한작지(Korean J. Crop Sci.), 66(4): 375~382(2021)
DOI : https://doi.org/10.7740/kjcs.2021.66.4.375

ISSN 0252-9777(Print)
ISSN 2287-8432(Online)

Original Research Article

Growth and Yield of Double Cropping Potatoes Produced Using Seed Tubers of Different Types and Sizes

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ABSTRACT For stable cultivation in double cropping, it is important to use potato (*Solanum tuberosum* L.) cultivars with a short dormancy period of 50–70 days and plant seed tubers of appropriate type and size. An experiment was conducted during 2018–2019 to investigate the effects of seed tuber type and size on growth and yield performance in double cropping. Whole tubers of three sizes (10–20 g, 30–40 g, and 50–60 g) and conventional cut tubers weighing 30–40 g from three cultivars with different dormancy periods, namely 'Daeji' (40–60 days), 'Eunsun' (50–60 days), and 'Saebong' (50–80 days), were planted, and their field performance was compared. Regardless of the cultivar, the increase in the whole tuber weight up to 30–40 g led to fast emergence, thereby increasing ground cover rate, shoot growth rate, and tuber growth rate, which ultimately improved tuber yield by 33–54%. Comparing the whole and cut tubers, 'Daeji' and 'Eunsun' showed similar growth and yield performance; as such, the performance of whole tubers weighing 10–20 g was comparable to that of cut tubers weighing 30–40 g. However, 'Saebong', a cultivar with relatively long dormancy period, performed better with cut tuber than with whole tubers. Based on these results, we recommend the use of whole tubers weighing over 30 g for double cropping. Further studies to break tuber dormancy are warranted in cultivars with relatively long dormancy periods (50–80 days), such as 'Saebong'.

Keywords : cut tuber, double cropping potato, seed size, seed tuber, whole tuber

For successful crop production, using a good quality of seed is crucial for maximizing the yield (Ambika *et al*., 2014). Seed size is one of the important indicators of seed quality and a widely accepted measure to determine seed quality (Adebisi *et al*., 2013). In general, seed size influences germination, initial growth, and other related agronomic aspects in many crops such as wheat (Mian & Nafziger, 1992), onion (Asaduzzaman *et al*., 2012), and soybean (Rezapour *et al*., 2013).

Instead of the seed, tubers are generally used as a way of vegetative propagation in potato (*Solanum tuberosum* L.) crops (Otroshy & Struik, 2008). Whole tuber (WT) and cut tuber (CT) are commonly used as a seed in growing potato crops (Hardenburg, 1951). Using a CT facilitates initial growth vigor by breaking dormancy earlier than using WT (Wiltshire & Cobb, 1996). Wiersema (1989) noticed that the size of WT is related to the number of eyes, which affects sprouts potential and the number of stems per plant. In the case of WT, *in vitro* micro-tubers, which usually have one limited main stem, at least 0.5 g weight of tubers are recommended as seeds (Park *et al*., 2009).

In South Korea, potatoes are produced through double cropping system. Spring potatoes which accounted for about 60% of the potato growing area are harvested in June (KOSIS, 2020). In spring season, cut seed tuber piece within the size range of 30–40 g is generally used (RDA, 2018). Fall cropping starts with planting the seed tubers in August, which is harvested through

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<Received 13 July, 2021; Revised 15 September, 2021; Accepted 27 September, 2021>

spring cropping system, and ends with harvesting in November (RDA, 2018). Therefore, potato cultivars with short dormancy, such as 'Daeji' (40–60 days), 'Eunsun' (50–60 days) and 'Saebong' (50–80 days), are required for the double cropping system. Furthermore, high temperature during seed tuber storage makes conventional CT decay and inhibit uniform growth of plant after planting, which finally results in poor tuber yields in double cropping system (Levy *et al*., 1986).

There is, however, limited information on the appropriate seed tuber type and size for double cropping potatoes, and growth and yield characteristics of its. Therefore, present study aims to find optimal seed tuber type and size for double cropping by evaluating the differences in growth characteristics and yield components.

