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Effects of pre-elite seed size and planting density on development and propagation efficiency of two virus-free potato cultivars in Sichuan Province, China

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The aim of the experiment is to develop a high-output and low-cost method for propagating elite potato seed in the field from pre-elite seeds. Field experiments were conducted in spring and autumn season of southwestern China (Yucheng in 2010 and Hanyuan in 2011). Randomized-block design was used with 3 seed-size rates, 4 planting densities and 2 cultivars of pre-elite seed from virus-free potato. During potato-growing periods, dry-matter accumulation, number, volume, and dry weight of tubers, and propagation efficiency of pre-elite seed from virus-free potato were measured. The results indicated that medium planting density with large pre-elite potato seed increased tuber volume and dry matter accumulation (per-plant), and prolonged rapid-growth period, resulting in a large amount of final growth. In addition, seed volume, number of plants harvested, rate of seed set per plant, and mass of individual tubers increased, reproductive yield and the coefficient of tuber number and weight increased but the weight coefficient decreased. Per-plant rate of seed set and propagation coefficients of weight, tuber number, and tuber weight decreased with increasing plant density, while number of plants harvested and reproductive output increased. The yields of elite seed of virus-free potato reached a peak in autumn season with large pre-elite seed and high planting density, and in spring season with large seed and medium planting density. Propagation coefficient of tuber numbers and weight reached a peak with large seeds and low planting density, but the highest propagation coefficient of weight was obtained with small pre-elite seeds and low planting density.

Key words: Virus-free potato, pre-elite seed, tuber size, planting density, propagation efficiency.

INTRODUCTION

Potato (*Solanum* spp.) is an important crop in Sichuan Province, China. Local governments and agricultural departments have placed high importance on potato production due to its advantages, which include

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adaptability to various agro-ecological regions, high yields, and diversity of uses, both fresh and processed. It is reported that the coverage of potato in Sichuan has expanded by 172.2% and potato yields have increased by 189.9% from 2005 to 2014 (Ministry of Agriculture, 2006, 2015). Although industrialized potato production has been developed in Sichuan to some extent, potato output in this province is approximately 20 t/ha^{-2} times lower than that in developed countries (Wu et al., 2012). The main reason for the lower output is that identical potato cultivars have been planted for many years, without any alteration. According to research by Xie et al. (2010), approximately 70% of farmers plant their own potato cultivars in Sichuan, but virus-free potato seeds are utilized only in a small area, which greatly limits the rapid industrialization of this crop.

Virus-free potato seeds are generally classified into 5 levels (The national standard of the People's Republic of China, 2006) or 3 levels (Xie et al., 2011), and different production technologies should be utilized for different seed levels or generations (Li, 2007; Yan et al., 2008). Some research has indicated that lowering planting density can result in an increased number of tubers per plantlet in all grades, improved plantlet survival, and increased numbers of stems per plant (Van der Veeken and Lommen, 2009). Muro et al. (1997) found that the number of tubers increased significantly with seed density, without a decrease in number of large-diameter tubers, and the number of the minitubers formed per unite area was in line with the increase in plant density (Jin et al., 2013). Wu et al. (2011) found that the size of minituber planted at the same density had significant influence on the occurrence of late blight and high yield of elite seed was achieved when the minitubers planted were 21 g or more. In another study, yield and number of tubers increased, but average weight of individual tubers decreased, as planting density increased (Yang et al., 2009). When virus-free seedlings of miniature potatoes were planted at a density of 400/m^2 (2 seedlings per hole), good growth, survival rate, and yield were obtained (Yan et al., 2006); at a constant planting density, high seed-tuber weight significantly affected tuber yield (He et al., 2007). Most research on the use of virus-free seedling products, pre-elite seed, or cultivated potato products as commodities has studied the effects of density or seed size on tuber number and yield; however, there have been few reports on the dynamics of tuber growth or the propagation efficiency of elite seed tuber in potato. Elite seeds are usually produced using the same methods as for commodity-potato production, but this approach is inefficient, and has a high cost and low output. The popularization of virus-free potato seeds is therefore limited to some extent. In this paper, we consider volume and planting density of pre-elite potato seed in an attempt to determine an efficient method for reproducing elite seed in the field. Our results may facilitate an increase in use and coverage of virus-free potato seed, which may further contribute to the industrialization of potato production in Sichuan, China.

