Effects of Cell Shape of Plug Trays on Shoot and Root Growths of Chinese Cabbage [*Brassica campestris* L. (pekinensis group)] Transplants

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Summary

The effects of cell shape of plug trays on shoot and root growth of Chinese cabbage 'Fuyu Touge' transplants were investigated. The cell shapes were: round, pentagonal, square, and triangular; holding equal volumes of the growing medium.

Root circling of the plug transplants was fastest in round cells and slowest in triangular ones. At the second leaf stage, roots grew better in round cells, had higher N and K contents and respiratory activity than did those of other shapes. No significant difference was found in shoot growth of the plants among shapes. However, at the third leaf stage, the plants grown in round and triangular cells had smaller roots with lower N, K and P contents than did those in pentagonal and square ones. Root respiratory activity and photosynthetic rate were unaffected by cell shape. At the fourth leaf stage, shoot grew slower in round cells, had a lower K and P contents, and a reduced photosynthetic rate compared to others. No significant difference was observed in plant growth between pentagonal and square cells at any growth stage. The growing medium in round cells had the lowest water – holding capacity, followed by pentagonal, square, and triangular ones.

Key Words: cell shapes, Chinese cabbage, plug transplant, root circling.

Introduction

The use of plug transplants has increased greatly in recent years. Compared with traditional transplants, plug transplants have some unique features. For example, the roots of the plug transplants are intertwined, forming root balls in a small space (Salter, 1982; Styer and Koranski, 1997). Liptay and Edwards (1994) reported that the roots of transplants in cells proliferate mostly on the growing medium–cell interface and wind themselves into a root ball. Because of the proliferation and winding, the shape of the cell has great influence on root circling and transplant growth. Sulecki (1988) showed that seedlings started in square plugs produced transplants of a better quality. Tomato transplants, grown in square cells, are always larger than those grown in round ones (Larson et al., 1987). Latimer (1991) found that leaf area and shoot dry weight of marigold transplants grown in the inverted pyramid cells were larger than those of transplants grown in round ones. These researchers attributed the influence of the cell shapes on the transplant growth to the difference in medium volume. However, it remains unknown how the cell shapes affect the growth and root circling of plug transplants grown in an equal volume of rooting medium. In this study, we investigated the effects of cell shapes on the growth and root circling of plug trans-

plants started with the same volume of growing medium.

Materials and Methods

1. Plant material and transplant procedure

The experiment was carried out in the greenhouse of the Faculty of Horticulture, Chiba University using the Chinese cabbage 'Fuyu Touge' *Brassica campestris* L. (pekinensis group) (Takii Seed). A piece of styrofoam plank about 4.5 cm thick was impressed to a depth of 4 cm with a heated iron dies having round, pentagonal, square, and triangular cross sections (Table 1). One plug tray consisted of 40 individual cells with the same shape. A 4.5 mm round drainage hole was made at the bottom of each cell. On June 22, seeds were sown into nine plug trays having the same cell shape. Each cell was filled with 21 ml of growth medium (Cell-baido, Sumirin Agro-products), containing N: 100, P₂O₅: 1,000, K₂O: 50 mg · liter⁻¹. The density of transplants was 500 plants · m⁻². The plug trays were set on the steel pipe frame in a greenhouse kept at 32 °C and 19 °C (maximum/minimum). After emergence, the seedlings were overhead irrigated uniformly with an overhead tap water system according to the weather and plant size.

2. Measurement and analyses

Sampling dates and replications

Plants were collected at 14 (2 true leaves), 19 (3 true leaves) and 24 (4 true leaves) days after sowing. On each sampling day, triplicate trays per cell shape were

Table 1. Sizes and shapes of dies used in experiment.

