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Influence of Crown Size of Day-neutral Strawberry on Its Growth, Flowering, and Yield

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ABSTRACT

The use of cold storage transplants is becoming popular in summer strawberry production, replacing freshly dug bare-root transplants, in which the crown size indicates vigor. Three cultivars of day-neutral strawberry, Albion, Seascape, and San Andreas, were grown at the Daegwallyeong Research Center, Korea, inside a glasshouse during the summer growing season. Since the crown size of the strawberry transplant is associated with transplant vigor, this experiment was carried out to evaluate plant growth, development, and fruit yield of strawberry plants from cold storage bare-root transplants with different crown diameters. Three classes of crown diameters (small, medium, and large) were compared in a 3 × 3 factorial and completely randomized experimental design with four replications. Transplants were planted on April 17, 2013, and ripe fruits were harvested from June 11 to August 21, 2013. Fresh fruit yield was determined throughout the experiment, and plant growth and development were determined at the end of the experiment. The number of leaves, shoot dry weight, number of crowns, and fruit yield were significantly different among the three cultivars. Seascape showed the best vegetative and generative growth performance compared to the other cultivars. There was no correlation between the crown diameter, plant growth, or fruit yield of the cultivars; however, a larger crown diameter induced significantly earlier flower initiation. This result suggests that crown size is not an important indicator of the growth and yield of day-neutral strawberries from cold storage transplants.

Keywords: Cold storage plants, Initial crown size, Propagation, Runners

Introduction

Strawberry (*Fragaria x ananassa* Duch.) belongs to the family Rosaceae and is clonally propagated by daughter plants, which progressively develop from runners, and are generally transplanted as either bare root plants or plugs (Ruan et al., 2009). Commercial strawberry growers have a preference for cold-stored transplants over freshly rooted runners because of their associated advantages, which specifically include improved yields and flexibility in planting date. The cold-stored transplant types that are used in production during the season have a strong influence on the yield and harvest time during the summer period (Duralija et al., 2006a). Cold-stored transplants also consist of two types: cold-stored bare root transplants (frigo plants) and cold-stored tray plants (TPs) (Duralija et al., 2006b). Cold-stored bareroot transplants often vary in size and are prone to damage due to unfavorable environmental conditions during the digging process and shipping (Bish et al., 2003). Successful production of strawberry depends upon a supply of high-quality transplants. Johnson et al. (2005) reported that using transplants with larger crowns leads to a high yield. Several components, including the number of leaves, crown diameter, and initial transplant weight, have been shown to influence strawberry yield (Cocco et al., 2010).

Currently, some strawberry growers discard smaller transplants when preparing them for planting. These growers have assumed that the smaller transplants do not yield as much as the larger transplants. The correlation between the size and/or age of strawberry transplants at planting with fruit production has been studied. Faby (1997) reported a positive correlation between the crown diameter of the transplant and total fruit yield (Cocco et al., 2010). Hochmuth et al. (2001) also mentioned that crown diameter is the main variable that has been used to determine the vigor of strawberry transplants. Large-crowned transplants (over 8.00 mm) have a higher early season yield than small-crowned plants (Durner et al., 2002). Bigger transplants can store more carbohydrate reserves at the crown, which are used by young plants at the beginning of the growing period. This statement is supported by Cocco et al. (2011), who found that for short-day strawberry cultivars, bare root transplants with crown diameters greater than 5.1 mm resulted in better growth and higher early yield compared to those with a smaller crown diameter. Bish et al. (1997), Takeda et al. (2004) and Baruzzi (2021) also suggested that the use of transplants with a larger crown size increases the total production of strawberry fruit.

There is little information about the effects of crown size on the growth and yield of day-neutral strawberry cultivars propagated from cold-stored bare roots during summer strawberry production. Therefore, the aim of this study was to determine the growth, development, and fruit yield of day-neutral strawberry cultivars from cold-stored bare roots with different crown diameters.

Materials and Methods

Plant materials and cultivation

The experiment was conducted from April−August inside a greenhouse in Daegwallyong Research Center, Hoenggye, Pyeongchang, Gangwon Province, Korea (37°40 0" N, 128° 42' 0" E). The climate was a humid continental climate (Köppen climate classification Dfb/Dfw) with warm, humid summers and long, cold winters. It was foggy and cloudy, with strong winds all year round (Surhone et al., 2011). The strawberry cultivars used were ‘Albion’, ‘San Andreas’, and ‘Seascape’. Bare root transplants (frigo plants) cold stored at -2^{C} after digging out from the field, were imported from the Lassen Canyon Nursery (California, USA) on March 30 via airline . They were sorted into three crown (center) diameter classes: 4.0 to 7.0 mm (small); 7.1 to 10.0 mm (medium), and >10.0 mm (large). Transplants of all treatments were planted on April 17th, and the experiment was terminated on August