MATERIALS AND METHODS

Materials and experimental sites

Zhongshu *2*, provided by the Potato Research and Development Center of Sichuan Agriculture University. Eshu 5, provided by the South China Potato Research Center, Hubei Province. Both Zhongshu 2 and Eshu 5 were pre-elite potato seeds obtained from virus-free potato plantlets. The soils in the experimental site were of medium fertility (it contained 30.54 g.kg^{-1} organic matter, 74.50 mg.kg^{-1} available N, 61.98 m g.kg^{-1}available P, 50.11 m g.kg^{-1} available potassium), and rice had been harvested before the potatoes were planted.

Experimental design

This experiment was conducted in Randomized-Block Design with 2-factors (A and B), and 3 replications, and each block comprised an area of 12 m^2. Factor A represented the volume of pre-elite potato seed, and included 3 levels: A1 (1-3 g), A2 (5-6 g), and A3 (9-10 g). Factor B represented planting density, included 4 levels: B1 (9 plants/m^2), B2 (12 plants/m^2), B3 (15 plants/m^2), and B4 (18 plants/m^2).

Cultivation and management

Zhongshu 2 seed was planted in autumn (28 September 2010) in Caoba Town, Yucheng District, altitude 600 m and harvested on 9 December 2010. Eshu 5 seed was planted in spring (10 January 2011) in Shuangxi Town, Hanyuan County, altitude 1600 m and harvested on 19 May, 2011. Planting density was established as described above, and rows were spaced 40 cm apart. The same management practices as used in large-scale production were used in the experimental blocks. Pure nitrogen fertilizer about 150 kg/ha, 70% fertilizer as a base fertilizer and a 30% as an additional fertilizer. P, K fertilizers about K_2O 135 kg/ha, and P_2O_5 45 kg/ha as a base fertilizer, after seeding, flowering and tuber bulking, when drought, irrigation 50, 80 and 80 mm, respectively. To protect and control potato disease, Choose a 58% frost spirit manganese zinc, 64% antivirus alum, and 72% du bangke dew, which were used alternately every 10 days, spray 2-3 times.

Observation and investigation

The seedling emerging rate was observed and uniform plants (with same emergence time, same plant size, and same plant growth) were tabbed as samples. Five sample plants were taken from each block every 10 to 12 days. The volume of tubers and roots were measured using the drainage method for each replicate, after which roots, stems, leaves, and tubers were dried for weighing. Plants harvested in all of the blocks were numbered and weighted, and their tubers were counted.

Data analysis

Data were analyzed using Microsoft Excel 2003, DPS 7.05, and SigmaPlot 12.0. Growth dynamics were fitted to the Logistic Equation $y = k/(1 + ae^{-bt})$, where "t" represents the days after seeding from which the date of maximum growth rate (t_0) and two inflection points (t_1 and t_2) were calculated.

$t_0 = \ln(a)/b$ (t_0: the accumulation of dry matter or nutrient rate of the biggest moments).

$t_1 = = -\ln((2+\sqrt{3})/a)/b$ (t_1: d^2y/d^2 in t1 time derivative to the maximum)

$t_2 = -\ln((2-\sqrt{3})/a)/b$ (t_2: d^2y/d^2 in t2 time derivative to the minimum).

RESULTS

Effect of volume of pre-elite seed and planting density on per-plant accumulation of dry matter

The dynamics of per-plant dry matter accumulation was met to the logistic equation $y = k/(1 + ae^{-bt})$, where "t" represents the number of days after seeding at which elite seeds were reproduced by pre-elite seeds. Accumulation of dry matter exhibited a slow-fast-slow curve (Figure 1), and was affected to some extent by volume of pre-elite seed and planting density.

The volume of pre-elite seed planted was larger, the fast-growth period (t_1 – t_2) lasted was longer, and the initial growth period (t_0 – t_1) became shorter, stimulating an increase in plant dry matter. Compared to small pre-elite seeds, large pre-elite seeds showed an initial growth period 5.8 days shorter, and a fast-growth period 17 d longer. In addition, the rate of dry matter was increased by 125% during the initial growth period, and the accumulation of dry matter increased by 90% during both the initial and fast-growth periods. The total weight of per-plant dry matter was increased by 90% on average.

