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Comparison of Aeroponics and Conventional Soil Systems for Potato Minitubers Production and Evaluation of Their Quality Characters

Zahra Movahedi[1], Ahmad Moieni[1*] and Ali Soroushzadeh[2]

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[1] Former Ph.D Student, Department of Plant Breeding, Faculty of Agriculture, Tarbiat Modares University and Assistant Prof., Department of Agronomy and Plant Breeding, Faculty of Agriculture, Malayer University
[2]Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran
[*]Correspondence to: E-mail: moieni_a@modares.ac.ir

Abstract
Two different propagation procedures including aeroponics and soil systems were compared for the minitubers production in potato. The minitubers were evaluated for several quality characters. The plant materials were from three cultivars, Agria, Marfona and Savalan. The plantlets were grown in aeroponics and soil production systems at a plant density of 100 plants per m^{-2} and stem length, root length, stem diameter and yield were measured in both experiments. In the other experiment, germination, stem length and yield were measured for minitubers which were produced in aeroponics production system. Analysis of variance indicated that the main effects of cultivar and production system were significant for stem length, root length, stem diameter and yield. Also cultivar by production system interaction was highly significant at 0.01 probability level for stem length, root length and minituber yield of the plants. The aeroponics system led to increase in stem length, root length, stem diameter and yield. Cultivars Agria in terms of stem length and Marfona in terms of root length, stem diameter and minituber yield were the most favorable genotypes obtained from aeroponics production system. Minitubers of Marfona had more yield and better quality characters. It seems that cultivar Marfona could be considered as the most favorable genotype due to high performance in minituber production and having quality characters after planting.

Keywords: Minituber; Production system; Quality characters; *Solanum tuberosum* L.

Introduction
Potato (*Solanum tuberosum* L.) as an important crop is on the second place after cereals in the world. Potato is regarded as an important crop in Iran with 180,000 hectares of growing area and 5400000 tons of production (FAO 2013). It indicates the potential of second bread for human's alimentation in the third millennium (Baciu *et al.* 2009). The average yield performance of potato is relatively low in Iran (about 26,700 Kg ha^{-1}) in comparison to the countries with high mean yields such as Germany (44,757 Kg ha^{-1}; FAO 2013). Improving for high yield and good quality traits as well as resistance to diseases are the most important targets in potato breeding programs of Iran (Asghari-Zakaria *et al.* 2007).

Potatoes are propagated vegetatively and cultivated as clones. Suitable procedures such as macro-propagation have been developed during last decades (Hoque *et al.* 2010). Although, investigations to improve macro-propagation procedures continues, but has lost some impetus in recent years with the continued extension of tissue culture methods (George and Debergh 2008). *In vitro* production of potato is mainly done to maintain genetic stability and the mass tuberization for virus-free potato production (Wang and Hu 1982). Production of healthy potato clones combined with *in vitro* procedures have become an important part of potato seed production, resulting in high quality seed tubers (Jones 1994). Producing potato minitubers from *in vitro* cultures permits a faster multiplication rate in seed programs. Minitubers can be produced in greenhouse (Wiersema *et al.* 1987), aeroponics (Jones 1988) and hydroponics (Rolot and Seutin 1999). These procedures have some advantages and disadvantages which have been discussed in the literature (Ritter *et al.* 2001). The aeroponics system is regarded as an alternative procedure of potato multiplication and optimal tool of the soil-less procedures in the growth-controlled conditions. Aeroponics systems are efficient tool for the root studies and optimize potato root aeration. It also applies in crop nutrition studies and is economic in potato seed production. This system involves spraying plant roots with a fine mist of a complete nutrient solution. Aeroponics system optimizes potato root aeration, which is important factor causing to the yield increase as compared to classical systems (Softer and Burger 1988). The main target of a potato multiplication system for seed production should be to maintain a stock of base seed and increase its economical value. An aeroponics system for potato production was established in tropical and subtropical conditions (Kim *et al.* 1999). Each functioning seed system starts with healthy plant material which is multiplied several times with low rates. Kang *et al.* (1996) reported that the minituber production via immersed organs or continuous mist system can be promoted in comparison to certain stress conditions such as nitrogen deficiency or pH reductions (Krauss and Marschner 1982, Wan *et al.* 1994). Ritter *et al*. (2001) indicated that aeroponics system can produce potato minitubers under temperate weather conditions with improved mini-tuber production. Finally, harvesting in aeroponics system is convenient, clean and permits tuber size control by continuous harvesting. To optimize the aeroponics system for mini-tuber production in potato, different factors such as appropriate nutrient solutions, plant densities, number of harvests and harvesting intervals and their interactions must be regarded (Ritter *et al.* 2001).