Shape	Interior surface area (cm ²)	Top area (cm ²)	Bottom area (cm ²)	Height (cm)	Volume (cm ³)
Round	32	9	2.25	4	21
Pentagonal	35	9	2.25	4	21
Square	37	9	2.25	4	21
Tringular	42	9	2.25	4	21

randomly selected and the plants analyzed as below:

Root circling degree

Before irrigation, when the growing medium was still relatively dry, the extent of root circling was measured by removing 10 plants from each tray and dropping them to the cement floor from a height of 50 cm. The extent of root circling was classified into 5 pre-defined degrees, as previously described (Nobuoka and Taimatsu, 1995; Nishimoto and Taimatsu, 1996); the root ball is totally damaged (0), half damaged (1), 1/3 damaged (2), slightly crazed (3), and not damage (4).

Growth investigation

On each sampling day, 10 individual plants from the middle row of each tray were removed and the roots washed until the growing media were removed. Plant height, stem diameter, leaf area, relative chlorophyll content, shoot and root fresh weights were measured. Relative chlorophyll content was measured with chlorophyll meter (SPAD-502, Minolta) at 3 locations in the second or third true leaf, according to the growth stages of the transplants.

Mineral content analysis

Transplants from each tray were divided into shoot and root, which were dried in an oven at 65 °C for one week and then weighted. The dry samples were milled and digested with H₂SO₄-Salicylic-H₂O₂ in flasks for mineral determination. Cations were determined by an atomic absorption spectrophotometer (Z-6100, Hitachi), P was measured by a spectrophotometer (U-2000, Hitachi) and N was determined by a modified Kjeldhal method (Walinga et al., 1995).

Root respiratory activity and photosynthetic rate

Root respiratory activity was measured by the TTC. A 0.3 g-FW of root from each tray was put into 0.4% TTC solution (2,3,5-triphenyl-tetrazolium chloride, pH 7.0, 0.1 M phosphate buffer) for 3 hr in darkness, and then formazan was extracted by 99% ethyl acetate. The reduction of TTC to formazan was determined by a spectrophotometer (U-2000, Hitachi) at 485 nm (Yoshida, 1966).

Photosynthetic rates (Pn) on five plants per tray were measured at 1:00 PM on a sunny day under natural light in a greenhouse (36 °C, temperature; 1200 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}^{-1}$, photosynthetic active radiation (PAR); 300 $\mu\text{mol} \cdot \text{mol}^{-1} \text{CO}_2$ concentration), using a portable porometer (Kip-8510. Ver.2.03, Koito Manufacturing). At the second and third leaf growth stages, Pn was measured on the first true leaf, whereas at the fourth leaf growth

stage, Pn was determined on the third leaf.

Water-holding capacity of growing medium

Ten styrofoam cells (rough inner wall) and five iron cells (smooth inner wall) were filled with 10.5 g (21 ml) growing medium (Cell-baido, Sumirin Agro-products) and soaked in water for 24 hrs. After that, the saturated growing medium was again weighed for water-holding capacity calculation. The water-holding capacity of the rooting medium is the difference in its weight before and after soaking, expressed as a percentage.

Results

Root circling

The root circling degree of Chinese cabbage transplants grown in plug trays varied with different cell shapes at different growth stages (Fig. 1). Root circling was promoted in round cells, whereas it was retarded in triangular ones at the second and third leaf stages. No difference was found between square and pentagonal cells. At the fourth leaf stage, plants from all treatments completely formed root balls; no difference was found in root circling among all the treatments.

Plant growth

At the second leaf stage, the plants grown in round

Fig 1. Root circling of Chinese cabbage transplants grown in plug trays with different cell shapes at different growth stages. The extent of root circling was classified into five degrees according to the extent of root deformation when plants pulled out from cells were dropped to the ground, 0: totally damaged; 1: half damaged; 2: 1/3 damaged; 3: slight crazed and 4: not damage.

cells had significantly heavier dry roots than those grown in pentagonal, square, and triangular ones, but no significant difference was found in shoot dry weights among the treatments (Table 2).

