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Mass Propagation of Plug Seedling using Stem Cutting and Their Tuber Yield in Potato

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ABSTRACT

For the mass production of plug seedlings in cultivar 'Dejima' potato (*Solanum tuberosum* L.) the optimal apical cutting diameter for rooting and rapid multiplication of stem cuttings in hydroponics were determined. In addition, the best planting date was predicted to increase tuber yield of plug seedlings at fall cropping in Cheju-Do, Korea.

Days to initial rooting decreased as the cutting diameter was reduced. Plant height, leaf number, root length and root weight per plant were favorable as the cutting diameter was small. The ideal cutting diameter was 1~2 mm in this experiment.

In the hydroponic cultures, the Japanese standard (JS) nutrient solution was the most effective for multiplication of stem cuttings. It was able to propagate more than 20 times a month from a single mother plant.

Viability of plants, which were derived from plug seedlings using stem cuttings, was excellent when transplanted to the field. The number of tubers and tuber yield in both of the plug seedlings and seed potato planting plots were high when planted on 25 August. The number and yield were reduced when planted on 15 August, 5 September and 15 September. The degree of decrease of tuber yield in the plug seedling planting plot however, was lower than that of seed potatoes when the planting date was late. In the case of small tubers (under 30 g), the number of tubers and tuber yield were evidently increased in the seed potato tuber planting plot; the yield of large tuber (over 80g) in the plug seedling planting plot was higher than that of the seed potato. The total tuber yield per plant in the plug seedling planting plot was less than that of the seed potato; therefore, in order to increase tuber yield it was necessary to increase field plant density.

Keywords : seed potato, plug seedling, stem cutting, rooting, planting date.

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Since potatoes are vegetative propagating plants, the quantity of plants required by means of seed is high, above 150 kg/10a. Nevertheless, the multiplication rate is very low because of using tuber propagation instead of seed.

Because the rate of seed potato deterioration is high due to the pathological and physiological disadvantage, various methods for the mass production of seed potatoes have recently been developed and used, such as microtubers *in vitro* and stem cuttings.

The mass production of microtubers using the *in vitro* technique as seed potatoes and its application were reported by Joung (1989). Microtubers, as seed potatoes, have been planted directly in the field in Korea, but their early growth and emergence ratio are very low. The decrease in yield makes it difficult to do mass area cultivation (Wattimena et al., 1983; Kim et al., 1996; Yiem et al., 1990).

Many researchers have studied stem cuttings of potatoes for one century (Bryan et al., 1981; Cip, 1975; Cole & Wright, 1967). The stem cutting method is also used for the rapid multiplication of seed potatoes in North America and Europe; 30% in North America and 25% in Europe of the total seed potatoes (Jones, 1988; 1991).

Apical cutting originating from small tubers is able to induce rooting under high-temperature, long-day, optimal moisture and shade conditions. Until the plug seedlings are induced from stem cuttings, it is necessary that the stem cuttings be kept under conditions which are more than 16 hr photoperiod and at 20°C since growth of the upper ground parts is very low, subsequently, they can form microtubers under low-tem - perature and short-day conditions (Park & Kim, 1997).

We investigated variations in seedling quality of stem cuttings according to the differences of the apical cutting diameter, which originated from virus-free microtubers. We also studied cutting multiplication in a hydroponic medium and tuber production of fall-type potatoes according to the planting date of plug seedlings in Cheju-Do, Korea.

MATERIALS AND METHODS

This experiment was conducted at the experimental field and glass greenhouse of Cheju University from 1997 to 1998 with 'Dejima' potatoes (*Solanum tuberosum* L.)

