qingdao, that might be due to the overgrowth caused by the high temperature and heavy rain under Shanghai climate (Table 1). After September, the moderate temperatures in Shanghai

Table 5. The progression of flower bud formation in sweet cherry cv. Hongdeng (2007)

Date (month/day)	Site	Bract	Flower	Sepal	Petal	Stamen	Pistil
		primordia					
06/01	Shanghai	13.3	86.7				
	Qingdao	33.3	66.7				
06/15	Shanghai		100				
	Qingdao		100				
07/01	Shanghai		16.7	83.3			
	Qingdao		36.7	63.3			
07/15	Shanghai		33.3	66.7			
	Qingdao			30.3	69.7		
08/01	Shanghai			53.3	33.3	13.3	
	Qingdao			13.3	13.3	46.7	26.7
08/15	Shanghai			46.7	33.3	20	
	Qingdao					48.8	51.2
09/01	Shanghai				33.3	66.7	
	Qingdao					3.3	96.7
09/25	Shanghai				6.7	20	73.3
	Qingdao					6.7	93.3
10/05	Shanghai			6.7		6.7	86.6
	Qingdao						100
10/25	Shanghai						100
	Qingdao						100

kept shoots growing strongly and also delayed defoliation. The climate in Shanghai induced a higher total number of shoots per tree, lower spur proportion and larger tree size. These made it difficult to prevent trees from potential damage caused by rain or birds. The super abundant shoots also reduced the canopy light transmittance. Furthermore, it is reported that large tree size makes them harder and more expensive to manage, and they often produce fruits of lower quality (Predieri et al. 2003).

Flower initiation and differentiation variable and dependent on the cultivar; furthermore, it is a complex process regulated by many factors, such as current shoot growth, environmental and genetic factors (Núńez-Elisea, Davenport 1995). In general, flower differentiation of sweet cherry begins immediately after harvest of the present year's crop (Watanabe, Umetsu 1980; Guimond et al. 1998; Engin, Ünal 2007). On the other hand, fast development of the leaf primordia, and of young leaves during the early stage of growth, is a prerequisite for floral initiation (Ding et al. 1999). Our results also found that the flower initiation in Shanghai showed a more rapid process compared to Qingdao before July 1 because of the earlier phenological stages (Table 5). With shoot growth entering stage III; we noted that the flower bud differentiation process in Shanghai was slow. However, the petal primordia formed by August 15 in Qingdao, followed by the stamen, the organs of the flower in Qingdao attained their normal forms until about September 1. The whole process in Qingdao just finished by the shoot growth stage III. The same process in Shanghai ended during the end of October. There seemed to be a competitive relationship between flower buds differentiation and shoot elongation. Another reason for the delay of flower bud differentiation in Shanghai was probably due to high temperatures and abundant rainy days. It is reported that high temperature interfered with floral initiation and differentiation in some species of *Prunus* (Shen et al. 1999), and warm temperatures rather than a long photoperiod inhibited floral induction in mango. Beppu and Kataoka (1999) found that the higher the temperature, the slower the progression of flower differentiation in Satohnishiki sweet cherry. On the other hand, many researches suggested that moderate water stress is sufficient to induce fruit bud differentiation without any visible damage to the trees (Stern, Naorb 2003), though severe water stress could delay the development of the flower buds in apricot and cherry (Alburquerque et al. 2003; Engin 2008). For example, though the monthly average temperature in western Turkey is higher than in Shanghai, flower bud formation of sweet cherry is much earlier than Shanghai. Engin's (2007) data showed there is little rainfall during the growth season in western Turkey (Engin, Ünal 2007). Our study indicated that the total rainfall in Qingdao was lower than that in Shanghai (Table 1), perhaps, it accelerated the progress of flower differentiation.

Planting sweet cherry in the warm regions could get early harvest and increase economic benefits. The research studied the phenophase, growth characteristics and flower bud differentiation of two cultivars of sweet cherry in the climate condition of Shanghai, from which researchers and orchard managers will get reliable information for their study or planting. In conclusion, in these growing conditions, the vegetative growth of sweet cherry tree was very vigorous, but the flower organs performance worse with more malformed flowers and low fruit setting. Then, a chemical treatment or cultural practice such as application of HC should be carried out to break the dormancy and to advance flowering to avoid the damage caused by high temperature. Canopy management should consider the influence of light on flower bud differentiation, fruit development, and quality traits at harvest. Dwarf rootstock or harsh pruning might be adopted to control the tree size. We can also take some other agronomical practices to avoid high temperature damage during the sensitive period of flower bud differentiation, such as the use of over-tree sprinkler irrigation or artificial shading (Beppu, Kataoka et al. 2000).

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