At the third leaf stage, the leaves of plants grown in round cells were significantly smaller and the dried shoots were lighter than those grown in pentagonal cells. The plants grown in pentagonal, square, and triangular cells had comparable leaf areas and shoot dry weights. No significant difference was found in plant height among all treatments. Root dry weights of plants from triangular and round cells were markedly less than those

of plants from pentagonal and square ones.

At the fourth leaf stage, the plants grown in round cells were shorter and had smaller leaf area, their shoot dry weight were lighter than those grown in pentagonal and triangular ones. Root dry weights of plants from triangular cells were significantly less than those of plants from pentagonal ones. At each growth stage, no significant difference was found in leaf chlorophyll content among all treatments (data not shown).

Mineral element content

The mineral element contents were shown for Chinese

Table 2. Growth of Chinese cabbage transplants grown in plug trays with different cell shapes at different growth stages.

Treatment (Cell shape)	Growth stage ^z	Plant height (cm)	Leaf area (cm ²)	Shoot dry weight (mg)	Root dry weight (mg)
Round	2nd leaf	6.9NS ^y	17.5NS	68.0NS	4.9a
Pentagonal		7.0	16.5	63.2	3.6b
Square		6.7	16.1	60.2	3.8b
Triangular		6.8	17.1	60.6	3.4b
Round	3rd leaf	9.6NS	33.1b	102.2b	7.1b
Pentagonal		10.3	43.9a	128.3a	9.5a
Square		9.5	40.8ab	117.8ab	9.3a
Triangular		9.7	40.4ab	113.9ab	7.0b
Round	4th leaf	10.8c	49.7c	210.5b	16.7ab
Pentagonal		11.6ab	58.2ab	259.2a	20.9a
Square		11.4b	54.8bc	252.7a	17.6ab
Triangular		12.1a	61.9a	253.3a	15.2b

^z Plants at the 2nd leaf, 3rd leaf and 4th leaf growth stages were sampled 14, 19 and 24 days after sowing, respectively.

^y Different letters within columns show significant differences by Duncan's new multiple range test at 5% level.

Table 3. Mineral element contents of Chinese cabbage transplants grown in plug trays with different cell shapes at different growth stages.

Treatment (Cell shape)	Growth stage ^z	Shoot			Root		
		Total N (mg · g ⁻¹ DW)	K (mg · g ⁻¹ DW)	P (mg · g ⁻¹ DW)	Total N (mg · g ⁻¹ DW)	K (mg · g ⁻¹ DW)	P (mg · g ⁻¹ DW)
Round	2nd leaf	43.7NS ^y	119.5a	10.1NS	52.5a	130.1a	38.1NS
Pentagonal		43.1	11.4b	10.1	46.9b	128.5b	37.9
Square		42.6	114.7b	10.2	48.4b	127.3b	37.8
Triangular		43.3	113.7b	10.4	46.9b	127.8b	38.0
Round	3rd leaf	37.6NS	100.8b	11.3NS	37.4NS	101.2b	22.2NS
Pentagonal		37.8	108.1a	11.6	38.7	108.8a	22.5
Square		37.4	106.1ab	11.9	37.4	108.7a	22.3
Triangular		38.3	108.8a	11.8	36.8	107.9a	23.7
Round	4th leaf	24.7b	101.2b	13.2b	21.6b	59.2b	15.5b
Pentagonal		27.4ab	108.8a	13.9a	22.2a	63.2a	17.8a
Square		26.5ab	108.7a	13.9a	22.6a	62.8a	17.2a
Triangular		28.6a	107.9a	13.8a	21.8b	60.1b	16.1b

^z Plants at the 2nd leaf, 3rd leaf and 4th leaf growth stages were sampled 14, 19 and 24 days after sowing, respectively.

^y Different letters within columns show significant differences by Duncan's new multiple range test at 5% level.

Table 4. Root respiratory activity and photosynthetic rate in Chinese cabbage transplants grown in plug trays with different cell shapes at different growth stages.

