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Development of a Functional Plug Tray for Producing High-Quality Strawberry Transplants

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Abstract

This study was conducted to develop functional plug trays capable of optimizing the root growth environment and inducing early flowering in strawberry plants. Experimental treatments included trays with no drainage slit, two drainage slits, four drainage slits, and a control bottom drainage hole or commercial tray. The effect of the functional plug trays was studied on two strawberry (*Fragaria* × *ananassa* Duch.) cultivars ('Seolhyang' and 'Maehyang') and two different rooting media (commercial medium and peat moss wrapped in a paper pot). The experimental units were arranged in a completely randomized design, with five and four replications for nursery and post-transplanting studies, respectively. Shoot and root growth characteristics and rhizosphere temperature were measured in the nursery study and flowering and yield in the post-transplanting study. Growth parameter results showed that compared to the existing plug trays, the new trays with two and four slits produced transplants of significantly higher quality. These treatments induced lower root temperature in rooting media and plants generally flowered earlier, thus providing higher early and total yields regardless of the media or cultivars used. This effect was further enhanced as the number of drainage holes increased. Thus, an increase in the number of drainage slits in plug trays can lead to higher-quality transplants that can flower and produce fruits earlier than those with poor drainage.

Additional key words: containers, drainage hole, flower initiation, root development, strawberry seedlings

Introduction

Strawberry plug plant-based nurseries worldwide have increased substantially over the past several decades due to their capacity to produce strawberry transplants of optimum quality. With this system, seedlings establish quickly after transplanting as the root system remains undisturbed during the transplanting process, allowing growth to resume faster compared to traditional bare roots (Hochmuth et al., 2006). Generally, quality characteristics of strawberry seedlings are evaluated via health status and size of the root system and crown diameter; improving these characteristics leads to an early harvest and high yield (Treder, 2014; Heuver and Lumis, 2017; Park et al., 2018). Previous studies have revealed that the root growth of containerized plants is a key element for overall plant performance during

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propagation, production, or post-production because of the essential roles of roots, including anchorage, support, and water and nutrient uptake (Judd et al., 2015). The container design influences the morphology and physiology of the root systems of containerized seedlings (Landis et al., 1990). Strawberry plant roots are very sensitive to water extremes and require high amounts of oxygen (Iwasaki, 2008). If the rooting media is not properly drained, the root system becomes too small because of a lack of reduced oxygen for root respiration (Bowling, 2000) and the root system may even become rotten if it is under severe waterlogging conditions (Robbins and Evans, 2011). Therefore, the design and structure of the tray cell are critically important for the growth of the seedling root system.

The design of the plug trays used for commercial production of strawberry transplants is characterized by cells generally having one to four minuscule holes located at the bottom of the tray cell to facilitate water drainage and gas exchange. These drainage holes may not maximize the respiration and temperature requirements of the naturally shallow rooted strawberry plant. Consequently, the resultant plugs are of low quality due to poorly developed and matted root systems and have poor performance when planted in fields, thus restricting the early harvest and total yield. In South Korea, the early winter yield of strawberry plants is important for not only farmers but also consumers because in December (around Christmas and the New Year), the demand for strawberries usually surpasses supply, and the market price often increases significantly than in any other period. Recently, the hot summer during transplant production has had detrimental effects on the shoot and root growth. The containers used to grow plants must be designed for good evaporation in the root system. Therefore, there is an urgent need to find a reliable technology capable of producing ready-to-flower transplants of satisfactory quality that meet the preferences of farmers. Hence, the objective of this study was to evaluate the effect of strawberry functional plug trays on the characteristics of strawberry transplants during the nursery and post-transplanting stages.

Materials and Methods

This experiment was conducted at the Agricultural Research Farm of the Department of Plant Science, Gangneung-Wonju National University, in the city of Gangneung (elevation: 10 m, latitude: 37.450 N). The location is characterized by a temperate and humid climate with cold winters.

