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Evaluation of pepper seedling growth according to the growing period and tray for automatic transplanting

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Abstract

The effective growth of pepper seedlings relies on the growing period and tray used, which both aim to minimize seedling damage during the transplantation process. Therefore, the objective of this study was to evaluate the effect of red and green pepper seedling growth in plug and cylindrical paper pot (CPP) trays with different growth periods of the seedlings. Two different seedling growth trays were used for the two varieties of pepper seedlings in the same growing media. The pepper seedling growth rates were investigated at 15, 30, and 45 days for each of variety. Important parameters, e.g., the plant height, fresh weight for the plant and root, number of leaves, leaf length and width, and leaf chlorophyll contents, were measured. During the experiment, the CPP tray maintained uniform seedling growth as compared to the plug tray. CPP trays ensured the height of the seedling, with these results 0.84 to 1.6 times higher than those of the plug tray for all conditions, indicating the good quality of the pepper seedlings. The shoot and root weights were found to be greater with more leaves in the CPP tray seedlings for 45 days compared to the seedlings grown in the plug tray, whereas the green pepper variety showed a greater leaf ratio than the red pepper seedlings. The analysis of pepper seedling growth presented in this study will guide the selection of suitable growth trays and seedling periods for farmers when they undertake automatic pepper transplantation in the field.

Keywords: growing period, pepper, seedling growth, seedling tray

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Introduction

Pepper (*Capsicum annuum* L.), an essential spice in Korea, is a natural flavoring and coloring agent worldwide. It is widely cultivated in tropical and subtropical regions, including India, Indonesia, Malaysia, Thailand, Brazil, Sri Lanka, Vietnam, and China (Islam et al., 2020). Although pepper production is increasing globally, decreased rates were recorded in some countries (e.g., Korea and Japan) over the last few decades due to small agricultural land areas and the aging of farmers (Iqbal et al., 2021; Islam et al., 2021). Besides, Korean red and green peppers are famous for their unique color, pungency, and aroma (Lee et al., 2004; Rahman et al., 2018; Faqeerzada et al., 2020). For favorable pepper cultivation, selecting the proper growing technique at an early period is an important consideration (Shin et al., 2020).

Several researchers reported that the seedling period and tray improved the growing condition, such as plant height, weight for plant and root, leaf length, width, and chlorophyll content during the seedling nursing periods (Di Benedetto and Klasman, 2004; Ge et al., 2012). The selection criteria of the seedling tray is an essential factor of seedling morphology and physiology. Generally, in many cases, the loss occurred due to the inability to find a suitable tray based on the seedling period and variety. In the improper tray, the root became too old, the root decreased, and as a result, seedling growth was slow after transplantation. Examining a different tray could help find the proper method at variable seedling periods or variety. Otherwise, the seedling quality and the seedling vegetate growing speed after transplantation will be affected (Yaping and Diankui, 2005).

Researchers investigated several types of seedling tray; among them, the Plug seedling tray (Plug) and cylindrical paper pot (CPP) were the most popular methods for producing seedlings (Xu et al., 2021). The difference between the Plug and CPP tray lies in substrate support for the root. In the Plug tray, a tray is filled with soil to create a physical environment. However, the CPP tray is not supported by a plastic tray. It can maintain its physical shape because the soil is wrapped with paper. Unlike the Plug tray, the CPP tray can create gaps between the root surfaces of seedlings and the plastic tray surface (Jang et al., 2020). Removing Plug seedlings from a Plug tray is complex and can easily damage roots (Kumar and Raheman, 2008); instead, the CPP tray could protect the plant root. Most importantly, the characteristic of protection avoids having to transplant the plants until the roots are fully distributed in the substrate (Seo et al., 2017), which in turn can shorten the length of the seedling raising period to reduce the ratio of aging seedlings (Jang et al., 2018).

Most seedling studies have been conducted on the establishment of quality seedling standards using the Dickson quality index (DQI) and relative growth ratio (RGR) (Seo et al., 2018), air pruning effect (Munroe et al., 2018), and localization of manufacturing equipment (Park et al., 2017). Most of the previous CPP studies were focused on trees (Wu, 2013; McGrath et al., 2017). Studies involving fruits and vegetables using CPP were reported only recently (Seo et al., 2017; Jang et al., 2018; Kim et al., 2018; Shim et al., 2018). Most of the previous studies investigating moisture management after transplanting in the agriculture field and greenhouse (Shim et al., 2018; Ndikumana et al., 2019).

The analysis of the seedling growth before transplanting could select the proper growing period for a specific variety. Besides, choosing the appropriate growing tray to reduce of pepper seedling damage would be of great importance to farmers for automatic pepper seedling transplantation. Therefore, the objective of this study was to select a suitable seedling tray for automatic pepper transplantation by evaluating the Plug and CPP tray in terms of the green and red pepper seedlings variety and different growing periods.