Treatment (Cell shape)	Growth stage ^z	Root respiratory activity (TTC reduced $\text{mg} \cdot \text{g}^{-1}$)	Photosynthetic rate ($\text{gCO}_2 \cdot \text{m}^{-2} \cdot \text{hr}^{-1}$)
Round	2nd leaf	0.76a ^y	0.76NS
Pentagonal		0.63b	0.74
Square		0.64b	0.74
Triangular		0.60b	0.72
Round	3rd leaf	0.77NS	0.94NS
Pentagonal		0.80	1.10
Square		0.79	0.96
Triangular		0.77	0.98
Round	4th leaf	0.57b	0.64b
Pentagonal		0.59ab	0.82a
Square		0.60a	0.84a
Triangular		0.59ab	0.85a

^z Plants at the 2nd leaf, 3rd leaf and 4th leaf growth stages were sampled 14, 19 and 24 days after sowing, respectively.

^y Different letters within columns show significant differences by Duncan's new multiple range test at 5% level.

cabbage transplants grown in plug trays with different cell shapes at different growth stages (Table 3). At the second leaf stage, the shoots and roots of plants grown in round cells had significantly higher K content while the roots had higher N content than those grown in other treatments. No difference was found in shoot and root P contents or shoot N content among the treatments.

At the third leaf stage, the plants grown in round cells had markedly less K content in shoot than those grown in pentagonal and triangular ones, which were comparable. Potassium content in roots of plants from round cells was significantly lower than that of plants grown in other shapes. No significant difference was found in shoot and root total N, P contents among all treatments.

By the fourth leaf stage, the shoots of plants grown in round cells had significantly less total N, K, and P contents than those grown in triangular ones; no difference developed among triangular, pentagonal, and square cells. The N, K, and P contents in the roots of plants from triangular and round cells were significantly lower than those of plants from square and pentagonal ones.

At each growth stage, no statistical difference was found in Mg and Ca contents in shoots and roots among all treatments.

Root respiratory activity and photosynthetic rate

At the second leaf stage, the root respiratory activity of the plants grown in round cells was significantly higher than that of plants grown in other cells (Table 4). At the third leaf stage, no significant difference was found in root respiratory rate and photosynthetic rate among all treatments, but by the fourth leaf stage, root

respiratory activity of plants from round cells was significantly less than that of plants grown in square ones; it was comparable among pentagonal, square, and triangular cells. The photosynthetic rate of plants from round cells was lower than that from other cells.

Water-holding capacity of growing medium

The water-holding capacity of growing medium filled in styrofoam cell was significantly greater than that filled in iron cells (Table 5). Whether styrofoam cell or iron cell, the water-holding capacities increased in the following order: round, pentagonal, square, and triangular cells.

Discussion

Ease of pulling of transplants

Plug transplants were generally used in combination with transplanting machines. Thus, ease of pulling out transplants from the cells is an important requirement for plug transplant culture (Tsukada et al., 1989). This ease of plug removal is closely related to the degree of root circling/balling. In this experiment, round cells promoted the fastest root circling, while, triangular cells yielded the slowest (Fig. 1). Fast root circling which contributes to the ease of pulling transplants out from the cells in early growth stage is attributed to the interior surface area and angles of the cells. Geometrically, with equivalent root medium volume, the interior surface areas of the round, pentagonal, square, and triangular cells were 32 cm^2 , 35 cm^2 , 37 cm^2 and 42 cm^2 , respectively. Cell angles decreased in the order of round, pentagonal, square, and triangular cells.

Table 5. Effects of cell shapes on water-holding capacity of the growing medium.

Cell material	Cell shape	Water-holding capacity (g · 100g ⁻¹)
Styrofoam	Round	134.4
	Pentagonal	140.4
	Square	149.0
	Triangular	155.4
Iron	Round	125.4
	Pentagonal	132.9
	Square	138.9
	Triangular	150.1
ANOVA ^z		
Cell material		*
Cell shape		**
Cell material × Cell shape		NS

^z NS, *, ** indicate non-significance, or significance at $P < 0.05$ or < 0.01 , respectively.