Cold-stored plants of domestic cultivars ‘Seolhyang’ and ‘Maehyang’ were grown in a greenhouse from April 4 to August 18, 2017 to produce runner tips. Mother plants were established using a rectangular container of 80 × 35 × 20 cm. The containers were filled with a strawberry commercial medium, planted with four plants each (20 cm spacing), and placed on the plastic-covered floor of the greenhouse. New plug trays (Fig. 1) were ordered from Nam Kyung Co., Ltd. (Hwaseong, Korea), a company that specializes in the manufacturing of agricultural facilities, with the following dimensions: 57 × 42 ×

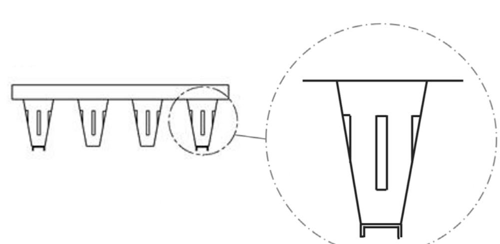

Fig. 1. Design of functional plug tray capable of optimizing the root growth environment.

10 cm with 30 cells. The tray cell shape was round with 120-cm^3 volume and consisted of four slits (side draining holes) of 1 × 6 cm. The 200 trays received from the company were manually customized to create trays with two slits per cell and zero slits per cell following the research design. This was achieved by sealing the existing slits with plastic stickers. The experimental treatments consisted of functional tray cells with four slits (H4) and two slits (H2), nonfunctional trays with no slits (H0), and a control (commercial tray, C). The four drainage holes of C are relatively small (1 × 1 cm) and are located at the lower sides of the cell.

To develop trays with a wider range of use, the effect of the newly developed plug trays was tested on two common Korean strawberry cultivars ('Seolhyang' and 'Maehyang') and two rooting media (commercial medium and peat moss wrapped in a paper pot [hereafter referred to as Ellepot]). On August 27, 2017, plugging was completed by directly attaching the runner tip still attached to the mother plant (without clipping it) onto the medium in the plug tray cell with plastic hooks. Plugs were produced from the runner tips that had two to three leaves and with crown diameters ranging from 2.8 to 3.8 mm. Plugs were grown for 1 month, and on September 28, 2017, they were transplanted to the fruit-producing greenhouse that used drip irrigation.

In the fruiting greenhouse, polyvinyl chloride gutters (20 m long, 200 mm wide, and 300 mm high) were used, suspended at 1 m above the tunnel floor in a north-south orientation. The spacing between gutters was 1.2 m. The gutters were filled with the commercial medium to the top and were covered with white polyethylene film as a mulching material. A complete nutrient solution was supplied throughout the growing period using the drip irrigation system with emitters at 300-mm spacing and a flow capacity of 2 L per minute per 30 m tube length. In the gutter, plant spacing was 30 cm within the row and 20 cm between rows. Diseases and pests were checked for regularly, and pesticides were sprayed if required.

The experiment was established using a completely randomized design with five replicates for the nursery stage and four replicates for the post-transplantation stage. All cultivars were separately evaluated for the newly invented trays but received similar management. Each replicate included 64 plants, with the 32 plants being randomly chosen for destructive data collection. The remaining plants were maintained for post-nursery study. For the nursery phase, the data were collected weekly for 4 weeks starting from the second week after rooting. At each sampling, eight plants were unplugged from the tray cell in each replicate and roots were washed over a fine mesh sieve to remove soil from roots. The sampled plants were examined for the following growth parameters: crown diameter, plant height, leaf area, leaf number, shoot fresh weight, shoot dry weight, number of main roots, root length, root fresh weight, root dry weight, and shoot width. The dry weight was determined by bagging all plant parts (roots and shoots separated) and dried in an oven at 70°C for 3 days. The temperature was monitored in the root zone of plugs in each treatment using a HOBO data logger (HOBO 4-Channel Analog Data Logger, Onset Computer Corp, Bourne, Massachusetts, USA) during nursery phase. At the onset of flowering, days to first and to 50% anthesis, early yield, and total yield amounts were recorded. All data obtained from all the trials were entered into Microsoft excel 2013 and subjected to analysis of variance and mean separation by Duncan's multiple range test (DMRT) at $p \leq 0.05$ using SAS 9.1.3 portable software (Institute Inc., Cary, NC, USA).