The initial growth period tended to shorten with increasing planting density, and the fast-growth period tended to lengthen initially, and then ultimately to shorten. The accumulation of dry matter and growth rate of both initial and fast-growth periods revealed a tendency to increase at first, and then to decline. Low planting density (9 plants/m^2) resulted in the longest initial growth period, but middle-to-high planting densities (15 plants/m^2) resulted in the longest fast-growth period. Growth rate and rate of accumulation of dry matter reached their highest values with middle-to-low planting density (12 plants/m^2). At a planting density of 18 plants/m^2, the duration of the initial and fast-growth periods were the shortest, and growth rate and accumulation of dry matter during the initial and fast-growth periods were the slowest.

Effect of volume of pre-elite seed and planting density on tuber development

The process of potato tuber development met the logistic equation of $y = k/(1+ae^{-bt})$, in which "t" represents the number of days after formation of tubers, and this process was affected by both the volume and planting density of pre-elite seeds (Table 1). After initial formation, tubers increased in size and accumulated dry matter; the number of tubers per plant increased rapidly and reached a peak (t_0) within 10.1 to 14 days, with a very short fast-growth period. Enlargement of tubers (tuber volume) and accumulation of dry matter (tuber weight) increased slowly, with long fast-growth periods of 12.7 to 26.4 days and 9.2 to 25.5 days respectively, and reached a peak within 29 to 35.8 days and 28.1 to 37.9 days respectively. In order to obtain a high yield, it is thus advantageous to stimulate formation and enlargement of tubers, and to adequately prolong the fast-growth period of tuber enlargement and dry matter accumulation.

The initial, fast, and smallest growth period were reduced with increasing volume of seed planted. Compared to small seeds, large pre-elite seeds showed a fast rate of seeding within a short time; according to the average value of the 4 planting densities, large pre-elite seeds reproduced 38% more tubers than small ones.

Although tuber volume, dry matter, and tuber number were increased identically, but occurred earlier and shorter duration for large pre-elite seeds than small ones. In addition, large pre-elite seeds had longer and later fast and fastest growth periods, exhibited higher dry weight at harvest, and produced a greater volume of tubers. The fast-growth periods corresponding to tuber volume and weight were 13.1 and 14.3 days longer respectively in large pre-elite seeds than in small seeds. The time required for the maximum growth rate was increased by 5.9 d and 5.6 days respectively, and the harvested tuber volume and weight were increased by 103 and 110% respectively, when small pre-elite seeds were replaced by large seeds.

Volume of pre-elite seed exerted a stronger effect on development especially number of tubers than did planting density. The highest growth period, fast growth duration, and growth rate of tuber volume and weight increased initially and then declined. The fast-growth period was shortened and the growth rate was reduced by excessive planting density, which ultimately resulted in small tuber volumes and low per-plant dry weight.

Effect of pre-elite seed volume and planting density on biomass and distribution of dry matter in tubers

Biomass and distribution of tuber dry matter differed because of differences in the experimental seasons and sites (Table 2). Temperature in Hanyuan changed dramatically from day to night, and there was an abundance of sunlight in spring. The growing period was longer, and more dry matter accumulated and was distributed to tubers in Hanyuan than in Yucheng (in autumn season).

Biomass and distribution of dry matter into tubers were affected somewhat by volume and planting density of pre-elite seeds in both seasons. Biomass increased with