Materials and Methods

Description of the seedling growing condition

All seedlings used in the experiments were grown from May 4, 2018 to June 18, 2018 at the nursery greenhouse (latitude 36°12'N and longitude 127°5'E) in Nonsan, Chungcheongnam-do, Korea. Conventionally, the farmers practice transplanting 30 to 45 days old seedlings (Iqbal et al., 2021). Hence, three levels of 15, 30, and 45 days old seedlings were considered in two growing trays: the Plug seedling tray (Plug) and cylindrical paper pot (CPP). The pepper verities included green pepper (*Capsicum annum* L. Cultivar Dangjo), and red pepper (*Capsicum annuum* L., var. Hanbando and var. Dabotop) were considered to study the physical properties of pepper seedlings and to determine the suitable transplanting tray. After sowing the pepper seeds in the tray, they were transferred to a germination room for two days at a temperature of 28°C and humidity of 90%. During the seedling period, the nursery greenhouse inside temperature was maintained at an average of 17 to 20°C for 24 hours. For the CPP, seedlings were wrapped with a biodegradable paper (Ellepot paper, Ellegaard, Esbjerg, Denmark) and grown in a 128-cell tray with 60 cc volume (ø 39 mm × height 39 mm). In the Plug system, the growing trays contain 128, 200, or 288 cells in which the arrangement of cells is 8 × 16, 10 × 20, and 12 × 24. The most popular one being used has 8 × 16 or 12 × 24 cells, whereas, in this study, the seedlings were grown in an 8 × 6 tray and filled with the same volume (60 cc in each cell). In order to measure the seedling growth, the considered variables in the experiment are illustrated in Table 1.

Table 1. Parameters of the considered variable to evaluate the seedling growth.

Variable	Parameter
Variety	Green and red pepper
Growing tray	Plug and CPP
Growing period	15, 30, and 45 days
Plant growth	Plant height, and fresh weight for plant shoot and root
Leaf growth	Number of leaves, leaf length and width, and SPAD index

CPP, cylindrical paper pot; SPAD, soil plant analysis development.

Growth parameters measurement

After 15, 30, and 45 days, the growth parameters such as plant height, number of leaves, leaf length and width (mm), and fresh length (mm) were measured (Fig. 1A). To measure fresh weight for plant and root, the seedlings were removed manually from the cells. Plant and root were weighted separately. After separating the root, the plant height was measured up to the highest leaf tip. The measurement of plant height, and leaf length and width were recorded with a steel rule with the least count of 0.5 mm (Fig. 1B and 1C). The leaf chlorophyll was measured using a soil plant analysis development (SPAD) meter (SPAD 502 Plus Chlorophyll Meter, Spectrum Technologies, Inc., Illinois, USA).