Results

Root zone temperature variation among treatments was observed for both rooting media and strawberry cultivars throughout the 4-week period of the nursery experiment (Fig. 2). Most of the temperature oscillations were more pronounced during the daytime than at night. The lowest root zone temperatures were observed in the functional tray cells (H2 and H4), whereas the root zone in the H0 tray had the highest temperature. The functional trays (H2 and H4) produced morphologically better root systems, resulting in overall higher quality of seedlings (Figs. 3 and 4). Compared to the other treatments, the seedlings from the functional trays showed a root ball consisting of more thick and long first root systems. In contrast, a very small root system with rotten roots was observed in tray cells without drainage holes (H0). At the completion of the nursery experiment, the analysis of variance results revealed significant differences among treatments for most of the growth parameters (Tables 1 and 2) in all cultivars ('Seolhyang'and 'Maehyang') and rooting media, with the functional plug trays (H2 and H4) generally producing strawberry plugs of significantly higher quality than that of the other treatments. Growth responses such as crown diameter, plant height, number of first roots, root length, and root fresh and dry weights had significantly higher values in these trays than that of nonfunctional trays (H0 and C). There was a clear tendency for the quality of the seedling parameters to improve as the number of drainage holes per tray cell increased. This observation was similar regardless of the type of rooting media or cultivar used.

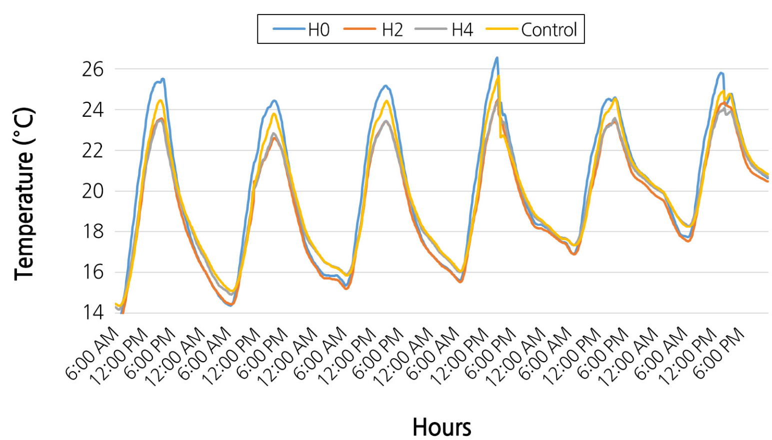

Fig. 2. Temperature change among treatments. H0, H2, and H4 represent the tray cells with 0, 2, and 4 drainage slits, respectively.

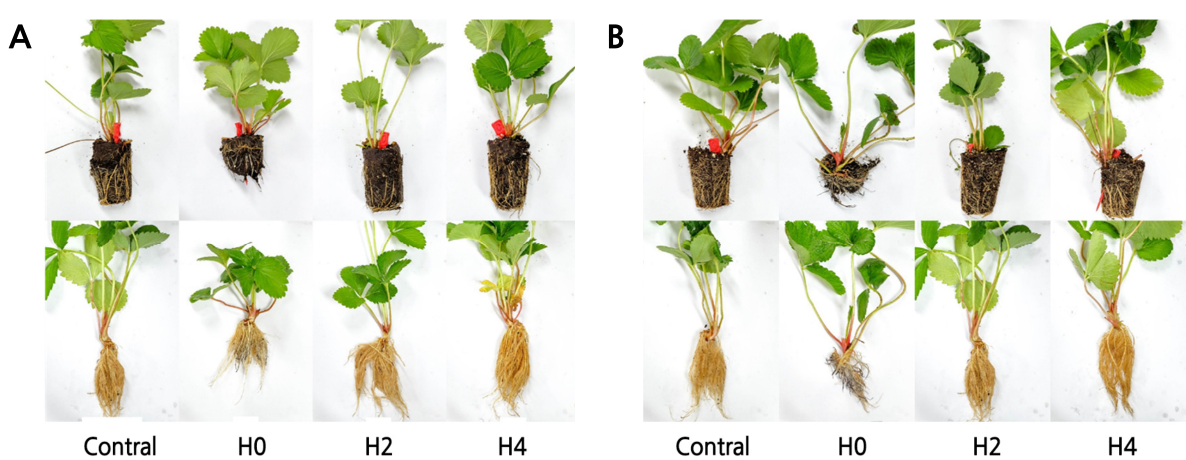

Fig. 3. Effect of functional plug trays on root morphological characteristics of plugs rooted in a commercial medium at 5 weeks after plugging in 'Seolhyang' (A) and 'Maehyang' (B) strawberries. H0, H2, and H4 represent the tray cells with 0, 2, and 4 drainage slits, respectively.