MATERIAL AND METHODS

Plant Materials and Environmental Conditions

The experiment was conducted during the fall season (August –November) of 2018 and 2019 at the experimental field (37° 77' N, 128° 94' E) of Highland Agriculture Research Institute located in Gangneung, South Korea. Three sizes of WT (10–20 g, 30–40 g, and 50–60 g) and a CT (30–40 g) of three potato cultivars 'Daeji' (Chishiki *et al*., 1979), 'Eunsun' (Cho *et al*., 2017), and 'Saebong' (Cho *et al*., 2011) were used as plant materials and compared during the fall season. The three potato cultivars were reported to have a short range (40–80 days) of dormant period. Each seed tuber was harvested in late June in spring season and planted in mid–August, in both years. The plants were harvested at 87 to 95 days after planting (DAP). The soil of the trial site had a loamy sand with 6.65 pH, 0.19 dS m^{-1} EC, 12.2 g kg^{-1} organic matter, 0.93 $cmol^+$ kg^{-1} K, 3.7 $cmol^+$ kg^{-1} Ca, 2.2 $cmol^+$ kg^{-1} Mg. All fertilizers, pesticides, and fungicides were controlled using the standard potato growing practices of the Rural Development Administration (RDA, 2018). The meteorological data during the growing season were collected in the Korea Meteorological Administration (KMA, 2018–2019) (Table 1). The common meteorological data provided by Korea Meteorological Administration were the average values for 30 years from 1991 to 2020. In both years, all treatments were arranged in a split–plot design with three replications. The main plot was the cultivars, while the subplots were seed tuber treatments. The row width was 80 cm, and the spacing between seed tubers was 25 cm.

Growth Analysis and Yield Measurement

As plants start to emerge, the total number of plants was counted twice a week until it reached 80% emergence during each year. Stem length was measured on main stem at 60 DAP and stem numbers were counted at harvest. During the canopy development, ground cover rate was measured at intervals of 10 days between 40 DAP and 60 DAP using an 80 x 80 cm grid system (Chang *et al*., 2020). Shoot growth rate (SGR) and tuber growth rate (TGR) were calculated by measuring the changes in dry weight as follows (Chang *et al*., 2016):

$$SGR\ (g \cdot m^{-2} \cdot day^{-1}) = (S_2 - S_1) / (t_2 - t_1)$$
$$TGR\ (g \cdot m^{-2} \cdot day^{-1}) = (T_2 - T_1) / (t_2 - t_1)$$

where S_1, S_2 and T1, T2 are shoot dry weight and tuber dry weight in 40 DAP (t_1) and 60 DAP (t_2) for 'Daeji' and 'Eunsun', and 60 DAP (t_1) and 80 DAP (t_2) for 'Saebong', respectively.

Representative three plants per replication were sampled

Table 1. Meteorological data during the growing season in Gagnueng.

Meteorological factor	Month				
	Aug.	Sep.	Oct.	Nov.	Mean (total)
Maximum temp. (°C)	35.0[z]	30.1	23.8	20.9	27.4
Minimum temp. (°C)	17.5	11.6	3.8	-2.8	7.5
Average temp. (°C)	24.9	19.8	14.5	9.3	17.1
Accumulated precipitation (mm)	346	196	332	85	959
Sum of sunshine (hours)	189	144	188	176	697

[z]Average values from 2018 to 2019.

and then oven-dried at 85°C for more than five days and then each dry matter was measured. Ten plants per plot area were harvested by hand. Tubers were counted, weighed and then graded into three groups, < 80 g, 80-250 g, and > 250 g. Tubers over 80 g was sorted to calculate marketable yield according to RDA standards (RDA, 2016).

Statistical Analysis

All the data in this study are mean values of 2018 and 2019. An open-source statistical package (http://www.r-project.org) of R was used to perform statistical analysis. Data were analyzed using the analysis of Duncan's Multiple Range Test. All statistical analyses were compared at 95% level of confidence, and the significance was determined for each variable.