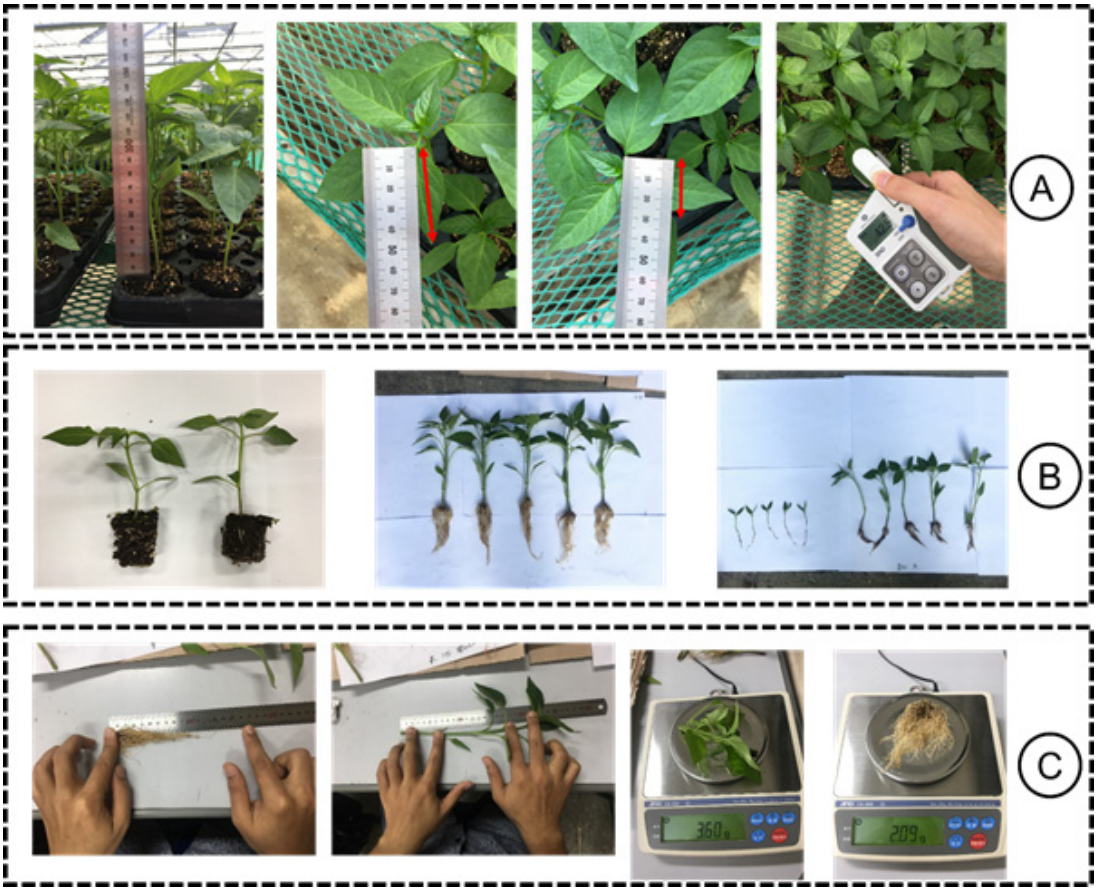

Fig. 1. (A) Measurement of plant and leaf length, width and chlorophyll data, (B) wash out the soil from seedlings with water, then remove the water completely, and (C) measure the fresh length and weight of the body of plant and root.

Statistical analysis

Seedling growth data were subjected to identify the statistical differences among different growth conditions according to Tukey's one-way comparisons ($p \leq 0.05$). The results were expected to optimize the variables to achieve maximum influencing growth of Plug and CPP seedlings with appropriate variety and growing period. Seedling emergence was determined on all the cells of a tray. After that, growth parameters were measured using fifty random seedlings from each repetition throughout the study. In addition, the relatively plant height (RPH), shoot fresh weight (RSFW) and root fresh weight (RSFR), number of leaves (RNL), and leaf length (RLL) and width (RLW) were also calculated using the following equation (1) to understand the impact of the seedling growing period.

$$\text{Relative growth, percentage} = \left(\frac{\text{second measurement - first measurement}}{\text{period, days}}\right) \times 100 \quad (1)$$

Results and Discussion

Seedling growth by tray

Plant growth

Results of average plant height in Plug and CPP trays based on seedling verity and period are presented in Fig. 2A. The growth range of the Plug and CPP trays were from 25 to 38 mm, 71 to 126 mm, and from 154 to 196 mm, respectively, for the seedling period 15, 30, and 45 days, respectively. According to Fig. 2A, the plant height for red verity was approximately 1.2 times higher than the green verity for 15 and 30 days. On the other hand, for 45 days, the growth rate was increased for green verity, approximately 1.05 times higher than the red verity.

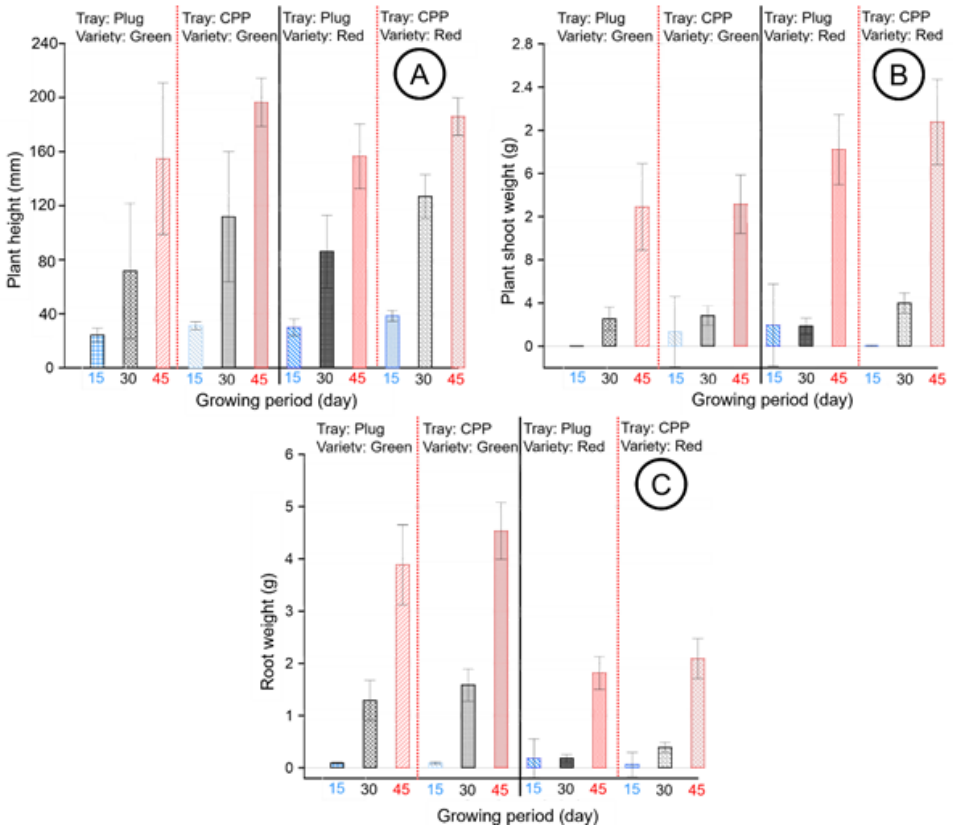

Fig. 2. (A) Average plant height, (B) shoot fresh weight, and (C) root fresh weight in Plug and cylindrical paper pot (CPP) tray for red and green paper.