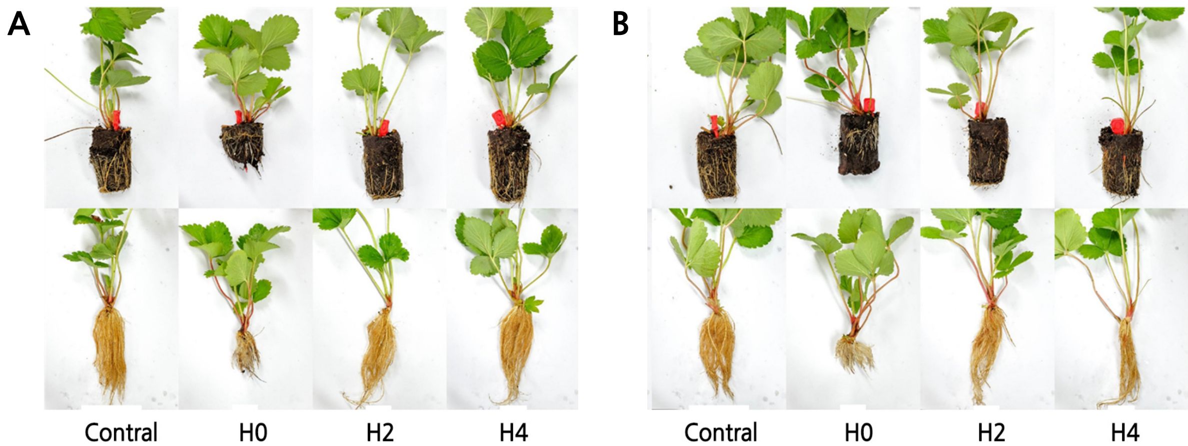

Fig. 4. Effect of functional plug trays on root morphological characteristics of plugs rooted in Ellepot at 5 weeks after plugging in 'Seolhyang' (A) and 'Maehyang' (B) strawberries. H0, H2, and H4 represent the tray cells with 0, 2, and 4 drainage slits, respectively.

The effect of the functional plug trays was clear among treatments. At the same level of significance, the H2 and H4 tray cells produced greater crown diameter, plant height, shoot fresh weight, and more and longer first roots than the other treatments for both cultivars when the commercial mix was used as the rooting medium. For 'Seolhyang' seedlings rooted using Ellepot, plant height, shoot fresh and dry weights, root number, and root length were significantly higher in both H2 and H4 functional trays than in the other treatments. In particular, the H4 tray produced the thickest crown diameter, with the largest shoot width and root fresh weight among all treatments. For 'Maehyang' seedlings rooted with Ellepot, the crown diameter, leaf area, shoot dry weight, root number and length, and root fresh and dry weights for the H2 and H4 treatments were significantly higher than that of the other treatments.

The effect of the number of holes on the early flowering of strawberry transplants is shown in Fig. 5. The 'Seolhyang' transplants raised using the commercial mix in the H2 and H4 tray cells opened their first flower 7 and 6 days earlier and attained 50% anthesis 8 and 5 days before the control, respectively. 'Seolhyang' transplants grown using Ellepot in H4 and H2 tray cells showed earlier flowering with the first plant opening their flower 5.5 and 3 days before the control, respectively. The 'Maehyang' transplants rooted with commercial mix first flowered in plants from H2 and H4 tray cells 4 and 2 days earlier than in the control, respectively, and attained 50% anthesis earlier than that of the control. The 'Maehyang' transplants rooted using Ellepot and functional trays opened the first flower 9 days earlier than that of the control. In general, all treatments had similar aspects of 50% anthesis for this cultivar.

The effect of tray cell hole number on strawberry yield is shown in Fig. 6. For the transplants rooted using the commercial medium, the analysis of variance results showed that the early yield was significantly higher in the seedlings raised with H4 functional trays than in other treatments for all transplant cultivars. Although the transplants grown in the H4 tray cells had the highest yield, there was no significant difference with those grown in the H2 tray cells. The total yield was also higher in H4 trays; however, there were no significant differences among treatments in all cultivars. For the transplants grown in the Ellepot medium using the H4 plug tray cells, the early and total yields were higher than those in the other trays. For the total yields, the transplants from H4 tray cells produced a statistically better yield than other treatments.