Although, there is increasing interest in the soil-less procedures in commercial potato seed production but, little practical use has been reported. The objective of this investigation was to compare a new designed aeroponics system for basic seed mini-tuber production with conventional system in some current potato cultivars in Iran with a particular emphasis on the applicability of the aeroponics technology for the mini-tuber production.

Materials and Methods

Three commercial potato cultivars including, Agria, Marfona and Savalan, were used in the present investigation as the plant materials. Agria was originated from Germany with yellow and deep yellow primary tuber flesh color, a high resistance to the most potato viruses and very high yield potential in the early harvest. Marfona was originated from the Netherlands with light yellow primary tuber flesh color, a medium resistance to the most potato viruses and very high yield potential in the early harvest. Savalan originated from Iran with light yellow and yellow primary tuber flesh color, a medium resistance to the most potato viruses and high yield potential in the early harvest. The virus-free potato plants, produced from virus-free minitubers of these cultivars, were cultured in the controlled conditions in pots containing soil, peat moss and fine sand with equal proportion (1:1:1). These plants were micro-propagated by single node culture in a hormone – free MS medium and the new single node explants provided from the regenerated plant were used for comparing the aeroponics system with conventional system for basic seed minituber production.

Plantlets were acclimatized under humid conditions and regenerated to small potato plants. Two cultivation systems (conventional soil and aeroponics) were performed. Aeroponics system was carried out in growth chamber by monitoring environmental factors (such as temperature, photoperiod, etc. This growth chamber had two twin culture spaces (120×100 cm) and the lower compartment was a closed container of 100 cm deep, which had a removable front panel for control and harvesting (Figure 1). The potato plantlets were fixed at a point via a pelaxi after performing two perpendicular cuts. About one-half to two-thirds of the stem length was placed inside the lower compartment. The pelaxi was covered with foil to prevent light from entering the dark compartment. Potato stems grew in the upper compartment while roots, stolons and tubers developed in the lower compartment in the dark condition. Plant root and stolon were periodically sprayed (every 20 min for 20 sec) with the nutrient solution. Nutrient solution was renewed weekly and plants were staked when necessary using a wire mesh (Table 1). Growth and development of root and stem in the aeroponics system are shown in Figure 2.

Table1. Nutrient solution used in aeroponics system

Element	First 35 days	After 35 days
K	200 ppm K	260 ppm K
N	190 ppm N	150 ppm N
Ca*	150 ppm Ca*	150 ppm Ca*
S*	70 ppm S*	92 ppm S*
Mg*	45 ppm Mg*	45 ppm Mg*
P	35 ppm P	35 ppm P
Fe	1.00 ppm Fe	1.00 ppm Fe
Mn	0.50 ppm Mn	0.50 ppm Mn
B*	0.50 ppm B*	0.50 ppm B*
Zn	0.15 ppm Zn	0.15 ppm Zn
Cu	0.10 ppm Cu	0.10 ppm Cu
Mo	0.05 ppm Mo	0.05 ppm Mo

Stems were grown under a 16 hours photoperiod and a matching thermo period (22 to 25 ºC light and 18 to 19 ºC dark) for the first 59 days. On day 60, photoperiod was set to 12 hours to promote a quicker tuber initiation (the plants were grown according to the condition reported by Farran and Mingo-Castel (2006). Relative humidity was kept constant at 50%. Plant densities were 100 plants per m^{-2} and harvesting intervals of 10 days were assessed. The two twin spaces available in the growth chamber were planted one at 10×10 cm spacing. Several traits including stem length, stem diameter and yield were measured. Stem diameter and yield

Figure 1. Growth chamber of the aeroponics system (right) and plantlets after transfer (left)

A

B

Figure 2. A: Growth and development of roots in the aeroponics system, B: Growth and development of stems in the aeroponics system

were measured. All tubers larger than 20 mm in size were removed at each harvest. Similar traits were measured in the conventional soil system in the greenhouse. Experiment was carried out as factorial based on completely randomized design layout with 10 replications. Potato cultivar (Agria, Marfona and Savalan) was regarded as the first factor and production system (AP, Aeroponics production system; SP, soil production system) as the second factor. The quality characters of the minitubers for both production systems (AP, SP), including minituber germination after the dormancy period, stem length and yield were measured.

Primary statistical analyses such as normality test (Kolmogorov-Smirnov test) and homogeneity of variances (Levene's test) were conducted. After analysis of variance, the means of treatment combinations were compared using least significant differences (LSD) procedure. All of the statistical analyses were carried out using SPSS version 14 (SPSS Institute, 2004).