RESULTS AND DISCUSSION

Meteorological Data During the Growing Season

The average meteorological data from 2018 to 2019 is shown in Table 1. The maximum temperature of the common year during double cropping potato's growing season (August -November) was 34.6°C, 31.5°C, 26.6°C, and 22.2°C, while the minimum temperature was 17.3°C, 12.3°C, 5.5°C, and -1.8°C, The average temperature of the common year was 25.0°C, 20.5°C, 15.6°C, and 9.5°C, respectively. Thereby, August of the years we experimented was similar to the previous years, while from September to November were lower than the previous year. In particular, October from 2018 and 2019 showed 2.8°C lower maximum temperature, and 1.7°C lower minimum temperature, and 1.1°C lower average temperature than the common year. The accumulated precipitation of the years we experimented showed 104 mm higher precipitation than the common year in August and 85.3 mm higher in September, while 74.1mm lower in October and 94.9 mm lower in November.

Emergence and Stem Growth

The influence of seed type and size on plant emergence is shown in Fig. 1. Regardless of the cultivars, emergence rate increased with the increase of the WT weight. Masarirambi *et al.*(2012) reported that large seed tubers sprouted significantly earlier than smaller ones. They explained the result by great initial meristematic capital and more amount of reserve material in large seed tubers than smaller ones (Park *et al.*, 2009; Masarirambi *et al.*, 2012). Responses on plant emergence rate depended on potato cultivars. In cultivars 'Daeji' and 'Eunsun', plants derived from CT showed lower rate of emergence than those from WT, whereas relatively long dormant period of cultivar 'Saebong' showed an opposite result with the high emergence rate in the CT at 14 DAP. In general, using cut tubers result in early sprout vigor because cutting induces the break of dormancy (Otroshy & Struik, 2008) as in the cultivar 'Saebong'. In short dormant period of cultivars 'Daeji' and 'Eunsun', however, the CT did not induce early breaking of dormancy compared to WT. These differences in plant emergence can be attributed to the different characteristics of the dormant period among cultivars.

Above 80% of the plants in all treatments from cultivars 'Daeji' and 'Eunsun' emerged at 25 DAP (Fig. 1). On the other hands, 'Saebong', cultivar showed lower emergence and did

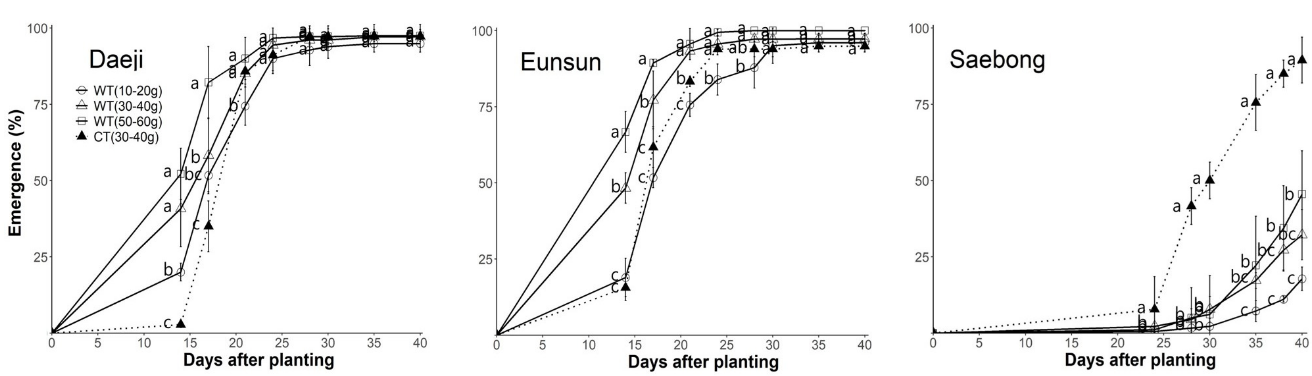

Fig. 1. Plant emergence of three potato cultivars produced from whole tubers of three sizes and cut tubers weighing 30-40 g. WT, whole seed tubers; CT, cut seed tuber. Within the same time point, means with the same letter are not significantly different at $p < 0.05$.