Table 1. Effect of tray cell hole number on strawberry seedling growth characteristics after 5 weeks in commercial medium

Cultivar	Treatment[z]	Shoots							Roots			
		Crown diameter (mm)	Leaf area (cm^2/ plant)	Plant height (cm)	Shoot width (cm)	Leaf number	Shoot fresh weight (g)	Shoot dry weight (g)	Number of first roots	Root Length (cm)	Root fresh weight (g)	Root dry weight (g)
Seolhyang	Control	9.4 b[y]	149.9 a	20.9 b	17.4 ab	5.7 a	9.40 ab	2.35 a	13.6 b	14.8 b	4.61 ab	0.42 ab
	H0*	8.6 b	110.7 a	15.4 c	14.8 b	5.6 a	7.06 b	1.86 a	12.6 b	8.0 c	2.50 b	0.28 b
	H2**	10.2 ab	194.1 a	23.6 ab	15.8 a	6.0 a	11.30 a	2.88 a	23.8 a	18.6 a	6.11 a	0.74 a
	H4***	11.6 a	200.4 a	24.8 a	14.6 a	6.2 a	12.74 a	3.10 a	23.4 a	17.0 ab	6.14 a	0.70 a
Maehyang	Control	10.0 b	200.8 a	22.5 bc	17.9 ab	6.0 b	11.78 b	2.89 a	14.5 bc	14.2 ab	5.21 b	0.61 b
	H0	9.6 b	108.2 b	19.0 c	13.8 b	4.8 a	8.32 c	1.96 b	11.2 c	9.2 b	3.06 a	0.44 c
	H2	10.6 ab	209.0 a	25.8 ab	18.0 ab	6.2 a	12.81 ab	2.85 a	18.8 ab	14.0 ab	5.47 a	0.61 b
	H4	11.6 a	235.2 a	29.4 a	18.8 a	6.4 a	15.71 a	3.59 a	21.0 a	17.8 a	6.17 a	0.79 a

[z]H0, H2, and H4: tray cells with 0, 2, and 4 drainage slits, respectively.
[y]Mean separation within columns by Duncan's multiple range test at $p < 0.05$.

Table 2. Effect of tray cell hole number on strawberry seedling growth characteristics after 5 weeks in Ellepot

Cultivar	Treatment[z]	Shoots							Roots			
		Crown diameter (mm)	Leaf area (cm^2/ plant)	Plant height (cm)	Shoot width (cm)	Leaf number	Shoot fresh weight (g)	Shoot dry weight (g)	Number of first roots	Root Length (cm)	Root fresh weight (g)	Root dry weight (g)
Seolhyang	Control	8.3 b[y]	118.3 a	16.0 bc	14.2 ab	4.6 a	7.00 ab	2.13 ab	20.4 ab	15.8 b	3.63 b	0.58 a
	H0*	8.0 b	101.8 a	14.4 c	12.4 b	5.6 a	6.39 b	1.91 b	16.6 b	6.4 c	2.31 b	0.26 b
	H2**	8.2 b	104.2 a	19.3 a	12.6 b	5.6 a	7.43 ab	2.05 ab	24.4 a	18.4 a	3.50 b	0.52 a
	H4***	9.7 a	124.9 a	18.0 ab	17.2 a	5.6 a	8.72 a	2.64 a	21.0 ab	17.6 ab	5.10 a	0.72 a
Maehyang	Control	8.5 b	95.8 bc	20.4 a	14.8 a	4.8 a	6.94 ab	1.82 ab	15.9 ab	14.3 b	2.95 b	0.48 b
	H0	8.6 b	76.0 c	16.4 b	14.8 a	4.6 a	5.71 b	1.68 b	11.8 b	6.6 c	1.16 c	0.15 c
	H2	9.3 ab	134.2 a	21.0 a	15.6 a	5.2 a	8.62 a	2.25 ab	18.2 a	18.2 a	4.28 a	0.62 a
	H4	9.6 a	126.0 ab	22.0 a	17.2 a	5.3 a	7.79 a	2.32 a	16.2 ab	16.8 a	3.60 ab	0.63 a

[z]H0, H2, and H4: tray cells with 0, 2, and 4 drainage slits, respectively.
[y]Mean separation within columns by Duncan's multiple range test at $p < 0.05$.