The average value of plant height indicating the seedling was from 0.84 to 1.6 times higher in the CPP tray than that in the Plug tray for all conditions. According to Kim et al. (2015), the pepper seedling maximum height was reported 181 mm for 45 days. In addition, Iqbal et al. (2021) investigated automatic pepper transplanter agronomic transplanting requirements using 45 days and 190 mm plant height seedling, and found a 96.79% success rate for seedling deposition. In the present study, the average height in the Plug and CPP trays were 185 and 196 mm, respectively, which indicates that plant height for CPP trays was maintained the recommended condition for transplant the seedling automatically.

Results of average plant shoot weight in Plug and CPP trays based on seedling period and verity and illustrated in Fig. 2B. The weight range of the Plug and CPP trays were from 0.001 to 1.29 g, 0.18 to 1.32 g, and from 0.004 to 2.07 g, respectively, for the seedling period 15, 30, and 45 days, respectively. According to Fig. 2B, the shoot weight for red verity was approximately 0.03 to 1.58 times higher than the green verity for 15, 30, and 45 days. The average value of plant weight indicating the seedling was from 0.01 to 2.14 times higher in the CPP tray than that in the Plug tray for all conditions. According to Kim et al. (2015), Liu et al. (2019), and Mayak et al. (2004), the pepper seedling maximum shoot fresh weight was reported from 2.00 to 4.31 g after 30 days period. In comparison, no or very little change in fresh weight was observed after 30 days. In the present study, after 30 days of the period, the average shoot fresh weight in the Plug and CPP trays were 1.13 and 2.07 g, respectively, and the increase rate was observed over 50% from 30 to 45 days period.

Fig. 2C shows the average plant root weight in Plug and CPP trays based on seedling period and verity. The root weight range of the Plug and CPP trays were from 0.06 to 0.18 g, 0.18 to 1.52 g, and from 1.81 to 4.53 g, respectively, for the seedling period 15, 30, and 45 days, respectively. According to Fig. 2C, the root weight for red verity was approximately 0.14 to 0.69 times higher than the green verity for 15 and 30 days. On the other hand, for 45 days, the root weight was increased for green verity, approximately 0.46 times higher than the red verity. The average value of plant root weight indicating the root was from 2.14 to 2.16 times higher in the CPP tray than that in the Plug tray for all conditions. According to Kim et al. (2015), Liu et al. (2019), and Mayak et al. (2004), the pepper seedling maximum fresh root weight was reported 1.71 g after 30 days of period. Similar to the shoot weight, no or very little change in root weight was observed after 30 days due to water not being supplied frequently. In the present study, after 30 days of the period, the average root fresh weight in the Plug and CPP trays were at the rate of 2.85 and 3.31 g, respectively, and the increase rate was observed over 55% from 30 to 45 days. Furthermore, the results of root growth show that the roots of the CPP tray were higher than the Plug tray for all conditions, which indicates that the CPP trays can grow the seedling more effectively by reducing the damage.

Leaf growth

Results of average no. of leaves in Plug and CPP trays based on seedling period and verity and illustrated in Fig. 3A. The number of leaves range of the Plug and CPP trays were from 2.12 to 4.80, from 2.32 to 5.44, and from 2.32 to 4.23, respectively, for the seedling period 15, 30, and 45 days, respectively. According to Fig. 3A, the number of leaves for red verity was approximately 1.1 times higher than the green verity for 15 and 30 days. On the other hand, for 45 days, the no. of leaves was increased for green verity, approximately 0.86 times higher than the red verity. The average value of no. of leaves indicating the seedling was from 0.91 to 1.11 times higher in the CPP tray than that in the Plug tray for all conditions.

Results of average leaf length in Plug and CPP trays based on seedling period and verity and illustrated in Fig. 3B. The leaf length range of the Plug and CPP trays were from 8.2 to 9.8 mm, 18.75 to 25.5 mm, and from 19.4 to 26 mm, respectively, for the seedling periods 15, 30, and 45 days, respectively. According to Fig. 3B, the leaf length for red verity was approximately from 0.85 to 1.18 times higher than the green verity for 15 and 30 days. On the other hand, for 45 days, the leaf length was increased for green verity, approximately 0.85 times higher than the red verity.

Results of average leaf width in Plug and CPP trays based on seedling period and verity and illustrated in Fig. 3C. The weight range of the Plug and CPP trays were from 9.08 to 20 mm, 18.75 to 74.17 mm, and from 19.47 to 113.96 mm, respectively, for seedlings periods 15, 30, and 45 days, respectively. According to Fig. 3C, the leaf width for red verity was approximately 0.19 to 2.20 times higher than the green verity for 15, 30, and 45 days. The average value of leaf width indicating the seedling was from 2.20 to 5.03 times higher in the CPP tray than that in the Plug tray for all conditions.