Relation of stem cuttings diameter and rooting

To investigate the rooting of plug seedlings according to the diameter of stem cuttings, 100 apical stem cuttings of 3 different diameters (1 mm, 2 mm and 3 mm) were transplanted in city water after 7 days, on 22 September. One-millimeter size of apical stem cuttings were selected from the stems of virus-free microtubers which were grown *in vitro* culture, which were about 5cm in height and 23 mgin weight. Two and three-millimeter apical stem cuttings were selected from stems of mini-tubers which were 8 cm in height, 43 mg and 52 mg in weight. Experimental water was aerated with an air-bubble system at 22~28℃ and 18~20℃ (day and night) in the glass greenhouse with 70% shading. Days to initial rooting were observed every day after 3 days of cutting, and the number of roots and fresh weight per plant were measured after 10 days. The number of leaves, stem diameter, root length and fresh weight per plant were measured after 30 days.

Multiplication of stem cuttings in a hydroponic medium

The rooted cuttings (plant height was about 10 cm) were rinsed and used for mother plants for the multiplication of stem cuttings in the hydroponics in order to investigate the rate of multiplication. The hydroponics bed was 100 × 800 × 23 cm (height × width × height) and was aerated with an air bubble system. A nutrient solution, supplied after 2 days of transplanting, was circulated for an hour and was renewed every 10 days. Four different plots for mass multiplication of stem cuttings were treated with 1) Japanese standard nutrient solution (Table 1), 2) its 1/2 diluted solution, 3) 1,000 mg/ *l* concentration of commercial Wondergrow solution (Table 1), and 4) solid medium (control, cocopeat : vermiculite : perlite). The experimental plots were arranged in a completely randomized design. In each treatment, 72 pieces of rooted cuttings were transplanted at a distance of 20×30 cm on 16 June. The multiplication rate of stem cuttings was determined on 28 June (first time, 12 days after planting (dap)), 17 July (second time, 31 dap), 30 July (third time, 44 dap) and 16 August (fourth time, 60 dap). Plant height, number of leaves, number of cuttings (shoots of about 3 cm length with more than one axillary bud) and fresh shoot weight were measured.

Table 1. Chemical composition of nutrient solutions for potato hydroponics culture.

JS†	(g/ton of water)	WG‡	(%/of content)
$Ca(NO_3)_2 \cdot 7H_2O$	944	Total N	10
KNO_3	810	Soluble K	25
$MgSO_4 \cdot 7H_2O$	492	Soluble P	8
$NH_4H_2PO_4$	156	Soluble Mg	2
Fe EDTA	15	Soluble Fe	0.05
H_3BO_3	2	Soluble B	0.1
$MnSO_4 \cdot 4H_2O$	2	Soluble Mn	0.05
$ZnSO_4 \cdot 7H_2O$	0.22	Soluble Zn	0.01
$CuSO_4 \cdot 5H_2O$	0.05		
$Na_2MoO_4 \cdot 2H_2O$	0.02		

† JS; Japanese standard nutrient solution.
‡ WG; wondergrow.

Planting date and tuber yield of plug seedling

The experiments involving growth traits and tuber yield on fall-type potatoes according to planting date of plug seedlings were conducted from July to December in 1998. Apical cuttings originating from virus-free microtubers were successively propagated in Japanese standard nutrient solution for the production of stem cuttings. Stem cuttings of 1 or 2 nodes were transplanted into the plug trays (72 units, 27.5 × 54.0 × 4.0 cm) with complex media (cocopeat 1: vermiculite 1: compost 1) under conditions of the shading (70~80%) during 16 hr photoperiod (20~25℃) and 20℃ (in the dark). Plug seedlings, with a height of about 15 cm after 20 days of cutting, were transplanted into the plots on 15 August, 25 August, 5 September and 15 September. The planting density was 70 × 20 cm. The experimental plots were arranged in a split-plot design with three replications. The main-plots consisted of two potato seedling types as plug seedlings and seed potatoes, and the subplots had four planting dates. The plant traits, such as SPAD reading value (measured by SPAD 502, Minolta Camera Co., Japan), stem diameter and number of stems were measured on 2 October, 27 October and 10 December.