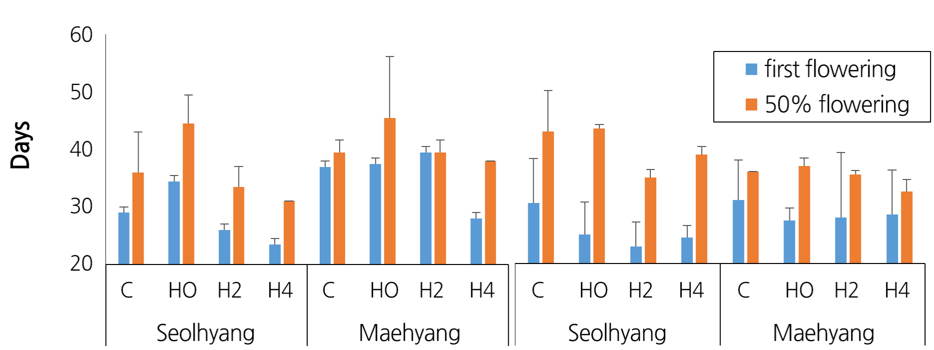

Fig. 5. Effect of tray cell hole number on early flowering in 'Seolhyang' and 'Maehyang' strawberries. H0, H2, and H4 represent the tray cells with 0, 2, and 4 drainage slits, respectively. Seedlings were rooted in commercial medium (A) or Ellepot (B). First flowering: days to the first flowering; 50% flowering: days to 50% flowering after transplanting.

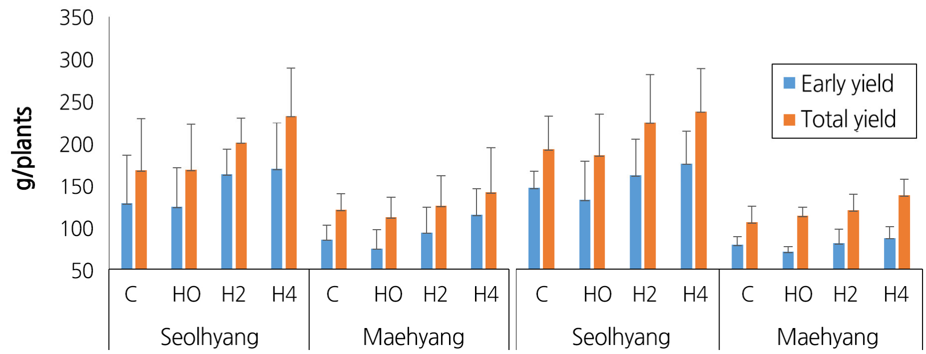

Fig. 6. Effect of tray cell hole number on strawberry yield. A: Seedlings were rooted in commercial medium. B: Seedlings were rooted in Ellepot. H0*: tray cells with no drainage slit. H2**: tray cells with two drainage slits. H4***: tray cells with four drainage slits.