Results and Discussion

The results of Kolmogorov-Smirnov normality test for four measured traits of minituber production systems (Table 2) indicated that all variables were normal. The results of Levene's test proved the assumption of homogeneity of variances (Table 2). Similar results were obtained for the quality characters as well (Table 3) Therefore, conventional parametric statistics were used to analyze the traits under study. According to the analysis of variance (Table 4), the main effects of cultivar and production system were highly significant at 0.01 probability level for stem length, root length, stem diameter and yield. Also the cultivar by production system interaction was highly significant at 0.01 probability level for stem length, root length and yield. The expressed variability of each trait estimated by coefficient of variation (CV) showed the lowest value

Table 2. Tests of normality and homogeneity of variances for measured traits of mini-tuber production system

Residual Normality		Stem Length (cm)	Root Length (cm)	Stem Diameter (mm)	Yield (minituber number/ plant)
Normal parameters	Mean	162.3	100.2	6.1	20.2
	Std. Deviation	29.91	25.73	2.50	11.19
Kolmogorov-Smirnov Z		1.04^{ns}	1.29^{ns}	1.25^{ns}	1.37^{ns}
Variances homogeneity					
	df 1	5	5	5	5
	df 2	54	54	54	54
Levene's statistic		2.15^{ns}	2.47^{ns}	2.81^{ns}	2.19^{ns}

^{ns} Non-significant at 0.05 probability level

Table 3. Tests of normality and homogeneity of variances for quality traits of minitubers which were produced in different production systems

Residual Normality		Germination (mm)	Stem Length (cm)	Yield (minituber number/ plant)
Normal Parameters	Mean	22.9	91.58	9.17
	Std. Deviation	2.93	10.27	3.54
Kolmogorov-Smirnov Z		1.08^{ns}	1.12^{ns}	0.94^{ns}
Variances Homogeneity				
	df 1	5	5	5
	df 2	54	54	54
Levene's Statistic		0.07^{ns}	3.28*	0.74^{ns}

^{ns},* Non-significant and significant at 0.05 probability level

Table 4. Analysis of variance for measured traits of the minituber production system based on factorial experiment

SOV	df	Stem length (cm)	Root length (cm)	Stem diameter (mm)	Yield (minituber number/ plant)
Cultivar (C)	2	11811.5**	438.8**	6.472**	503.7**
PS	1	27008.8**	31327.4**	348.968**	6020.0**
C × PS	2	430.1**	1006.4**	0.008^{ns}	83.7**
Error	54	24.0	89.6	0.148	3.5
CV		3.0	9.5	6.313	9.3

PS: Production System
^{ns} Non-significant, ** Significant at 0.01 probability level

(CV=3.0%) for stems length and the highest value (CV=9.5%) for root length (Table 4). The low CV values are the indication for good index of reliability.

Analyses of variance for the quality characters of the minitubers obtained from both production systems (Table 5) showed that none of the main effects of production system or cultivar ×

production system interactions were significant for germination, stem length and yield (Table 5). However, the main effect of cultivar was significant for stem length and yield. The lowest CV (CV=9.9%) belonged to stem length and the highest value (CV=22.1%) was obtained for yield (Table 5).

Table 5. Analysis of variance for quality traits of minitubers which produced in different production systems based on factorial experiment

SOV	df	Germination (mm)	Stem length (cm)	Yield (minituber number/ plant)
Cultivar (C)	2	0.65^{ns}	849.1**	255.6**
PS	1	0.27^{ns}	16.02^{ns}	1.67^{ns}
C × PS	2	7.62^{ns}	15.27^{ns}	2.12^{ns}
Error	54	9.05	83.00	4.10
CV		13.1	9.9	22.1

PS: Production System
^{ns} Non-significant, ** Significant at 0.01 probability level

The results of mean comparison through LSD procedure for both main effects and interactions are given in Table 6. Because of significant cultivar × production system for stem length, root length and yield, mean comparison of main effects were not mentioned. Mean comparison of treatment combinations (cultivar × production system) indicated that Agria cultivar had the highest stem length (211.70 cm) in the aeroponics production system and Savalan had the lowest stem length (121.70 cm) in the soil production system. The results showed that the aeroponics production system was better than the soil production system for all of the three potato cultivars considering stem length (Figure 2B). It has been shown that stem length in aeroponics was longer than using the other systems (Kang *et al.* 1996; Farran and Mingo-Castel 2006). Savalan as an early cultivar had higher vegetative growth and delayed mini-tuber production in the aeroponics system as compared to other cultivars. Furthermore, Marfona had the highest root length (134.60 cm) in the aeroponics production system (Table 6). These findings are in agreement with the results of Figure 2A which indicate that the aeroponics production system resulted in longer root length than the soil production system in all studied cultivars. Aeroponics production system optimizes root aeration, as a major factor, leading to a yield increase as compared to classical production systems (Softer and Burger 1988). Kang *et al.* (1996) declared that a long growth period before mini-tuber production maybe seen due to increase of nitrogen supply in the aeroponics system. Also, delay in minituber production may be seen when the stolons do not encounter mechanical stress in the aeroponics system compared to the other production systems (Lugt *et al.* 1964; Farran and Mingo-Castel 2006).