Growth and physiological activity

Growth and physiological activity of seedlings, before and after transplanting, are closely related to the transplanting shock, rooting ability, survival ratio, and yield following transplanting (Knavel, 1965; Cox, 1984; McKee, 1981a, 1981b; Warren and Blazich, 1991; Leskovar and Cantliffe, 1994; Shimizu et al., 1995; Fukuoka, et al., 1996). Therefore, they are the most important indexes for the quality of transplant. In this experiment, we found that at the second leaf stage, round cells promoted root growth and improved root respiratory activity (Tables 2, 3, and 4), whereas by the third and fourth leaf stages, round and triangular cells inhibited root growth. Moreover, shoot growth of plants in round cells was slowest, and Pn was lowest at the fourth leaf stage during which the root ball had completely formed (Tables 2, 3 and 4). Although the formation of root ball is a prerequisite to plug transplant culture, our data on the ease of plant removal, overall growth, nutrition, and survival rates reveal that the pentagonal and square cells yielded the best plants.

Cell shapes and water-holding capacity

Milks et al. (1989b) concluded that plants grown in small containers showed limited growth which is due to poor water-holding capacity of the growing medium. Therefore, water management is an important factor in plug transplant production. Cell depth exerts an immense effect on the water-holding capacity of the growing medium (Spomer, 1975; Milks et al., 1989a). In this experiment, we found that even if the cell depth was the same, cell shapes also affected the water-holding capacity of the growing medium. Independent of the cell material, the larger the interior surface area of

cells, the greater was the water-holding capacity (Table 5). The water-holding capacity also increased, the rougher the cell's inner wall (Table 5). This result suggests that water was held by the growing medium and in the periphery of the growing medium adjacent to the inner wall of the cells due to surface tension. The round cells had the minimum exposed surface area and the lowest water-holding capacity. Thus, it was easier to cause water stress, although this can be avoided by increasing the frequency and amount of irrigation.

Literature Cited

- Cox, E. F. 1984. The effect of shape of compost blocks on the propagation, transplant establishment and yield of four vegetable species. *J. Hort. Sci.* 59: 205–212.
- Fukuoka, N., H. Yoshioka, E. Shimizu and T. Fujiwara. 1996. Effect of shading cabbage seedlings on their physiological processes and rooting ability after transplanting to the nursery. *J. Japan. Soc. Hort. Sci.* 65: 545–551.
- Knavel, D. E. 1965. Influence of container, container size and spacing on growth of transplants and yields in tomato. *Proc. Amer. Soc. Hort. Sci.* 86: 582–586.
- Larson, R. A., C. B. Thorne and R. R. Milks. 1987. Plug nutrition: A controversial subject. *Greenhouse Grower*. August: 103–110.
- Latimer, J. G. 1991. Container size and shape influence growth and landscape performance of marigold seedlings. *HortScience*. 26: 124–126.
- Leskovar, D. I. and D. J. Cantliffe. 1994. Transplant production systems influence growth and yield of fresh-market tomatoes. *J. Amer. Soc. Hort. Sci.* 119: 662–668.
- Liptay, A. and D. Edwards. 1994. Tomato seedling growth in response to variation in root container shape. *HortScience*. 29: 633–635.
- McKee, J. M. T. 1981a. Physiological aspects of transplanting vegetables and other crops. I. Factors which influence re-establishment. *Hort. abstr.* 51: 265–272.
- McKee, J. M. T. 1981b. Physiological aspects of transplanting vegetables and other crops. II. Methods used to improve transplant establishment. *Hort. abstr.* 51: 355–368.
- Milks, R. R., W. C. Fonteno and R. A. Larson. 1989a. Hydrology of horticultural substrates: II. Predicting physical properties of substrate in containers. *J. Amer. Soc. Hort. Sci.* 114: 53–56.
- Milks, R. R., W. C. Fonteno and R. A. Larson. 1989b. Hydrology of horticultural substrates: III. Predicting air and water content of limited-volume plug cells. *J. Amer. Soc. Hort. Sci.* 114: 57–61.
- Nishimoto, T. and T. Taimatsu. 1996. Studies on varietal differences in lodging resistance of cabbage plug seedlings. *Bull. Nara. Agri. Expt. Sta.* 27: 17–23 (In Japanese with English summary).
- Nobuoka, T. and T. Taimatsu. 1995. Studies on the improvement in production of grafted vegetable nurs-