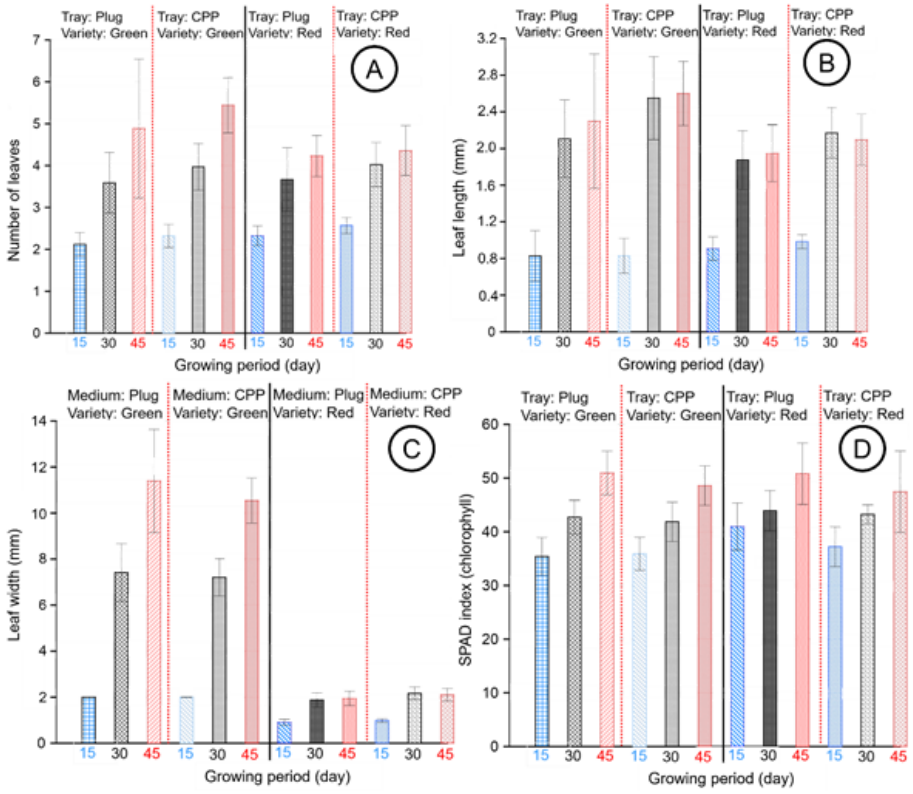

Fig. 3. (A) Average number of leaves, (B) leaf length, (C) leaf width, and (D) soil plant analysis development (SPAD) index in plug and cylindrical paper pot (CPP) tray for red and green paper.

Results of average leaf SPAD index (chlorophyll content) in Plug and CPP trays based on seedling period and verity and illustrated in Fig. 3D. The main factor in seedling quality is the concentration of leaf chlorophyll. The period of seedling production and the amount of nutrients affect the leaf chlorophyll index (Souri and Sooraki, 2019). Supplying seedlings with essential nutrient elements can improve leaf greenness (Dufault and Melton, 1991). With inadequate nutrition, there may be additional time required to reach optimum leaf chlorophyll, which could affect the time to harvest. The leaf SPAD index range of the Plug and CPP trays were from 35.39 to 40.98, 41.85 to 43.90, and 47.45 to 50.95, respectively, for the seedling period 15, 30, and 45 days, respectively. According to Fig. 3D, the leaf SPAD index for red verity was approximately 0.86 to 1.03 times higher than the green verity for 15 and 30 days. On the other hand, the value for 45 days condition was changed slightly. The green verity leaf SPAD index is 0.99 times higher than the red verity. The average value of the SPAD index indicating the seedling was from 0.98 to 1.07 times higher in the Plug tray than that in the CPP tray for all conditions.

Seedling growth by growing period

Plant growth

Plant growth characteristics of pepper seedlings with different seedling growth periods are summarized in Table 2. According to Table 2, no statistical difference was addressed among 15 days seedling plant height for all verity and growing trays. However, for 30 and 45 days conditions, no statistical difference was observed between the same growing tray, but significant differences were observed between the different verity and growing tray. Fig. 4 shows the spider graphs illustrating

the impacts on plant growth. The seedling period, related to RPH, reflects the seedling quality (Liu et al., 2019). In this study, the RPH was significantly increased in CPP and Plug seedlings.

According to Table 2, no statistical difference was addressed among 15 and 30 days seedling shoot fresh weight for all verity and growing trays. However, for 45 days conditions, no statistical difference was observed between the same growing tray, but significant differences were observed between the different verity and growing tray. RSFW was also higher in the CPP system than that in the Plug as shown in Fig. 4. These results suggest that the 30 - 45 seedling period can accelerate the growth of the seedling.