20th. Before planting, dead leaves were removed, and roots longer than 10 cm were cut off according to the commercial cultivation method. Planting was performed inside a greenhouse using individual pots (14 cm diameter and 14 cm depth, equivalent to 1.5 L) filled with strawberry medium imported from the Netherlands (BC2, BVB); two months after planting, the plants were transplanted into larger pots (35 cm diameter, 28 cm depth, equivalent to 20 L). Water and nutrients were supplied by dripping via a hydroponic irrigation system. The nutrient solution used in this experiment was a water-soluble compound fertilizer (Poly-feed Foliar, Haifa) with different component ratios (−19-19-19, 17-8-26) depending on the growth stage using the standard irrigation method. A standard spray program was used to control weeds, insects, and diseases.

Experimental design, data observation, and analysis

Treatments consisted of three genotypes (strawberry cultivars) and three crown diameter classes arranged in a 3 × 3 factorial randomized block design with four replications. Each plot contained 20 plants. Observations were made on vegetative and generative characteristics. The number of days from planting to flowering and fruiting was recorded when 50% of the plants in the plot had at least one flower at anthesis and one ripe fruit, respectively. Ripe fruits were harvested twice a week at 100% red epidermis, counted, weighed, and then screened as marketable if the fresh weight was over 10 g and considered unmarketable if it was less than 10 g. Four weeks before the end of the experiment, four plants from each treatment were removed from the soil. Roots were washed over a fine mesh sieve to separate the soil from the root tissue. The plants were then divided into roots and shoots. The numbers of crowns and number of leaves were counted, the lengths of shoots and roots were measured, fresh shoots and roots were weighed, and the dry mass of shoots and roots was determined after drying at 65 °C until a constant mass was reached. The fulfillment of the assumptions of the mathematical model for the analysis of variance was verified by the error normality test. All data were subjected to analysis of variance, and the significance of differences among means was determined by the Tukey test ($p < 0.05$).

Results and Discussion

The temperature in the greenhouse during the experiment changed over time (Fig. 1). There were no significant interactions between cultivars and crown diameter on any growth characteristics. The growth patterns of the three cultivars were significantly different, but there was no significant difference among the crown diameter classes. 4 weeks later (early growth), fresh weight (shoot and root) and dry weight (shoot and root) were higher in the large-crowned transplants ($p \leq 0.05$). However, shoot length, root length, and number of crowns were similar among the crown diameter classes (Table 1). The plant size difference between the small, medium, and large crown sizes decreased as the season progressed. Approximately 8 weeks after planting (one month after the initial harvest), all plants were nearly equal in size and remained consistent for the rest of the harvest period. At the end of the experiment, all growth variables, including the number of crowns, did not differ among crown diameter classes

(Table 2). There were significant differences in the vegetative growth variables among the three cultivars used in this experiment. ‘Seascape’ exhibited a higher number of leaves, shoot dry weight, and number of crowns compared to other cultivars ($p \leq 0.05$).

The pattern of vegetative growth is shown in Fig. 2. The number of leaves was significantly higher ($p \leq 0.05$) in plants with large crown diameters in the first month (4 weeks after planting). The difference in the number of leaves between the initially small, medium, and large crown diameters at planting decreased as the season progressed. About one month after planting, all plants were nearly equal in number of leaves, and this remained the same until the end of the experiment. A large crown diameter resulted in higher shoot and root fresh weights at the beginning of the growing period ($p \leq 0.05$). The fresh weights of shoots and roots started to be similar among the crown size classes in the second and third months, respectively. The dry weight difference between the initially small, medium,