Table 6. Mean comparison for the main effect of cultivar (Agria, Marfona and Savalan) and the production system (AP, airoponic production; SP, soil production), and treatment combinations for measured traits of minituber production system

Cultivar	Production system	Stem length (cm)	Root length (cm)	Stem diameter (mm)	Yield (minituber number/ plant)
Agria		186.45 A	101.65 A	5.66 B	14.90 C
Marfona		162.65 B	103.90 A	6.73 A	24.90 A
Savalan		137.85 C	94.90 B	5.87 B	20.65 B
	AP	183.53 A	123.00 A	8.50 A	30.17 A
	SP	141.10 B	77.30 B	3.67 B	10.13 B
Agria	AP	211.70 A	122.60 B	8.07 B	24.30 C
Agria	SP	161.20 C	80.70 D	3.24 D	5.50 E
Marfona	AP	184.90 B	134.60 A	9.12 A	37.20 A
Marfona	SP	140.40 E	73.20 D	4.34 C	12.60 D
Savalan	AP	154.00 D	111.80 C	8.30 B	29.00 B
Savalan	SP	121.70 F	78.00 D	3.44 D	12.30 D

In each category and trait, means with different letters are significantly different at 0.05 probability level.

Marfona with the mean stem diameter of 6.73 mm was better than other cultivars and the aeroponics production system with the mean of 8.50mm was better than the soil production system (Table 6). The aeroponics production system had higher stem diameter than the soil production system in potato cultivars (Figure 5A). The highest minituber yield (37.20 per plant) was obtained for Marfona in the aeroponics production system while the lowest yield (5.50 per plant) was realized for Agria in the soil production system. Again the aeroponics production system had better yield than the soil production system in all of the three potato cultivars (Figure 5B). Our finding about the superiority of the aeroponics production system is in agreement with Ritter *et al.* (2001) who showed that the aeroponics system for producing potato minitubers improved the yield production.

Although the cultivar maturity could affect the duration of minituber production, but potato plantlets in the aeroponics production system were produced with sequential harvesting. This result could be due to the removal of the dominant large minitubers, which permits initiation of new minituber formation and the development of the existing minitubers (Lonmlen and Struik 1992). It is clear that the aeroponics production system improved all of the measured potato traits in comparison to the soil production system. Also, Marfona could be regarded as the most favorable genotype regarding most of the studied traits. The yield of Marfona in the aeroponics production system was almost three times higher than the soil production system (37.20 and 12.60 minituber per plant, respectively).

The mean comparisons for quality characters of the minitubers from both production systems showed that Agria had the longest (99.05 cm) and Marfona and Savalan had the shortest stem length. Furthermore, Marfona had the highest yield potential than Agria and Savalan (Table 7). It seems that Marfona could be considered as the most favorable genotype due to high performance in mini-tuber production and having better quality characters after cultivation.

Table 7. Mean comparison for the main effect of cultivar (Agria, Marfona and Savalan) for quality traits of minitubers which were produced in different production systems

Cultivar	Production system	Germination (mm)	Stem length (cm)	Yield (minituber number/ plant)
Agria		22.75 A	99.05 A	5.15 C
Marfona		23.10 A	87.05 B	12.00 A
Savalan		22.85 A	88.65 B	10.35 B

In each column, means with different letters are significantly different at 0.05 probability level

Soil-less systems for production of different crops has several benefits compared with the soil production system. Hydroponics system results in higher production in different crops (Resh 1978) and nutrient film techniques or NFT (Cooper 1979) have produced higher yield for tomatoes (Gysi and von Allmen 1997). The results presented here show that aeroponics production system could be a proper system for potato minitubers production. Minitubers produced were healthy, free of infections especially for virus disease. However, many aspects of aeroponics production system have to be studied in order to optimizing of this minituber producing method. Also, some other important considerations must be addressed for a commercial system of mini-tuber production. A fully automatic system monitoring both nutrient solution and dynamic environmental parameters seems desirable. In addition, in order to recommend the aeroponics production system for large-scale minituber production an economic evaluation is need. The aeroponics production system must be equipped with appropriate high-tech security devices to control pumping, spraying and chemical properties. The cost of these facilities and manual harvesting of potato minitubers must be economically studied.

Among the cultivars under study, Marfona was the most favorable genotype regarding most of the studied traits and produced about three times higher yield in the aeroponics production system as compared to the soil production system. Marfona had short stem lengths in both producing and evaluating stages. It seems that, this difference is due to the nature of the genotypes and does not dependent to growth stages or environmental conditions. This cultivar had also good quality characters for the obtained minitubers and exhibited the highest yield performance. In conclusion, our results presented here showed that the aeroponics production system can be a proper system for producing potato minitubers under climatic conditions of Iran.

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