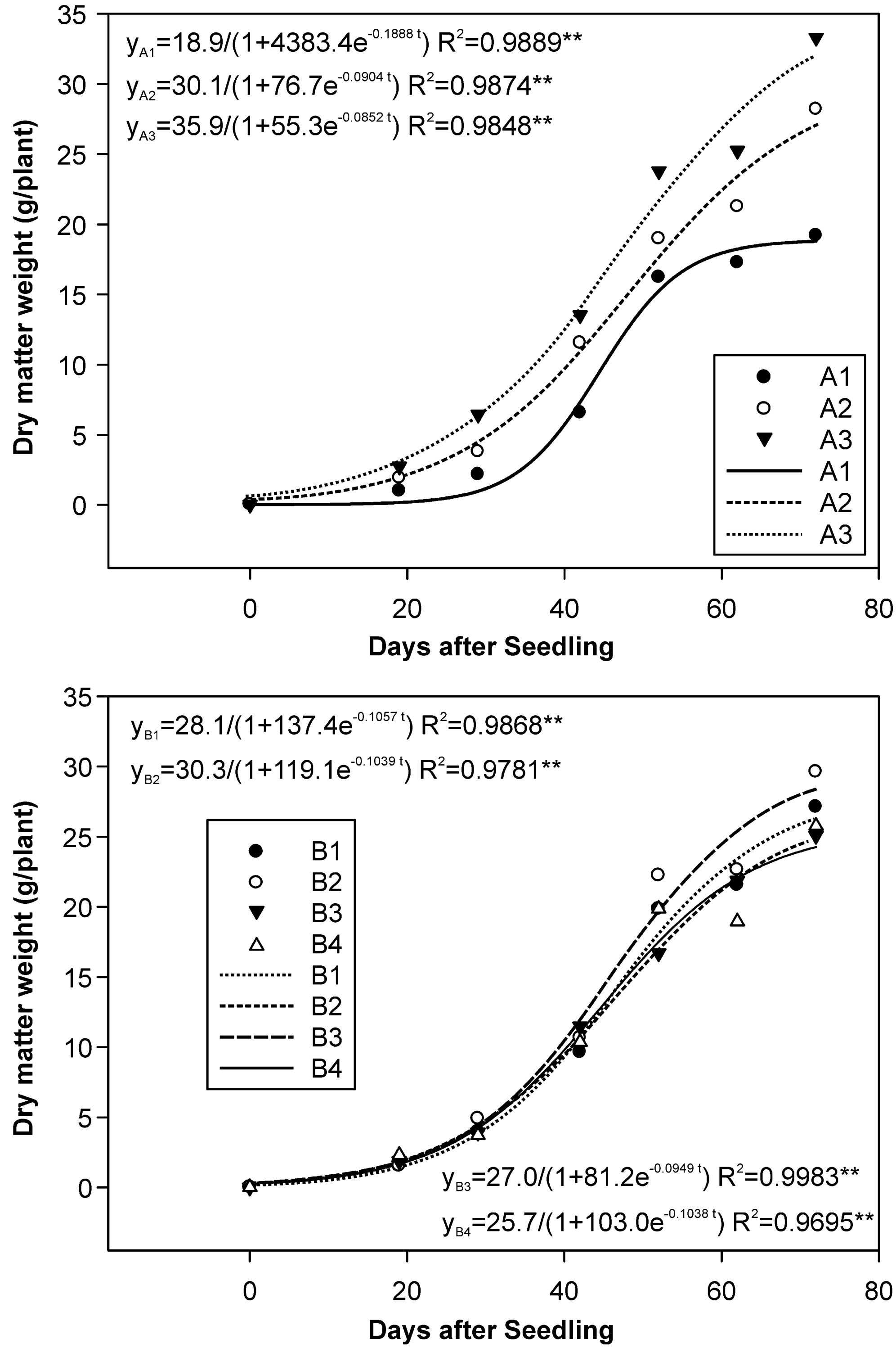

Figure 1. Effect of seed pre-elite seed volume and planting density on dry matter accumulation of individual plant of Zhongshu *2* (planted in autumn). **P < 0.01.

increasing volume of pre-elite seed. Biomass showed a tendency to increase with increased planting density, while the distribution ratio of dry matter to tubers showed the opposite pattern a decreasing trend although dry weight per plant also tended to decline. The biomass of large pre-elite seeds was 68% greater than that of small

Table 1. The growth coefficient of tubers of Zhongshu *2* meets logistic equation $y = k/(1 + ae^{-bt})$ in autumn.