- eries by plug system. (2) Plug tray size studied for grafting in young seedling of tomato. Bull. Nara. Agri. Expt. Sta. 26: 17-22 (In Japanese with English summary).
- Salter, P. J. 1982. Advantages and Disadvantages of 'Module'-Raised Vegetable Plants. Scientia Hort. 33: 76-81.
- Shimizu, E., H. Yoshioka, N. Fukuoka and T. Fujiwara. 1995. Effects of plug seedling age on root respiration and growth after planting in spinach. Bull. Natl. Res. Inst. Veg. Jpn. 3: 2-3 (In Japanese).
- Spomer, L. A. 1975. Small soil containers as experimental tools; Soil water relations. Soil. Sci. Plant Anal. 6: 21-26.
- Styer, R. C. and D. S. Koranski. 1997. Plug & transplant production. A grower's guide. p.1-12. Ball Publishing, Batavia, Illinois, USA.
- Sulecki, J. 1988. It's hip to use square. Greenhouse Grower. February: 66-68.
- Tsukada, M., S. Shimojou, M. Fujimori and F. Outani. 1989. Studies on the systematization of vegetable mass-production seedling. A simple mass-production seedling method of lettuce. Bull. Nagano Veg. Orn. Crops Exp. Sta. Japan 5: 25-38.
- Walinga, I., J. J. van der Lee, V. J. G. Houba, W. van. Vark and I. Novzamsky. 1995. Plant analysis manual. p.2/1-2/30. Kluwer Academic Publisher, Dordrecht Netherlands.
- Warren, S. L. and F. A. Blazich. 1991. Influence of container design on root circling, top growth and post-transplant root growth of selected species. J. Environ. Hort. 9: 141-144.
- Yoshida, M. 1966. The measurement of root activity. Jpn. J. Soil Sci. Plant Nutr. 37: 63-68 (In Japanese).

異なるセル形状がハクサイセル成型苗の生育並びに根鉢形成に及ぼす影響

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摘 要

セルの形状がハクサイ '冬峠' のセル成型苗の生育並びに根鉢形成に及ぼす影響を調査した。セル横断面の形状が円形、五角形、四角形および三角形で、等容積の発泡スチロール製セルトレイを自作して実験を行った。根鉢形成は円形セルで育てられた苗で最も早く、三角形セルで育てられた苗で最も遅かった。根鉢形成前の2葉期において、他の形状のセル苗に比べて円形セル苗の根の乾物重は重く、根中の全窒素およびカリウム含有率並びに根の呼吸活性も高かった。地上部の生育にはセルの形状による違いは認められなかった。しかし、3葉期の調査では、円形および三角形セル苗の根の生育は四角形および五角形セル苗に比べて劣った。根の呼吸活性

および光合成速度にはセル形状による有意差は認められなかった。根鉢形成後の4葉期において、円形セル苗の地上部の生育は他の形状のセル苗に比べて劣り、地上部のカリウムおよびリン含有率並びに光合成速度も低かった。また、四角形および五角形セル苗に比べて、円形および三角形セル苗の根の全窒素、カリウムおよびリン含有率は低かった。四角形セル苗と五角形セル苗の生育には調査期間を通して有意差は認められなかった。セル形状は培地の保水力に影響し、保水力は円形セルで最も低く、次いで五角形、四角形、三角形セルの順に増加した。