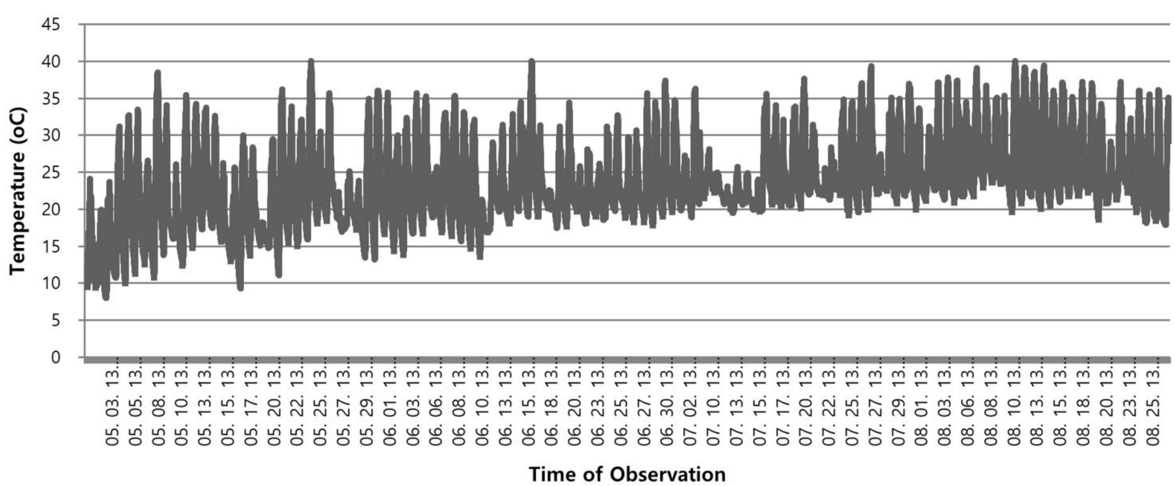

Fig. 1. Temperature changes during the experiment.

Table 1. Plant growth and development of day-neutral strawberry cultivars with different initial crown sizes at the beginning of the experiment (4 weeks after planting)

Source of variation	Shoot length (cm)	Root length (cm)	Number of Leaves	Fresh weight (g)		Dry weight (g)		Number of crown
				shoot	root	shoot	root	
Cultivar	**n.s.**	**n.s.**	**n.s.**	**n.s.**	*	**n.s.**	**n.s.**	**n.s**
Albion	9.29	13.57	2.55	4.07	2.75 a^z	0.76	0.58	1
San Andreas	9.44	15.21	2.18	3.83	3.81 ab	0.8	0.76	1
Seascape	11.74	16.02	3.92	5.39	4.3 b	0.99	0.83	1
Crown size	**n.s.**	**n.s.**	**n.s.**	*	*	*	*	**n.s.**
Small	10.04	16.43	1.58	2.97 b	2.57 b	0.52 b	0.45 b	1
Medium	10.37	14.7	2.4	3.61 b	2.66 b	0.64 b	0.49 b	1
Big	10.23	13.73	4.67	6.66 a	5.53 a	1.36 a	1.21 a	1
Cultivar × Crown Size	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*Significant effects at $p \leq 0.05$; n.s. = not significant.

^{z}Mean separation within column by Duncan’s multiple range tests at $p = 0.05$.

Table 2. Plant growth and development of day-neutral strawberry cultivars with different initial crown sizes at the end of the experiment (16 weeks after planting)

Source of variation	Shoot length (cm)	Root length (cm)	Number of Leaves	Fresh weight(g)		Dry weight (g)		Number of crown
				shoot	root	shoot	root	
Cultivar	**n.s.**	**n.s.**	*	**n.s.**	**n.s.**	*	**n.s.**	*
Albion	21.32	29.88	21.00 b[z]	79.18	19.84	19.000 b	3.07	3.88 ab
San Andreas	20.04	29.42	20.55 b	94.10	29.14	29.40 a	5.55	3.22 b
Seascape	21.37	26.73	29.55 a	108.86	25.45	33.05 a	4.90	4.88 a
Crown size	**n.s.**	**n.s.**	**n.s.**	**n.s.**	**n.s.**	**n.s.**	**n.s.**	**n.s.**
Small	20.65	26.94	25.00	86.35	22.03	26.92	3.80	4.00
Medium	20.96	28.42	22.44	94.96	22.34	24.44	4.00	3.66
Big	21.12	30.67	23.66	100.83	30.06	30.08	5.73	4.33
Cultivar × Crown Size	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*Significant effects at $p \leq 0.05$; n.s. = not significant.

[z]Mean separation within column by Duncan's multiple range tests at $p = 0.05$.