RESULTS AND DISCUSSION

Relation of stem cuttings diameter and rooting

The relationship between the diameter of stem cuttings and days to initial rooting are shown in Table 2. As the diameter of stem cuttings was larger, the days to initial rooting were more numerous. The number of roots and leaves per plant, plant height and root weight per plant were relatively low. However, stem diameter and shoot fresh weight per plant were significantly higher. Ewing & Wareing (1978) reported that the apical cuttings, which had not yet formed a tuber, developed root and shoots vigorously. Park & Kim (1997) also found that rooting was early and the number of roots was very high, the formation of tubers therefore was significantly higher when using 13 mm diameter stem cuttings in the hydroponic culture. Based on these results, we think that the optimal diameter of stem cuttings is 1~2 mm for the rooting and plug formation of potato stem cuttings.

Rate of multiplication of stem cuttings in hydroponic medium

Tables 3 and 4 shows the effects of nutrient solutions on mass propagation stem cuttings during four cuttings at 15-day intervals in hydroponics. Plant heights of stem cuttings in hydroponics were significantly higher than those in the solid medium, and plant heights and the fresh shoot weight per plant increased to the 3 rd cutting date (30 July) but decreased at the 4 th cutting date (16 August) in all the treatments. The number of cuttings per mother plant in the Japanese standard nutrient solution (JS) and 0.5 × JS increased more significantly than those in the range from the 2nd to the 4 th cutting date, although no difference was observed at the 1st cutting date.

The multiplication rate of stem cuttings in the Japanese standard nutrient solution was 25 pieces per one stem cuttings after 60 days. When the reproduced seedlings were transplanted, it was possible to transplant the seedlings 20 days after cutting. Subsequently, the seedlings were able to reproduce more than 20 plants every month. The most important factor is the mother plant, which reproduces mass stem cuttings to multiply mass reproduction by plug seedlings. Cole et al. (1967) reported that 5,000 stem cuttings could be reproduced by one tuber originating from 5 cm-long-stems during December to May the following year. Therefore, it is possible to do mass multiplication of plug seedlings through su-

Table 2. Quality of seedlings as affected by different stem cuttings diameter at 30 days after transplanted in potatoes.

Diameter of stem cuttings (mm)	Days to initial rooting	After 10 days planting			No. of leaves /plant	Stem diameter (mm)	Root length (cm)	Fresh weight/plant		
		No. of roots /plant	Fresh weight /plant(mg)	Plant height (cm)				Shoot	Root	Total
								------	(mg)	------
1	3.2	12.9	295.5	24.4	7.6	1.76	11.6	1332	322	1654
2	5.6	5.9	613.5	16.2	6.0	2.80	10.4	1844	280	2124
3	7.8	3.2	726.5	12.7	5.2	3.06	9.0	1978	216	2194
LSD (0.05)	-	1.72	66.54	1.28	0.61	0.16	0.81	98.33	15.83	103.56

Table 3. Effects of three nutrient solutions on plant height and leaf number per plant generated from stem cuttings in hydroponics at June 16.

Nutrient solution†	Plant height (cm)				No. of leaves/plant			
	1st (6/28)	2nd (7/17)	3rd (7/30)	4th (8/16)	1st (6/28)	2nd (7/17)	3rd (7/30)	4th (8/16)
JS	14.37	15.23	16.15	13.68	12.15	13.90	18.50	16.75
0.5 × JS	14.44	14.45	15.27	12.34	11.50	12.70	17.80	15.00
WG	14.02	13.97	14.95	11.28	11.00	10.60	15.20	12.10
SD	11.81	12.13	12.97	9.90	10.50	8.80	13.40	9.80
LSD(0.05)	1.22	1.43	1.38	1.31	1.12	1.19	1.73	1.54

† JS; Japanese standard nutrient solution, 0.5 × JS; 0.5 × concentration of the balanced JS, WG; wondergrow 1,000 mg/l, Solid medium; cocopeat + vermiculite + perlite, SD; solid medium.

Table 4. Effects of three nutrient solutions on number of cuttings and fresh shoot weight per plant generated from stem cuttings in hydroponics at June 16.