Discussion

In this study, the functional plug trays successfully produced transplants of optimum quality. These seedlings established quickly in the fruiting greenhouse and grew more vigorously than did the transplants from the existing trays. We attributed the superior quality of seedlings rooted in H2 and H4 tray cells to the number of benefits offered by the structure and design of the newly developed trays. The newly invented tray provided a relatively conducive environment for the ideal growth of strawberry plugs. In Korea and in many other winter strawberry farming areas, the strawberry nursery is established during the hot summer period when the temperature is relatively high, sometimes exceeding the upper range for normal growth. However, the elimination of any barrier that hinders roots to optimally have access to air may provide ideal growing conditions for the roots, thereby promoting the overall seedling growth conditions. Root zone temperature is reported to be an important plant growth factor controlling the plant physiological phenomena related to nutrient availability and their uptake by roots (Pregitzer and King, 2005; Malcolm et al., 2006). A decline in root growth due to high temperature in the root zone in strawberry plants was shown by Ganmore-Neumann and Kafkafi (1985). In an experiment to study the effect of various NO_3^- /NH_4^+ ratios in the nutrient solution at various root temperatures on strawberry plants, Sakamoto et al. (2016) also observed similar trends. They showed a general decrease in root growth with increasing root temperature and a higher root biomass when the temperature was lowered, stating that a higher root zone temperature was responsible for reducing oxygen consumption and cell viability of the root system. The effect of higher root zone temperature on root growth and plant in general has been thoroughly investigated in other crops. He et al. (2008) studied the effect of root zone temperature on Chinese broccoli and found that high temperature in the root zone adversely affected the root morphology as well as the mineral nutrition for *Brassica oleracea* var. *alboglabra* grown in geoponics. The amount of resources (nutrients and water) absorbed by a plant root system is related to its branching pattern and morphology, such as root length, radius etc. (Wang et al., 2006). In this study, the plugs rooted in the H2 and H4 functional plug trays had significantly longer and higher amounts of first roots. In a previous study, when the root zone temperature was controlled in cucumber plants exposed to high fluctuating air temperature during the hot season using cold water flowing through a pipe system buried beneath the root system, the root growth and yield were both increased (Moon and Kang, 2007).

With an increased number of lateral holes, the water drainage was enhanced and the adverse effects of oxygen deficiency to root respiration were minimized. This is consistent with observations by Iwasaki (2008), who stated that strawberry is a crop that has high oxygen requirements. In his study, which examined the effect of root zone aeration on improving growth and yields of coir-cultured strawberry plants, it was shown that the root zone aeration treatment was useful for strawberry production during the summer season. The absence of any opening in the bottom of the newly developed tray allows them to retain some moisture necessary for the plant during the watering intervals, while the side openings retain the functionality of the tray to optimize drainage and aeration of the tray cell content. Steffens et al. (2005) reported that oxygen deficiency due to waterlogging inhibited the synthesis of ATP in the rhizosphere and decreased the uptake of nutrients in wheat and barley. The penetration of outside air to the root zone also rendered the root system to be air-pruned in tray cells with the increased number of lateral slits, thereby resulting in thick and long roots. The importance of the air-pruning technique in containerized plants has been reported in previous studies as inhibiting root spiraling effects but promotes root branching, more even root distribution, and increased root growth in the growing media (Whitcomb, 1982; Huang and Ai, 1992). In this study, rooting the plugs still attached to the mother plants allowed all plugs, including those rooted in the H0 tray cell, to survive until the time of transplanting with the required minimum crown diameter (8 mm) based on Hochmuth et al. (2001) as cited in Cocco et al., (2011) standards for strawberry transplants. This is also in accordance with Treder et al. (2014), who showed that rooting of strawberry plantlets before detaching them from the mother plants leads to the successful growth of all transplants.

According to Robbins and Evans (2011), keeping the substrate in very wet containers results in the accumulation of rotting microorganisms in the root zone. This agrees with our observations, i.e., all seedlings rooted in the H0 tray cells had root systems with rotten root tips.

The results for flowering and yields revealed the efficiency of the new trays to shorten the flowering and production period of early fruit. These observations were possibly due to lower temperature and optimum aeration in the root zone that was observed in the H4 and H2 tray cells. Additionally, the root system was air-pruned, and water evaporation was faster in these trays compared to other treatments, which might be the cause of accelerated early flowering and early fruit production. Even though it is important to supply enough water to obtain acceptable strawberry yields, at the beginning of flowering, water stress is essential for flower induction (Massetani et al., 2011). The early flowering noticed in the functional plug trays may also be attributable to the leaching of nutrients (mainly nitrogen). Our findings agree with those of Yamasaki and Yano (2009), who noticed floral induction inhibition when a nitrogen-based fertilizer was applied to strawberry plants during the early period of flower induction. Lower temperature and restricted fertilizer application during the critical period of floral induction were also highlighted by Guttridge (1985) to be important for inducing flowering in strawberry plants.

The testing of the developed functional plug trays in both nursery and post-transplanting stages showed successful results in terms of seedling quality and early flowering and yield that were associated with their design. The trays induced lower temperature and water evaporation in the cell media content, and air-pruned transplants thereby had minimized root tangling and a matted binding, encouraging root branching that subsequently led to vigorous growth and early flowering and harvesting.

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