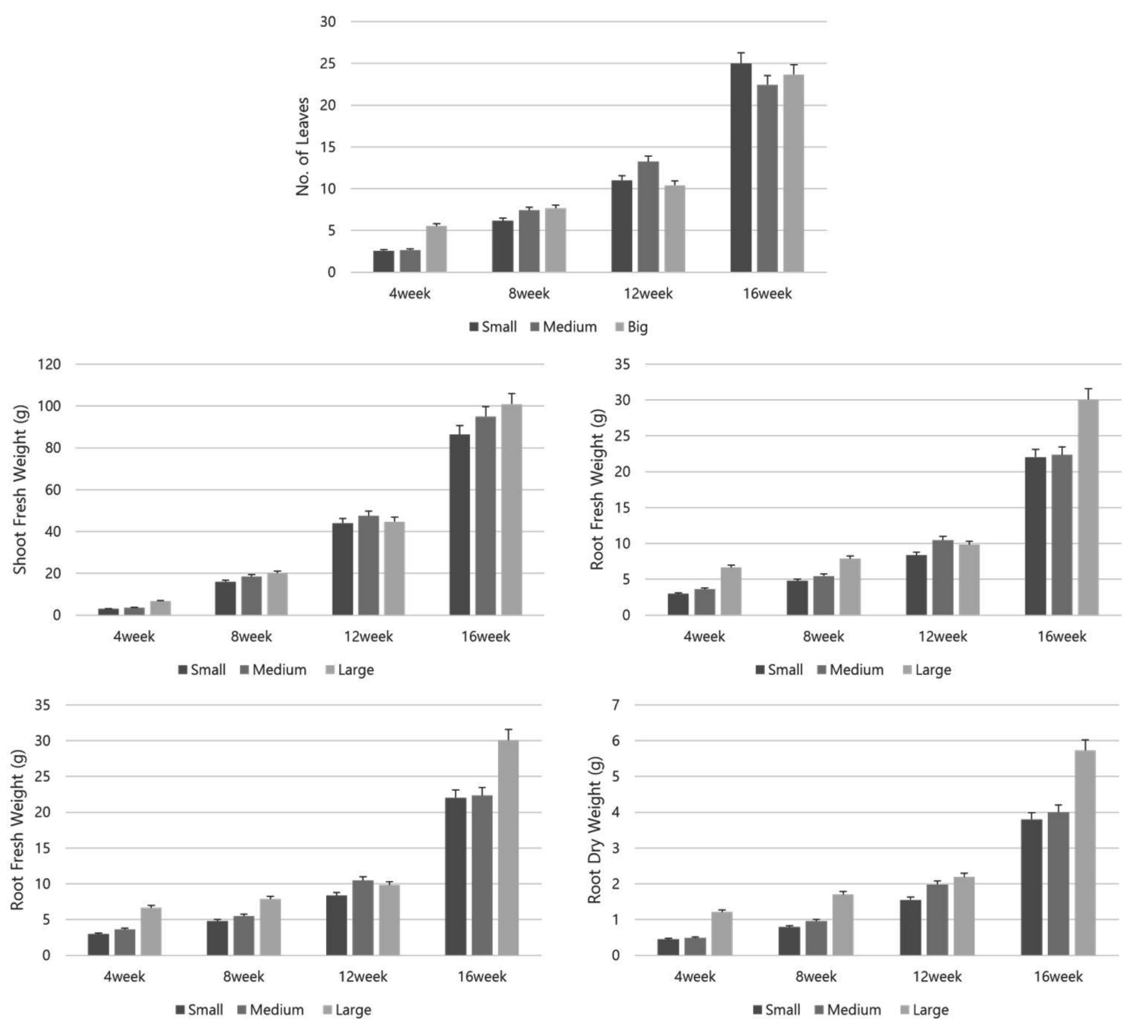

Fig. 2. Effects of different initial crown sizes on vegetative growth of day-neutral strawberry cultivars.

and large crown sizes at planting also decreased as the season progressed. About two and three months after planting, all plants were nearly equal in shoot and root dry weight, respectively, and maintained a similar pattern for the rest of the harvest period. At the end of the experiment, the fresh weight (shoot and root) did not differ among the crown diameter classes.

Initial crown diameter significantly affected days to anthesis but did not affect the number of flowers/plant and other yield components, such as number of fruits/plant and fruit weight (Table 3). A large initial crown diameter induced earlier flowering than the smaller ones ($p \leq 0.05$). Transplants with crown diameter >10 mm (large) required 18 days after planting, while other crown diameter classes (small and medium) took 24 and 26 days, respectively, to open flowers. The three cultivars used in this experiment had different characteristics for flowering and fruit yield. The cultivar 'Seascape' showed early flowering and higher yield than the other cultivars.

The results showed that a larger crown size (large crown diameter) produced more vigorous transplants at planting and plants with higher early vegetative growth (Table 1). This result was in agreement with the recommendation of Durner et al. (2002) for strawberry transplants with crown diameters over 8 mm. Gautier et al. (2001) mentioned that new roots of transplants are not immediately able to absorb water and nutrients; thus, plants are susceptible to stress in the days after planting. Strawberry plants have slow root growth; therefore, high-vigor strawberry transplants have faster initial growth (Cocco et al., 2011). The flowering initiation of plants was significantly affected by the crown size. The large crown diameter accelerated the beginning of flowering in the day-neutral strawberry cultivars used in this experiment. Nevertheless, it was expected that the effect of crown size on fruit yield would be of great importance.