Nutrient solution†	No. of cuttings/plant				Fresh shoot wt/plant (mg)			
	1st (6/28)	2nd (7/17)	3rd (7/30)	4th (8/16)	1st (6/28)	2nd (7/17)	3rd (7/30)	4th (8/16)
JS	3.4	4.4	10.9	7.2	567	685	968	876
0.5 × JS	3.7	4.1	8.1	7.1	510	649	865	746
WG	3.6	3.6	6.2	4.0	426	531	779	662
SD	3.2	3.9	4.5	3.6	299	342	669	548
LSD(0.05)	0.55	0.58	0.97	0.69	71.2	75.2	102.1	91.9

† See Table 3.

ccessive hydroponic culture of stem cuttings.

Planting date and tuber yield of plug seedling

Tables 5 to 8 show, the variances of growth and yield characteristics according to the planting date of plug seedlings of fall-type potatoes. Rooting was vigorous after planting in the field. Plant heights of the plug seedlings planting plot were significantly higher than that of the seed potatoes planting plot on 2 October, but was not different on 27 October. In the seed potatoes planting plot, the later the planting date, the shorter the plant height. The value of SPAD

Table 5. Analysis of variance of growth characteristics for seedling type and planting date in fall cropping potatoes.

Source of variation	df	Mean square						
		Plant height (cm)		SPAD† reading value		Stem diameter (mm)	No. of stems	Top DM† weight (g/plant)
		Oct. 2	Oct. 27	Oct. 2	Oct. 27			
Seedling type (S)	1	725.9**	22.5^{ns}	5.63^{ns}	1.30^{ns}	2.29^{ns}	13.69**	31.21*
Planting date (P)	4	2791.3**	1081.4**	1.65^{ns}	4.36^{ns}	11.92**	0.21^{ns}	25.11**
S×P	4	48.0**	63.8**	4.13^{ns}	3.92^{ns}	1.13^{ns}	0.63^{ns}	2.25^{ns}

† chlorophyll-meter(SPAD; Soil plant analysis development section(Minolta, Japan, SPAD-502)).
† DM; dry matter.

Table 6. Effects of seedling type and planting date on growth characteristics in fall cropping potatoes.

Seedling type	Planting date	Plant height (cm)		SPAD reading value		Stem diameter (mm)	No. of stems	Top DM weight (g/plant)
		Oct. 2	Oct. 27	Oct. 2	Oct. 27			
Plug seedling†	Aug. 15	55.1	56.2	39.3	37.3	8.8	1.6	8.0
	Aug. 25	52.0	49.8	39.2	39.9	8.8	0.8	7.0
	Sept. 5	35.4	34.2	40.1	38.2	6.5	1.0	4.3
	Sept. 15	22.4	29.0	40.4	38.6	6.1	1.2	4.2
	Mean	41.22	42.30	39.76	38.50	7.55	1.15	5.88
Seed tuber	Aug. 15	48.6	53.8	40.3	37.4	7.8	2.2	8.4
	Aug. 25	48.0	46.8	38.4	37.8	7.6	2.4	9.0
	Sept. 5	21.2	38.2	38.7	39.2	6.7	2.6	7.0
	Sept. 15	13.0	36.4	38.6	38.2	6.1	2.1	6.1
	Mean	32.70	43.80	39.00	38.15	7.05	2.32	7.63
LSD (0.05)	ST†	3.00	2.15	0.85	1.61	1.06	0.59	1.70
	PD	2.83	3.41	1.71	1.63	1.12	0.51	1.51

† plug seedling using stem cuttings from microtubers.
† ST; Seedling type, PD; planting date.

Table 7. Analysis of variance of tuber numbers per plant and tuber yield for seedling type and planting date in fall cropping potatoes.