not arrived at 80% emergence, except for CT. In particular, the smallest WT, 10–20 g, couldn't even get 20% emergence within the 40 DAP. This was due to the high occurrence of seed tuber of 10-20 g decay induced by high temperatures and precipitation in August (Table 1). During the storage of seed tuber at the ventilated plastic house before planting, 10–20 g also showed the most decay (data not shown). Seed tubers were decayed in the order of 2.0–4.4% for 10–20 g, 0.0–.7.0% for 30–40 g, 0.0–0.1% for 50–60 g, and 10.2–23.5% for cut tuber. Park *et al*. (2009) also reported that smaller micro tuber tended to be more susceptible to decay, even though the storage condition was uniform.

Growth of stems in terms of stem length and stem numbers was in accordance with the results of plant emergence. Stem length was significantly short in the smallest WT in all cultivars when it was measured at 60 DAP (Table 2). As reported by previous studies (Otroshy & Struik, 2008; Kumar *et al*., 2009; Masarirambi *et al*., 2012), the bigger the WT size, the higher the stems per plant. Although Otroshy & Struik (2008) reported that more stems grew out from CT, there were no significant differences in the stem numbers between tuber types in all cultivars used in the present study.

Canopy Development and Growth Analysis

Fig. 2 shows the results of ground cover rate during the periods of canopy development from 40 DAP to 60 DAP. The ground cover rate depended on the potato cultivars with the different dormant periods. In short dormant period of cultivars 'Daeji' and 'Eunsun', the biggest WT (50–60 g) showed significantly the highest rate of ground cover by 92.7% and 96.0% at 40 DAP, whereas small WT (10–20 g) recorded the lowest ground cover rate by 60.3% and 57.7%, respectively. After 10 days, the rate of ground cover in all tubers had reached above 90%. On the other hand, relatively long dormant period of cultivar 'Saebong' showed low ground cover rate than the short dormant period of cultivars 'Daeji' and 'Eunsun'. However, plants derived from CT showed relatively high ground cover rate of 80% at 60 DAP in cultivar 'Saebong', while plants from WT showed

Table 2. Stem length and stems per plant (at 62 days after plantation in 2018 and at 70 days after plantation in 2019) of potato cultivars produced from whole tubers of three sizes and cut tuber weighing 30–40 g.

Seed tubers[z]	Stem length (cm)			Stem numbers per plant		
	Daeji	Eunsun	Saebong	Daeji	Eunsun	Saebong
WT (10-20g)	50.0 b[y]	54.1 b	28.2 b	1.2 b	1.0 b	1.0 a
WT (30-40g)	62.8 a	61.2 a	38.6 ab	1.8 ab	1.4 ab	1.0 a
WT (50-60g)	67.9 a	65.8 a	49.8 a	2.4 a	1.9 a	1.1 a
CT (30-40g)	53.1 b	61.6 a	42.0 a	1.9 ab	1.6 ab	1.2 a

[z]WT, whole seed tubers; CT, cut seed tuber.
[y]Values within the same column followed by different letters are significantly different ($P < 0.05$) by Duncan's multiple range test.