Plant characteristics		Levels	k	a	b	R^2	t_0	t_1-t_2
Tuber number	Pre-elite seed volume (g)	1-3	2.98	117.437	0.34059	0.9948**	14.0	7.7
		5-6	3.77	7.2E+12	2.8085	0.9793**	10.5	0.9
		9-10	4.11	2.3E+23	5.2253	0.9268*	10.3	0.5
	Planting density(plants/m^2)	9	3.78	9.7E+08	1.8909	0.9247*	10.9	1.4
		12	3.81	1.5E+75	17.1712	0.9634**	10.1	0.2
		15	3.65	1.6E+09	1.9675	0.9871**	10.8	1.3
		18	3.43	1.5E+49	11.1948	0.9909**	10.1	0.2
Tuber volume	Pre-elite seed volume (g)	1-3	72.3	318.43	0.1986	0.9922**	29.0	13.3
		5-6	130.0	41.613	0.1088	0.9898**	34.3	24.2
		9-10	146.5	32.359	0.0995	0.9640**	34.9	26.4
	Planting density (plants/m^2)	9	93.6	263.117	0.2074	0.9464*	26.9	12.7
		12	134.9	43.576	0.1053	0.9788**	35.8	25.0
		15	114.0	32.743	0.1004	0.982**	34.7	26.2
		18	111.6	77.867	0.1345	0.9990**	32.4	19.6
Tuber weight	Pre-elite seed volume (g)	1-3	13	3475.5	0.2860	0.9762**	28.5	9.2
		5-6	24.1	46.004	0.1032	0.9793**	37.1	25.5
		9-10	27.3	45.309	0.1120	0.9747**	34.1	23.5
	Planting density (plants/m^2)	9	22.4	54.692	0.1164	0.9603**	34.4	22.6
		12	18.7	1012.8	0.2459	0.9575**	28.1	10.7
		15	22.9	52.886	0.1047	0.9943**	37.9	25.1
		18	19.6	65.425	0.1321	0.9784**	31.7	19.9

*P < 0.05, ** P < 0.01.

Table 2. Effect of seed pre-elite seed size and planting density on biomass and distribution of dry matter in tubers.

Seasons	Plant characteristics	Pre-elite seed volume (g)			Planting density (plants/m^2)			
		1-3	5-6	9-10	9	12	15	18
Spring	Biomass (dry weight, t/ha)	2.59^c	3.79^b	4.37^a	2.44^c	3.50^b	3.76^b	4.64^a
	Distribution of dry matter into tuber	75.3^b	78.6^a	76.4^b	77.6	77.1	76.7	75.7
Autumn	Biomass (dry weight, t/ha)	4.81^c	5.41^b	8.09^a	4.76^c	6.13^b	6.64^b	6.88^a
	Distribution of dry matter into tuber	83.5^b	80.5^c	85.7^a	86.1^a	85.8^a	82.2^b	78.9^c

The data were recorded from the final harvest of per plant for each treatment and the means of the three replications were shown. The different letter in the column of each growing season represents significant difference at P=0.05 by the LSD test (the value of LSD0.05 for each comparison was also presented).

seeds. Average biomass increased by 60%, and distribution of dry matter into tubers decreased by 4.6%, in treatment blocks with high planting densities.

Effect of pre-elite seed volume and planting density on propagation output

Propagation yields were over twice as high in spring as in autumn season. Yields were affected by seed volume and planting density in both spring and autumn, and increased with increasing pre-elite seed volume (Table 3). Reproductive yields of large pre-elite seeds were, on average, 76 and 51% greater than those of medium-sized and small seeds, respectively. It was clear especially in spring season that propagation yields increased with increasing plant density. In spring season the highest yields were at middle-to-high planting density with large pre-elite seeds, while in autumn season, the highest yields were at high planting density with large pre-elite

Table 3. Effect of pre-elite seed size and planting density on propagation yield.

Seasons	Pre-elite seed volume (g)	Planting density (plants/m^2)				
		9	12	15	18	Average
Autumn	1-3	6.86^{f}	7.53^{f}	7.84^{ef}	7.86^{ef}	7.52^{c}
	5-6	10.99^{de}	11.79^{cd}	12.36^{bcd}	13.12^{bcd}	12.07^{b}
	9-10	14.53^{abc}	15.49^{ab}	15.38^{ab}	17.85^{a}	15.81^{a}
	Average	10.80^{b}	11.60^{ab}	11.86^{ab}	12.94^{a}	
Spring	1-3	14.83^{e}	22.41^{cd}	22.49^{cd}	21.71^{cd}	20.36^{b}
	5-6	15.33^{e}	17.79^{de}	23.93^{bcd}	25.02^{bc}	20.52^{b}
	9-10	29.81^{ab}	34.96^{a}	34.54^{a}	34.02^{a}	33.33^{a}
	Average	19.99^{b}	25.05^{a}	26.99^{a}	26.92^{a}	

The data were recorded from the final harvest of per plant for each treatment and the means of the three replications were shown. The different letter in the column of each growing season represents significant difference at P=0.05 by the LSD test (the value of LSD0.05 for each comparison was also presented).