Source of variation	df	Mean square									
		No. of tubers per plant					Tuber yield (ton/ha)				
		Under 30 g	30~50 g	50~80 g	Over 80 g	Total	Under 30 g	30~50 g	50~80 g	Over 80 g	Total
Seedling type (S)	1	27.81**	8.21**	0.25ns	0.17*	52.99**	7.72**	11.22**	3.44*	46.40*	6.45*
Planting date (P)	4	1.58**	0.51ns	1.11**	2.83**	11.59*	9.74**	0.22ns	7.36**	97.28**	129.7**
S×P	4	0.04ns	0.75ns	0.52**	0.05ns	0.69ns	0.20ns	3.14ns	4.76*	1.57ns	10.35ns

Table 8. Effect of seedling type and planting date on tuber number per plant and tuber yield in fall cropping potatoes.

Seedling type	Planting date	No. of tubers/plant					Tuber yield (ton/ha)				
		Under 30 g	30~50 g	50~80 g	Over 80 g	Total	Under 30 g	30~50 g	50~80 g	Over 80 g	Total
Plug seedling†	Aug. 15	1.36	0.86	1.30	1.18	4.70	2.100	2.590	6.090	7.700	18.480
	Aug. 25	0.40	0.76	0.78	1.34	3.26	1.162	2.964	4.494	10.780	19.400
	Sept. 5	1.18	0.94	0.64	0.56	3.32	3.360	3.646	4.277	5.799	17.081
	Sept.15	0.84	0.98	0.60	0.30	2.72	1.670	3.542	4.487	3.402	13.101
	Mean	0.95	0.89	0.83	0.85	3.50	2.073	3.186	4.837	6.920	17.016
Seed tuber	Aug. 15	3.10	2.36	1.10	0.98	7.54	3.290	4.732	4.690	5.740	18.452
	Aug. 25	2.20	1.80	1.60	1.40	5.80	1.680	4.872	5.740	8.820	21.112
	Sept. 5	2.69	1.82	0.74	0.28	5.53	4.176	3.789	3.945	2.519	14.429
	Sept.15	2.46	1.16	0.52	0.20	4.34	2.661	3.585	2.626	1.985	10.858
	Mean	2.61	1.79	0.99	0.71	5.80	2.952	4.244	4.250	4.766	16.213
LSD (0.05)	ST‡	0.21	0.44	0.18	0.12	0.56	0.41	0.38	0.54	1.31	0.76
	PD	0.47	0.56	0.28	0.31	0.74	0.60	1.16	0.98	1.77	2.31

† plug seedling using stem cuttings from microtubers.

‡ ST; Seedling type, PD; planting date.

reading and the stem diameter was not different according to all of the treatments. The top DM weight of the seed potato planting plot was heavier than that of the plug seedling plot, and was lighter as the planting date was later.

In the case of small tubers (under 50 g), the number of tubers and tuber yield were evidently increased at the seed potatoes planting plot; however, the large tuber (over 80 g) yield of the plug seedling planting plot, was higher than that of the seed potato planting plot.

The ability of tubers to achieve high yields in the plug seedling planting plot was lower than in the seed potato planting plot; the number of total tubers per plant in the former was 3.5 and that of the latter was 5.8. In both planting plots, the number of tubers (above 50 g) decreased as the planting date was later, and the number of total tubers per plant was significantly decreased in the planting on 15 September. Cip (1975) reported that there was as many as 5 tubers in the stem cuttings. The tuber yields in the plug seedlings planting plot and seed potatoes planting plot were very high on 25 Aug, but were reduced on 15 August, 5 September and 15 September. The degree of decrease in tuber yield of the plug seedling planting plot was lower than that of seed potatoes when planted on the later dates.

In the seed potato production, Roy et al. (1995) reported that the number of tubers in stem cutting seedlings was lower than in the *in vitro* plantlets, and the tuber number of the greater than 40 g weight was increased but that of the under 20 g was decreased.

Plug seedlings tend to have few stolons because the rooted stem cuttings, instead of the tubers, are directly transplanted into the field. The resulting tuber weight of plug seedlings is higher than that of seed potatoes. As the above results show, the optimal planting date of plug seedlings and seed potatoes in Cheju-Do, Korea is on or about 25 August. In order to increase tuber yield it is necessary to increase field planting density of plug seedlings.

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