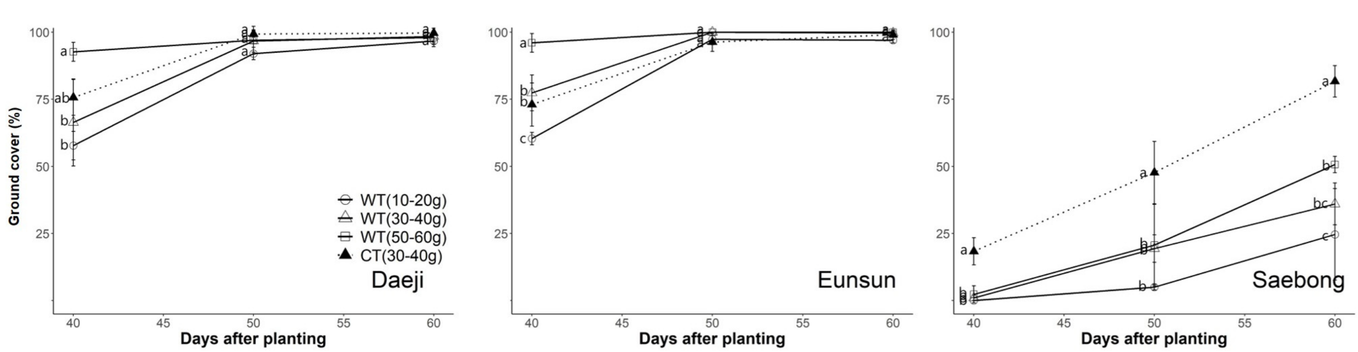

Fig. 2. Ground cover of three potato cultivars produced from whole tubers of three sizes and cut tubers weighing 30–40 g. WT, whole seed tubers; CT, cut seed tuber. Within the same time point, means with the same letter are not significantly different at $p < 0.05$.

low rates of ground cover in the order of 50.7% for 50–60 g, 36.0% for 30–40 g and 24.7% for 10–20 g. This low canopy development in small WT was attributed to the low emergence (Fig. 1), which was possibly due to the relatively long dormant period.

Growth analysis was performed for shoots and tubers grown from WTs and CT (Table 3). In the cultivars 'Daeji' and 'Saebong', SGR was not affected by type and size of seed tubers. These results are in agreement with those of Chang *et al.*(2011) who reported SGR was not affected by weight classes in the range of 0.7–40 g tubers. The significant difference in SGR was found in the cultivar 'Eunsun'. Tuber growth expressed as TGR was the greatest in WT of 30–60 g and lowest in CT in the cultivars 'Daeji' and 'Eunsun'. In contrast, 'Saebong' with long dormant period showed the greatest TGR in plants from CT, which was possibly due to the fast emergence (Fig. 1) and canopy development (Fig. 2). Another finding was that TGR was bigger than SGR between 40 and 60 DAP or 40 and 80 DAP when tubers were formed and enlarged (Beukema & van der Zaag, 1979). Chang *et al.* (2011) also reported that TGR was 2–3 times higher than SGR when seed tubers over 10 g weight were planted.

Yield Components

Seed type and size significantly influenced the number of tubers per plant (Table 4). The smallest WT (10–20 g) has recorded significantly less number of tubers per plant, whereas the largest WT (50–60 g) recorded the highest. These difference probably associated with the significant increase in stem numbers across the three-sized WTs (Table 2). CT and same-sized WT (30–40 g) produced similar number of tubers per plant. These results agreed with the data indicated that CT in the range of 45–57 g produced similar number of tubers to that obtained with same-sized WT (Wiersema, 1989). This might be due to the fact that there is no difference in number of eyes among same-sized seed tuber, regardless of cutting.

The influences of seed type and size on tuber number and tuber weight are shown in Table 4. Although stems were

Table 3. Growth analysis of potato cultivars produced from whole tubers of three sizes and cut tubers weighing 30–40 g.

Seed tubers[z]	Shoot growth rate[y] ($g \cdot m^{-2} \cdot day^{-1}$)			Tuber growth rate[x] ($g \cdot m^{-2} \cdot day^{-1}$)		
	Daeji	Eunsun	Saebong	Daeji	Eunsun	Saebong
WT (10-20g)	2.3 a[w]	3.4 b	3.6 a	11.0 ab	8.0 c	6.1 c
WT (30-40g)	1.7 a	6.3 b	3.0 a	13.5 a	18.3 a	8.1 c
WT (50-60g)	3.5 a	10.5 a	3.4 a	12.6 a	16.2 b	18.1 b
CT (30-40g)	0.7 a	10.7 a	2.8 a	6.8 b	8.4 c	23.7 a

[z]WT, whole seed tubers; CT, cut seed tuber.
[yx]'Daeji' and 'Eunsun' were calculated by the increase in dry weight between 40 DAP and 60 DAP for shoots and tubers respectively, and 'Saebong' was calculated between 60 DAP and 80 DAP; DAP, days after planting.
[w]Values within the same column followed by different letters are significantly different ($P < 0.05$) by Duncan's multiple range test.