According to Table 2, there has significant statistical difference was addressed among 15 days Plug and CPP tray for all verity. However, for 30 and 45 days conditions, no statistical difference was observed between the same varieties, but significant differences were observed between the different growing trays. For the green verities, the RRFW was relatively higher than the red verity. On the other hand, the root growth for CPP green verity was more uniform than any others conditions. These results indicated that the Plug size might reduce the growth for red verity and some modification required to improve the seedling growth.

Table 2. Plant growth characteristics of pepper seedling with different seedling growth periods.

Variety	Tray type	Days	Plant height (mm)	Fresh weight (g)	
				Shoot weight	Root weight
Green	Plug	15	24 ± 5.1e	0.001 ± 0.03d	0.09 ± 0.01f
		30	71 ± 50bcd	0.25 ± 0.11cd	1.29 ± 0.38e
		45	154 ± 56b	1.29 ± 0.40b	3.89 ± 0.77b
	CPP	15	31 ± 2.9e	0.13 ± 0.33cd	0.09 ± 0.02f
		30	111 ± 48a	0.28 ± 0.09cd	1.58 ± 0.31de
		45	196 ± 17.8a	1.32 ± 0.27b	4.53 ± 0.54a
Red	Plug	15	29 ± 6.1e	0.20 ± 0.38cd	0.18 ± 0.37f
		30	80 ± 27d	0.19 ± 0.07cd	0.19 ±0.07f
		45	156 ± 23b	1.82 ± 0.32a	1.81 ± 0.31cd
	CPP	15	38 ± 3.9e	0.004 ± 0.01d	0.06 ± 0.23f
		30	126 ± 16.1c	0.40 ± 0.09c	0.39 ± 0.10f
		45	185 ± 13.8a	2.07 ± 0.39a	2.09 ± 0.38c

CPP, cylindrical paper pot.

a - f: Identified the statistical differences within columns according to Tukey's one-way comparisons ($p \leq 0.05$).

Leaf growth

According to Table 3, for the number of leaves, no statistical difference was observed between the same growing tray for all seedling period conditions, but significant differences were observed between the different verity and growing trays. The results also indicate that no statistical difference was addressed among 15 days seedling leaf length for all verity and growing tray. However, for 30 and 45 days conditions, no statistical difference was observed between the same growing tray, but significant differences were observed between the different verity and growing tray. Similarly, for 15, 30 days conditions, no statistical difference was observed between the same verities for seedling leaf width, but significant differences were observed between the growing tray. However, for 45 days condition, significant differences were observed between the growing tray and verity. Based on Table 3, for 15 and 30 days seedling period conditions, no statistical difference was observed between the same verities for the SPAD index, but significant differences were observed between the growing tray. However, for 45 days condition, significant differences were observed between the growing tray and verity.

Table 3. Leaf growth characteristics of pepper seedling with different seedling growth periods.

Variety	Tray type	Days	No. of leaves	Leaf length (mm)	Leaf width (mm)	SPAD index, chlorophyll
Green	Plug	15	2.00 ± 0.00d	8.29 ± 2.75e	20.0 ± 0.00d	35.40 ± 3.51e
		30	7.41 ± 1.26c	21.00 ± 4.23bcd	74.1 ± 12.56c	42.72 ± 3.16cd
		45	11.40 ± 2.24a	22.98 ± 7.33b	114.0 ± 22.4a	50.95 ± 4.06a
	CPP	15	2.00 ± 0.00d	8.29 ± 1.90e	20.0 ± 0.00d	35.88 ± 3.06e
		30	7.21 ± 0.82c	25.50 ± 4.51a	72.08 ± 8.15c	41.85 ± 3.65cd
		45	10.54 ± 0.98b	26.00 ± 3.50a	105.4 ± 9.78b	48.58 ± 3.67ab
Red	Plug	15	2.33 ± 0.24e	9.03 ± 1.27e	9.08 ± 1.27e	40.97 ± 4.38d
		30	3.67 ± 0.76d	18.75 ± 3.19d	18.7 ± 3.19d	43.90 ± 3.76c
		45	4.23 ± 0.49c	19.47 ± 3.10cd	19.4 ± 3.10d	50.80 ± 5.71a
	CPP	15	2.57 ± 0.19e	9.85 ± 0.76e	9.85 ± 0.76e	37.20 ± 3.71e
		30	4.03 ± 0.53cd	21.70 ± 2.74bc	21.70 ± 2.74d	43.25 ± 1.78cd
		45	4.36 ± 0.60c	20.90 ± 2.76bcd	20.95 ± 2.76d	47.45 ± 7.57b

CPP, cylindrical paper pot; SPAD, soil plant analysis development.

a - e: Identified the statistical differences within columns according to Tukey's one-way comparisons ($p \leq 0.05$).