Table 4. Effect of seed pre-elite seed volume and planting density on propagation coefficients.

Treatments		Autumn			Spring		
		NNC	NWC	WWC	NNC	NWC	WWC
Pre-elite seed volume (g)	1-3	2.11^{c}	58.7^{c}	29.37^{a}	3.11^{b}	155.5^{b}	77.76^{a}
	5-6	2.76^{b}	93.9^{b}	17.08^{b}	3.25^{b}	154.3^{b}	28.04^{b}
	9-10	3.47^{a}	123.1^{a}	12.95^{c}	4.53^{a}	260.1^{a}	27.42^{b}
Planting density (plants/m^2)	9	3.37^{a}	119.9^{a}	25.77^{a}	4.32^{a}	222.1^{a}	49.41^{a}
	12	2.81^{b}	96.7^{b}	20.95^{b}	3.98^{b}	208.8^{a}	50.33^{a}
	15	2.71^{b}	79.1^{c}	17.30^{c}	3.33^{c}	179.9^{b}	42.74^{ab}
	18	2.23^{c}	71.9^{c}	15.17^{c}	2.89^{d}	149.5^{c}	35.16^{b}

NNC indicates the number-to-number propagation coefficient; NWI indicates the number-to-weight propagation coefficient; WWI indicates the weight-to-weight propagation coefficient. Different superscript letters indicate significant difference at P < 0.05.

seeds.

Effect of pre-elite seed volume and planting density on propagation coefficient

Seed volume and planting density did not only affect propagation yields, but also affected the number of tubers. Number of tubers per hectare was correlated positively with seed volume and planting density. Large pre-elite seeds produced 56 and 34% more tubers than did medium and small seeds, respectively. The number of tubers produced in the high-density planting treatment (18 plants/m^2) was 31 and 12% greater than that in 9 and 12 plants/m^2 respectively.

The number-to-number propagation coefficient (number of elite seeds reproduced per individual pre-elite seed) increased significantly with increasing volume of pre-elite seed, but decreased significantly with increased planting density (Table 4). The propagation coefficient was 53% higher in large pre-elite seeds than in small ones, and 50 and 27% higher at low planting density than at high and medium planting density, respectively.

The number-to-weight propagation coefficient (weight of elite seeds propagated per individual pre-elite seed) was positively correlated with volume of pre-elite seed, and negatively correlated with planting density. The number-to-weight coefficient was 79 and 54% higher in large pre-elite seeds than in small and medium-sized seeds, respectively, and 55 and 32% higher at low planting density than at high and medium-high planting densities, respectively.

The weight-to-weight propagation coefficient (the weight of elite seeds propagated by 1 kg of pre-elite seeds) was reduced with an increase in planting density and volume of pre-elite seeds. This coefficient was 165 and 137% higher in small pre-elite seeds than in large and medium-sized ones, and 49 and 25% higher at low planting density than at high and medium- high planting densities, respectively.

Table 5. Effect of seed pre-elite seed volume and planting density on components of tuber yield.

Treatments		Autumn			Spring		
		Plants harvested / m^2	Tubers / plant	Weight of one tuber (g)	Plants harvested / m^2	Tubers / plant	Weight of one tuber (g)
Pre-elite seed volume (g)	1-3	8.44^b	2.04^c	46.85^b	11.88^b	3.64^b	51.31^{ab}
	5-6	8.34^b	2.64^b	56.05^a	12.31^b	3.56^b	47.74^b
	9-10	9.79^a	2.98^a	59.15^a	14.03^a	4.38^a	57.94^a
Planting density (plants/m^2)	9	6.09^c	2.85^a	62.34^a	9.22^d	4.23^a	50.63^a
	12	8.24^b	2.55^{ab}	55.25^{ab}	11.11^c	4.29^a	52.70^a
	15	9.32^b	2.53^{ab}	50.16^b	12.57^b	4.04^a	53.97^a
	18	11.79^a	2.27^b	48.32^b	18.00^a	2.88^b	52.0^a

The data were recorded from the final harvest of per plant for each treatment and the means of the three replications were shown. The different letter in the column of each growing season represents significant difference at P=0.05 by the LSD test (the value of LSD0.05 for each comparison was also presented).