Table 4. Tuber number per plant, tuber number per stem, tuber weight per stem, and total yield of potato cultivars produced from whole tubers of three sizes and cut tubers weighing 30–40 g.

Seed tubers[z]	Tuber number per plant			Tuber number per stem			Tuber weight per stem (g)			Total yield ($t \cdot ha^{-1}$)		
	Daeji	Eunsun	Saebong	Daeji	Eunsun	Saebong	Daeji	Eunsun	Saebong	Daeji	Eunsun	Saebong
WT (10-20 g)	6.1 b[y]	5.5 c	5.2 b	4.7 a	5.5 a	5.1 b	486 a	615 a	476 c	27.7 c	30.8 b	17.9 c
WT (30-40 g)	6.4 ab	7.4 b	6.6 ab	3.9 a	5.4 a	6.4 a	459 a	578 a	672 a	36.4 a	39.1 a	27.6 ab
WT (50-60 g)	7.4 a	9.7 a	6.8 a	3.2 a	5.3 a	6.4 a	330 a	483 a	611 ab	38.3 a	43.8 a	26.2 b
CT (30-40 g)	7.4 a	6.6 bc	6.0 ab	3.5 a	4.3 a	5.5 ab	382 a	421 a	560 b	30.5 b	31.8 b	28.9 a

[z]WT, whole seed tubers; CT, cut seed tuber.
[y]Values within the same column followed by different letters are significantly different ($P < 0.05$) by Duncan's multiple range test.

increased with the increasing the size of WT in the short dormant cultivars 'Daeji' and 'Eunsun' (Table 2), tuber number and weight were not significantly different among the seed tubers (Table 4). Wiersema & Cabello (1986) also reported similar results of no difference in tuber number per stem when planting single sprouted WT of 5–10 g, 10–20 g, and 40–60 g. These results were not consistent with that of Wiersema (1989), who reported that increase of stems increased the competition between stems, and thereby resulted in the reduction of tubers set. On the other hand, the cultivar 'Saebong' with relatively long period of dormancy showed opposite tendencies: although there was no significant difference in stem number, tuber number and weight were increased in WT of 30–60 g than in WT of 10–20 g. Therefore, these different responses on tuber number and weight among cultivars could be attributed to the different degree of stem number.

Total yield increased with the size of WT in cultivars 'Daeji' and 'Eunsun', but the significances were not observed in WTs between 30–40 g and 50–60 g (Table 4). In the cultivar 'Saebong', total yield was the greatest in CT followed by WTs of 30–40 g, 50–60 g, and 10–20 g. Comparing WT with the same weight (30–40 g) of CT, significant differences in total yield were observed in all cultivars. The differences in total yield between the WT (30–40 g) and CT were possibly due to the fact that additional energy was required for healing the wounds given by the cut (Otroshy & Stuik, 2008).

Fig. 3 shows size distribution of tubers harvested from each WT size and conventional CT in each cultivar. Plants established from the small–sized WT (10–20 g) produced higher percentage of large tubers above 250 g, whereas those from the large–sized WT (50–60 g) produced higher percentage of small tubers bellow 80 g with an exception in cultivar 'Saebong'. These results were in accordance with the previous reports that as the size of WT increased, the percentage of tubers above 280 g tended to decrease (Arsenault & Christie, 2004).