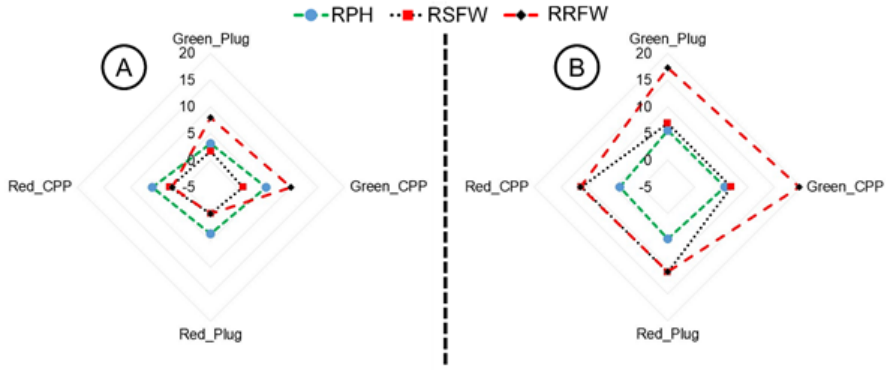

Fig. 4. Spider graphs illustrating the impacts on plant growth in (A) 15 - 30 days and (B) 30 - 45 days. RPH, relative plant height; RSFW, relative shoot fresh weight; RRFW, relative root fresh weight; CPP, cylindrical paper pot.

Fig. 5 shows the spider graphs illustrating the impacts on leaf growth. According to the graph, the RLL and RLW were uniforms for 15 - 30 and 30 - 45 days. In spider graphs, the lowest RNL was observed in the Plug tray, indicating that the adaptability of Plug seedling to the field is low when seedlings are early stage. Our results suggest that the CPP system can provide a wide range of transplanting period choices to produce seedlings, especially for green verity.

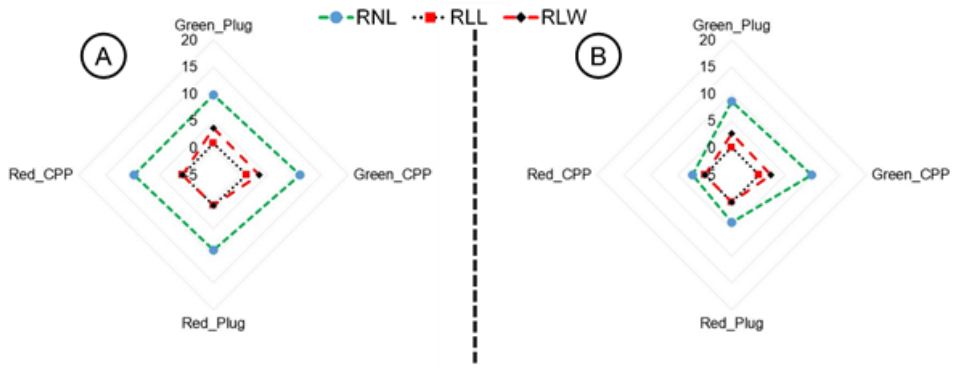

Fig. 5. Spider graphs illustrating the impacts on leaf growth in (A) 15 - 30 days and (B) 30 - 45 days. RNL, relative number of leaves; RLL, relative leaf length; RLW, relative leaf width; CPP, cylindrical paper pot.

Conclusions

According to the growth analysis, the average height in CPP trays for 45 days seedling period was 196 mm, which indicates that plant height for CPP trays was maintained as the recommended seedling height for transplanting the seedling using an automatic transplanter. The CPP tray for growing seedlings could be used to prevent seedlings from root damage. In addition, in the Plug tray, seedlings were not transplanted until the roots form a root ball since the root can easily be damaged when pulling seedlings from trays. However, the CPP tray has protected the root effectively, and the root ball was not required. The results of this study indicate the difference in pepper seeding growth in terms of the seedling tray and period; therefore, pepper growers could get enough information to use the appropriate seedling tray and period, especially for the automatic transplanting technique where the seedling extraction is fully dependent on the seedling growth such as height and root condition.

Conflict of Interests

No potential conflict of interest relevant to this article was reported.

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References

Di Benedetto AH, Klasman R. 2004. The effect of plug cell volume on the post-transplant growth for impatiens walleriana pot plant. European Journal of Horticultural Science 69:82-86.

Dufault RJ, Melton RR. 1991. Nitrogen, phosphorus, and potassium fertility regimes affect tomato transplant growth. HortScience 26:141-142.

Faqeerzada MA, Rahman A, Kim G, Park E, Joshi R, Lohumi S, Cho BK. 2020. Prediction of moisture contents in green peppers using hyperspectral imaging based on a polarized lighting system. Korean Journal of Agricultural