Table 6. The regression, correlation, and path coefficients of tuber yield and its components.

Coefficient	Propagation in autumn			Propagation in spring		
	Plants harvested	Tubers/ plant	Tuberweight	Plants harvested	Tubers/ plant	Tuber weight
Regression coefficient	1.2587	3.8186	0.2169	1.7077	5.9778	0.4397
Correlation coefficient	0.3635*	0.5815**	0.4915**	0.4145*	0.2177	0.6912**
Direct path coefficient	0.9047**	0.5928**	0.5685**	0.8102**	0.7257**	0.6519**
Contribution (%)	34.5	36.2	29.3	35.6	16.7	47.7

The intercept of regression equation in Yucheng and Hanyuan was -20.80 and -43.07 respectively. *P < 0.05, **P < 0.01.

Effect of pre-elite seed volume and planting density on composition of yield

The yield of elite seeds consisted of plants harvested, tubers per plant, and average weight per tuber. Propagation yield and its components were significantly affected by the size of pre-elite seed, planting density, and propagation region and season (Table 5). Propagation yields were higher in spring than in autumn, which we attribute to 2 factors. First, the average seedling rate in spring was 29% higher than that in autumn, leading to a 44% greater harvest. Second, the number of tubers formed by one plant was 51% greater in spring than autumn.

The larger the pre-elite seeds were, the higher the seedling rate, the more plants were harvested, the more tubers were formed by individual plants, and the greater the weight per tuber observed. Compared to small seeds, the number of plants harvested, tubers per plant, and weight per tuber produced by large pre-elite seeds were 17, 30, and 19% greater, respectively. When the same size of pre-elite seeds was used, the number of plants harvested increased with increasing planting density; the number of tubers per plant and the weight per tuber decreased in autumn season (in Yucheng), but increased initially and then declined in spring season (in Hanyuan). High planting density resulted in 95% more plants being harvested and 27% fewer tubers per plant, compared to low planting density.

Correlation and regression analysis

As revealed in Table 6, the reproductive yield of elite seeds was positively correlated with plants harvested, tubers formed per plant, and weight per tuber. Yield increased correspondingly by 1.26 to 1.71, 3.82 to 5.98, and 0.22 to 0.69 tons/ha, respectively, if 1 additional plant was harvested per m^2, 1 more tuber per plant was formed, and if weight per tuber increased by 1 g. The increased yield in Hanyuan in spring was higher than that in Yuchen in Autumn.

Propagation yield was extremely significant to the direct-path coefficient of plants harvested, tubers formed per plant, and weight per tuber. In addition, propagation yield was extremely significant to correlation coefficient of weight per tuber, and significant to the correlation coefficient of number of plants harvested. Propagation yield was extremely significant to the correlation coefficient of number of tubers formed per plant in

Yucheng but not in Hanyuan. Propagation yield in Yucheng was greatly impacted by tubers number per plant and least impacted by weight per tuber, but this scenario was reversed in Hanyuan. These results revealed that it is advisable to use different methods to propagate high yields of elite seeds in different regions. Harvested plants should consider in both Yucheng and Hanyuan; it would be preferable to increase the number of tubers formed per plant in Yucheng, and to increase he weight per tuber in Hanyuan.

DISCUSSION

It has been reported that seedling rate per tuber and number of stems per plant increased with increasing seed volume (Allen and Wurr, 1978), leading to high outputs (He et al., 2007; Qi et al., 2011; Yang and Tu, 2003). However, larger potato seeds are associated with lower propagation coefficients (Yang and Tu, 2003). Therefore, a reasonable volume of potato seeds can produce high yields. Many researchers believe that it is better to produce commercial potatoes using seeds that weigh from 30 to 50 g (He et al., 2007; Yang and Tu, 2003), or from 20 to 25 g (Qi et al., 2011). More larger sized minitubers (Pre-elite Seed) should be selected for elite seed I production, and when the minitubers planted were 21 g or more, the high yield of elite seed was achieved (Wu et al., 2011). But pre-elite potato seed is small generally no more than 20 g and usually between 3 to 5 g, so some way should be found to increase the yield of the elite seed.