There was no significant difference among crown diameter classes on number of flowers/plant, total yield, number of fruits/plant, and fruit weight (Table 3). The flowering response might be related to leaf area. Some researchers have shown that reduced leaf area inhibits flower production (Albregts, 1968). They stated that lower photosynthate production in the reduced leaf area and the lower reserves of carbohydrate in the smaller plant might affect flower initiation. Johnson et al. (2005) reported that different flowering responses of plants with different

Table 3. Days to anthesis, number of flowers/plant, total yield, number of fruits/plant, and fruit weight of day-neutral strawberry cultivars with different initial crown sizes

Source of variation	Days to anthesis	Number of flower/plant	Yield (g/plant)	Number of fruits/plant	Fruit weight (g)
Cultivar	*	*	*	*	*
Albion	21.08 b[z]	9.17 b	59.12 ab	5.75 ab	9.78 b
San Andreas	24.33 a	7.42 b	44.11 b	3.42 b	13.25 a
Seascape	22.92 ab	26.17 a	142.87 a	11.33 a	12.02 ab
Crown size	*	n.s.	n.s.	n.s.	n.s.
Small	26.00 a	18.92	101.07	8.25	11.39
Medium	24.08 a	15.08	94.14	7.42	12.36
Big	18.25 c	16.25	83.07	7.33	11.06
Cultivar × Crown Size	n.s.	n.s.	n.s.	n.s.	n.s.

*Significant effects at $p \leq 0.05$; n.s. = not significant.

[z]Mean separation within column by Duncan's multiple range tests at $p = 0.05$

crown sizes were not related to flower inhibitors inside the plants. It is suggested that early flowering in larger transplants is controlled more by the photothermic environment at the rooting stage or the photosynthetic capacity rather than by the flower inhibitor mechanism.

Transplants with large crown diameters were more vigorous, showing a higher fresh weight at 1−2 months after planting. Similar results were observed for dry weight, which showed that plants with large crown diameters had higher dry weights compared to plants with smaller crown diameters at 2−3 months after planting. As the growing season progressed, these differences decreased and disappeared. This result was in agreement with Bolda (2010), who reported that plants with a small crown size had smaller shoot diameters than those with larger crowns at one month after transplanting. Three months after transplantation, this difference disappeared. The initial crown diameter can influences on the fruit yield and quality of strawberry. The crown size of transplants can be related to the size of the assimilate pool. Fagherazzi (2021) suggested that the productivity and number of fruit values increased significantly with larger caliber plants. In bare root transplants, this pool is the main energy source for the emission and growth of new roots to replace those damaged at digging or cut off before planting. Cocco et al. (2011) found that transplants with crown diameters ranging from 2 mm to 7 mm did not show any difference in size 48 days after planting. These results can be explained by the dynamics of root and shoot growth. Shoot growth is not limited by physical constraints on root growth.

A large crown diameter leads to more vigorous strawberry transplants at planting and results in higher vegetative growth during the early growing period and early flowering without influence on fruit yield. This result was slightly different from that of Cocco et al. (2011), who found that fruit yield of short-day strawberry cultivars was influenced by the type of transplant and also by its vigor identified by crown diameter. Cocco et al. (2010) also reported that early flowering and fruit harvest were recorded in short-day strawberry plants with larger crown diameters. A hypothesis that might also explain this noticeable difference is the indirect influence of growth on plant development. Andriolo et al. (2003) stated that regardless of favorable environmental conditions, plants must attain a minimum size in their current development stage before proceeding to the next stage. Plant size is related to physiological age, which affects the physiological functions of plant organs. In this case, more vigorous transplants at planting could produce and store assimilates in a shorter time, reaching the physiological conditions for flowering earlier than less vigorous transplants. This is supported by the early flowering and fruit harvest recorded in plants from large crown diameter transplants. Nevertheless, this effect would be buffered onwards as vegetative growth, flowering, and fruit growth in the strawberry plant are simultaneous and indeterminate processes that continue while environmental conditions are favorable. Thus, the effect of transplant vigor at planting on the early yield of plants in the field becomes diluted or even disappears when observing total yield.

Conclusions

Screening the transplants based on crown diameter did not provide significant benefits to summer strawberry fruit yield. This result suggests that crown size itself is not an important factor determining the growth and yield of day-neutral strawberry cultivars from cold-storage transplants. Combining the crown diameter parameter with other parameters, such as fresh and dry weight of the strawberry transplants, crown number, length of roots, and number of leaves, is needed to screen transplants in order to gain higher fruit yield.

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