Science 47:995-1010.
Ge M, Chen G, Hong J, Huang X, Zhang L, Wang L, Wang X. 2012. Screening for formulas of complex substrates for seedling cultivation of tomato and marrow squash. Procedia Environmental Sciences 16:606-615.
Iqbal MZ, Islam MN, Chowdhury M, Islam S, Park T, Kim YJ, Chung SO. 2021. Working speed analysis of the gear-driven dibbling mechanism of a 2.6 kW walking-type automatic pepper transplanter. Machines 9:6.
Islam MN, Iqbal MZ, Ali M, Chowdhury M, Kabir MSN, Park T, Chung SO. 2020. Kinematic analysis of a clamp-type picking device for an automatic pepper transplanter. Agriculture 10:1-18.
Islam MN, Iqbal MZ, Chowdhury M, Ali M, Shafik K, Kabir MSN, Chung SO. 2021. Stress and fatigue analysis of picking device gears for a 2.6 kW automatic pepper transplanter. Applied Sciences 11:2241.
Jang CD, Kweon WY, Kim HS, Kim HD, Kim KJ, Heo YJ, Kim SI. 2020. Responses of vegetable seedlings grown on cylindrical paper pots or plug trays to water stress. Korean Journal of Horticultural Science & Technology 38:158-168.
Jang D, Kwon Y, Choi K, Kim IS. 2018. Comparison of growth characteristics fruit vegetable seedlings grown on cylindrical paper pot trays of plug trays. Protected Horticulture and Plant Factory 27:381-390. [in Korean]
Kim HC, Cho YH, Ku YG, Bae JH. 2015. Seedling qualities of hot pepper according to seedling growth periods and growth and yield after planting. Korean Journal of Horticultural Science and Technology 33:839-844. [in Korean]
Kim HM, Kim YJ, Hwang SJ. 2018. Physicochemical properties of newly developed artificial medium and proper irrigation interval for production of tomato plug seedlings. Protected Horticulture and Plant Factory 27:71-79. [in Korean]
Kumar GVP, Raheman H. 2008. Vegetable transplanters for use in developing countries—A review. International Journal of Vegetable Science 14:232-255.
Lee JH, Sung TH, Lee KT, Kim MR. 2004. Effect of gamma-irradiation on color, pungency, and volatiles of Korean red pepper powder. Journal of Food Science 69:C585-C592.
Liu N, Ji F, Xu L, He D. 2019. Effects of LED light quality on the growth of pepper seedling in plant factory. International Journal of Agricultural and Biological Engineering 12:44-50.
Mayak S, Tirosh T, Glick BR. 2004. Plant growth-promoting bacteria that confer resistance to water stress in tomatoes and peppers. Plant Science 166:525-530.
McGrath D, Henry J, Munroe R, Agro E. 2017. Effect of propagation tray design on early stage root development of *Acer rubrum*, *Quercus rubra*, and *Populus tremuloides*. Journal of Environmental Horticulture 35:35-40.
Munroe R, McGrath D, Henry J. 2018. Increasing amounts of coir dust in substrates do not improve physical properties or growth of tree seedlings in a novel air-pruning propagation tray. Journal of Environmental Horticulture 36:92-103.
Ndikumana JN, Lee YH, Yeoung YR. 2019. Development of a functional plug tray for producing high-quality strawberry transplants. Horticultural Science and Technology 37:345-353.
Park M, Lee S, Kang D, Kim J, Son J, Yoon S, An S. 2017. Development of cylindrical paperpot manufacturing equipment. Protected Horticulture and Plant Factory 26:242-248. [in Korean]
Rahman A, Lee H, Kim MS, Cho BK. 2018. Mapping the pungency of green pepper using hyperspectral imaging. Food Analytical Methods 11:3042-3052.
Seo TC, An SW, Jang HW, Nam CW, Chun H, Kim YL, Lee SH. 2018. An approach to determine the good seedling quality of grafted tomatoes (*Solanum Lycopersicum*) grown in cylindrical paper pot through the relation analysis between DQI and short-term relative growth rate. Protected Horticulture and Plant Factory 27:302-311. [in Korean]
Seo TC, An SW, Kim SM, Nam CW, Chun H, Kim YC. 2017. Effect of the seedlings difference in cylindrical paper pot trays on initial root growth and yield of pepper. Protected Horticulture and Plant Factory 26:368-377. [in Korean]
Shim CY, Park IS, Lee CW, Choi JM. 2018. Influence of compositions and concentrations of post-planting fertilizers on the growth of 'nokkwang' hot pepper plug seedlings. Horticultural Science and Technology 36:28-36. [in Korean]
Shin SY, Cho Y, Kim SB, Kim DC. 2020. Field performance analysis of a card cleaner type separating system for a self-propelled pepper harvester. Korean Journal of Agricultural Science 47:921-931. [in Korean]

Souri MK, Sooraki FY. 2019. Benefits of organic fertilizers spray on growth quality of chili pepper seedlings under cool temperature. Journal of Plant Nutrition 42:650-656.

Wu S. 2013. Nursery techniques influence the growth of hazelnuts. Accessed in http://atrium.lib.uoguelph.ca/xmlui/handle/10214/5349 on 27 July 2021.

Xu C, Kim SH, Kim JK, Heo JY, Vu NT, Choi KY, Jang DC. 2021. The effect of transplant age on vegetable growth characteristic in a cylindrical paper pot system. Horticulture Environment and Biotechnology 62:313-323.

Yaping S, Diankui C. 2005. Influence of plug cell size for root vigor and seedling quality on graft watermelon seedling. Proceedings of International Conference on Sustainable Greenhouse Systems-Greensys 691:107-112.