With a 10 g increase in seed volume, it was found that yield of elite seed and the propagation coefficient of number-to-number and number-to-weight increased, but that the weight-to-weight propagation coefficient was reduced. Number of tubers, rather than weight, is widely used as a standard index for measurement and valuation in the production of pre-elite to elite seed. It is important to use the largest pre-elite seeds possible in propagating elite seeds.

Compared to small seeds, large pre-elite seeds have a greater number of bud eyes, store more water and nutrients, and are more adaptable to adverse conditions such as cold weather, drought, or flood. As a result, large pre-elite seeds have higher seedling rates, produced more plants for harvest, and exhibit a longer fast-growth period of per-plant dry weight, tuber enlargement, and dry-matter accumulation. These advantages result in an increased number of tubers per plant and weight per tuber, which further results in a high propagation yield of elite seeds.

A proper planting density can balance the relationship between individual and grouped plants, which is a key to producing high yields. Therefore, planting density is one of the most vital research subjects in potato cultivation (Bussan et al., 2007; Cheng and Su, 2009; Love and Thompson-Johns, 1999; Luo 2011). Planting density for high yield varies with differences among regions, seasons, and potato varieties. Planting areas where can plant potato one or two seasons in southern China generally support 6.0 to 7.5 and 7.0 to 9.0 plants/m^2 respectively. It is appropriate to increase planting density by 3.0 to 3.75 plants/m^2 (Allen and Wurr, 1978) during autumn.

It is well known that the reproductive ability of pre-elite seeds is low because of the small tubers associated with these seeds. The aim of propagating elite seeds is not only high output, but also high composition of medium-sized tubers to be used for sowing without cutting, rather than large tubers to be used for commercial production. So the ideal planting density for production of elite seed is not adequate for commercial potato production.

Within the range of 7 to 9 plants/m^2 examined in this study, reproductive yield of elite seeds increased with increasing plant density, but number-to-number, number-to-weight, and weight-to-weight propagation coefficients were reduced. A low planting density can bring about faster accumulation of dry matter and a greater number of tubers per plant than can high planting density; thus, low planting density can produce higher propagation coefficients due to its superiority at the level of the individual plant. On the other hand, low planting density produces a lower yield of elite seeds, due to fewer plants harvested.

Early planting of top-shoot cuttings with closer spacing (high plant density）was recommended for the multiplication of breeder seed potato (Al Mamun et al., 2016) and proper planting densities vary in achieving high yields and propagation efficiencies. The solution for high yield in Yucheng in autumn is to use large (9 to 10 g) pre-elite seeds and high planting density (18 plants/m^2), but the solution for high propagation efficiency is to use low planting density (9 plants/m^2) rather than changing the volume of seeds planted. In Hanyuan in spring, the method for obtaining high yield is to use large (9 to 10 g) pre-elite seeds and medium planting density (12 to 15 plants/m^2), and the recommended method for obtaining high propagation efficiency is the same as that for Yucheng. The proper planting density for producing elite seeds is commonly higher than that for commercial potato production, and is determined by factors that include production objectives, propagation region and season, and size of pre-elite seeds.

Approaches should be taken in different propagation regions and seasons to achieve high outputs of original potato seeds, due to differences in environmental conditions. In spring, the highest rate of propagation yield and coefficient was obtained in Hanyuan due to the long developmental period, so elite seeds in Hanyuan should be planted as possible in spring. Based upon the results of correlation and direct-path analysis, propagation of elite seeds should first consider enough harvest plants, followed by weight per tuber in Hanyuan and number of tubers per plant in Yucheng.

Dry weight per plant, and volume and dry weight of tubers increased quickly when elite seeds were propagated by pre-elite seeds under the conditions of large pre-elite seed and medium-to-low planting density. Yield and number-to-number and number-to-weight coefficients of propagation increased with increasing size of pre-elite seeds, but weight-to-weight coefficient decreased, indicating that large pre-elite seeds should be the first choice for reproduction of original potato seeds. In addition, propagation yield increased but propagation coefficient decreased with increased planting density. Therefore, the ideal planting density should be comprehensively and systematically determined according to the objectives of reproduction, the size of pre-elite seeds, and cultivation season.

Conflict of Interests

The authors have not declared any conflict of interests.

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