As the size of the WT increase from 10–20 g to 30–40 g, marketable yields were significantly increased in all cultivars (Fig. 4). However, there were no differences in the marketable yield between the WTs of 30–40 g and 50–60 g. The marketable yield from CT was lowest but similar to small–sized WT (10–20 g) in the short dormant cultivars 'Daeji' and 'Eunsun'. However relatively long dormant cultivar 'Saebong' showed the high yield in the CT. This is probably because the fast emergence in the early growth stage (Fig. 1) and uniformity in the mid growth stage (Fig. 2), by using the big–sized WT in cultivars 'Daeji' and 'Eunsun', and CT in cultivar 'Saebong',

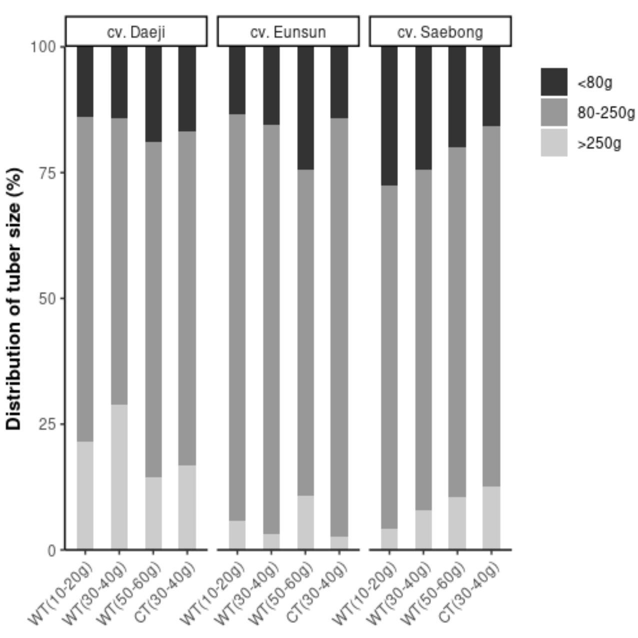

Fig. 3. Distribution of tuber size (%) in potato cultivars produced from whole tubers of three sizes and cut tubers weighing 30–40 g. WT, whole seed tubers; CT, cut seed tuber.

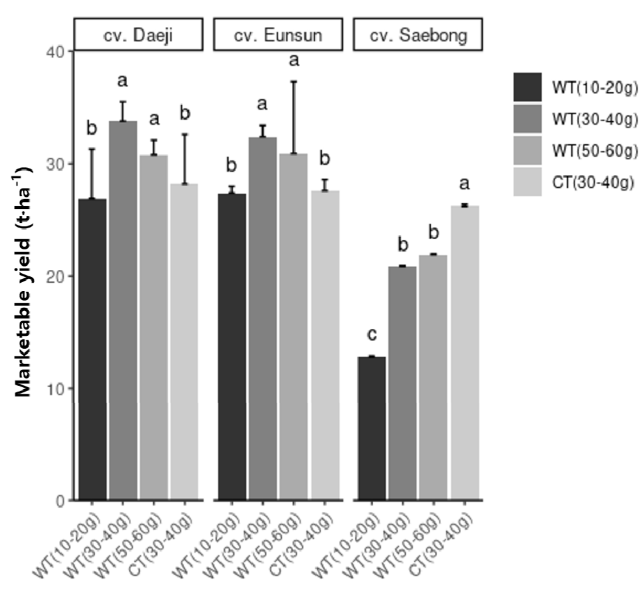

Fig. 4. Marketable yield of potato cultivars produced from whole tubers of three sizes and cut tubers weighing 30–40 g. WT, whole seed tubers; CT, cut seed tuber.

consequently resulted in the higher marketable yields.

Double cropping cultivation is carried out in not only Korea but also southern region of China and Japan. In South Korea, potato plants grow in the condition with relatively long days and broader temperature changes, which is a favorable condition for potato growth in the fall season. However, the constraint in this season is a short growth period in the double cropping season due to the early frost in November (RDA, 2018). The results obtained in this study indicated that planting 30-60 g of seed tubers showed faster emergence and more vigorous stem growth than 10-20 g whole tubers, which resulted in maximize marketable yield in double cropping potatoes. However, in the case of cultivar 'Saebong' with relatively long dormancy (50–80 days), further studies about breaking whole tuber dormancy earlier than cut tuber is needed.

ACKNOWLEDGMENT

This work was supported by the "Crop Science Research Program of NICS (Project No. PJ01361003)" Rural Development Administration, Republic of Korea.

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