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BASIC AREA - Article

Electrical conductivity of the nutrient solution and plant density in aeroponic production of seed potato under tropical conditions (winter/spring)

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ABSTRACT: The recent introduction in Brazil of production of quality seed potatoes in hydroponic systems, such as aeroponics, demands studies on the nutritional and crop management. Thus, this study evaluated the influence of electrical conductivity of the nutrient solution and plant density on the seed potato minitubers production in aeroponics system. The Agata and Asterix cultivars were produced in a greenhouse under tropical conditions (winter/spring). The experimental design was a randomized block in a split-split plot design. The plot consisted of 4 electrical conductivities of the nutrient solution (1.0; 2.0; 3.0; and 4.0 dS·m^{-1}); the subplot, of 4 plant densities (25; 44; 66; and 100 plants·m^{-2}); and the subsubplot, of the 2 potato cultivars (Ágata and Asterix), totaling 4 blocks. The 2.2 and 2.1 dS·m^{-1} electrical conductivities yielded the highest productivity of seed potato minitubers, for Ágata and Asterix cultivars, respectively, regardless of plant density. For both cultivars, the highest yield was observed for the 100 plants·m^{-2} density.

Key words: *Solanum tuberosum* L., greenhouse, pre-basic seed potato, soilless production, spatial arrangement, plant nutrition.

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INTRODUCTION

High yields of potato (*Solanum tuberosum* L.) in the field start with the production and use of high-quality seed potato. In Brazil, the key to this process is to increase the multiplication rate and availability of propagation material of good quality, which can reduce production costs and increase the competitiveness against the imported seed potato.

Historically, the country is not self-sufficient in seed potato production, and much is still imported. In 2014, 6,256 tons amounting to US$ 7,597,751 were imported from the Netherlands (60%), Argentina (14%), Canada (7%), United States (6%), Chile (5%) and other countries (8%) (Aliceweb 2015). Besides the high cost and dependence on propagation material from other countries, there is the risk of introducing exotic-pathogenic organisms in the country. Thus, it is essential to search for strategies to reduce dependence on imported material and increase the quality of the national basic seed potato.

In Brazil, however, almost all production of seed potato minitubers is planted in pots/boxes in agricultural substrates, with low yields, on average 3 to 7 units per plant (Daniels et al. 2000). In addition to low multiplication, the high use of labor and plant health problems linked to substrate reuse impact negatively the traditional production of seed potato minitubers.

Recently, the use of hydroponic systems is becoming one of the main strategies for producing seed potato. The NFT system (Nutrient Film Technique) has demonstrated excellent results (Boersig and Wagner 1988; Novella et al. 2008; Corrêa et al. 2008). However, Wheeler et al. (1990) reported that this system can injure the tuber periderm due to the salt accumulation on the surface of the organ, from the nutrient solution. Tibbitts and Cao (1994) found that the tuber initiation is lower in solid medium systems compared to porous ones.

In contrast, the aeroponics system stands out since it can achieve yields of up to 49 minitubers per plant, besides the repeated harvesting of tubers, which facilitates the standardization and marketing planning (Ritter et al. 2001; Factor et al. 2007; Otazú 2010).

The aeroponics system consists of adequate supply, continuous or not, of nutritive solution to the plant roots into small particles (mist), so that they remain suspended in the air, in a dark environment, without hindering growth (Ritter et al. 2001; Farran and Mingo-Castel 2006; Chiipanthenga et al. 2012). The repeated harvesting allows collecting minitubers of the desired size (Ritter et al. 2001). Furthermore, the non-destructive harvest that starts at the beginning of tuber initiation allows other stolons to start tuberization thus increasing the multiplication rate per plant several times (Lommen and Struik 1992).

To date, the aeroponics system is the most suitable technique for the production of seed potato minitubers. The main disadvantages of the system are the vulnerability to power outage (Farran and Mingo-Castel 2006; Chang et al. 2012), high cost of investment (Mateus-Rodriguez et al. 2013), and the lack of knowledge regarding system's adoption and operation.

In Brazil, very few producers have adopted the aeroponics system due to the lack of research and technical information. The few operating systems work on a trial and error basis, without any scientific support.

Therefore, several aspects of this technique have yet to be investigated and improved to support producers and companies specialized in the production of seed potato in the country. Among them, it is necessary to determine the optimal composition of the nutrient solution for different cultivars and developmental stage, planting density and number of harvests along the growth cycle, and the interaction between these factors (Rolot and Seutin 1999; Ritter et al. 2001).

Defining the best electrical conductivity (EC) of the nutrient solution is essential to reach the full potential of seed potato production. The EC reflects the total ion concentration in the nutritive solution while it affects the absorption of nutrients, plant growth, productivity and quality of tubers (Chang et al. 2011). The ideal composition of a nutrient solution depends not only on the concentrations of nutrients but also on other factors linked to cultivation, including the type of hydroponic system, environment, phenological stage, plant species and cultivars (Furlani et al. 1999).

The study on plant density is essential to achieve higher production of seed potato minitubers in a crop cycle. In addition, the potato cultivars respond differently to the minituber number and weight relationship, depending mainly on the spatial arrangement of plants (Santos and Rodriguez 2008).

Given the above, this study evaluated the influence of the electrical conductivity of the nutrient solution and

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plant density on the production of seed potato minitubers for Ágata and Asterix cultivars using the aeroponics system, under winter/spring conditions and at average altitude of northeastern São Paulo.

MATERIAL AND METHODS

The weather conditions and altitude, in northeastern São Paulo, allow producing seed potato during 2 growing seasons only (fall/winter and winter/spring).

Thus, the experiment was carried out from June to September 2014 (winter/spring), in the second growing season, in an area of the Agência Paulista de Tecnologia dos Agronegócios (APTA), Polo Regional Nordeste Paulista, located at lat 21°26′52.51′′S; long 46°59′07.89′′W, and 665 m average altitude, in Mococa (SP), Brazil.

The aeroponics system adopted was initially described by Factor et al. (2007), but adapted for commercial production conditions, according to Calori et al. (2014) (Figures 1,2). The system was installed inside a greenhouse (without climatic control) of arch type, with 8.0 × 21.0 m (168.0 m^2), 4.0 m ceiling height, and covered with 150-µm thick polyethylene film and anti-aphid side screen.

The experimental design was a split-split plot randomized block, in which the plots (4.4 m^2) consisted of 4 electric conductivities (EC) of the nutrient solution (1.0, 2.0, 3.0, and 4.0 dS.m^{-1}). The subplot (1.1 m^2) consisted of 4 planting densities (25, 44, 66 and 10 plants.m^{-2}), with row spacing of 0.2 × 0.2; 0.15 × 0.15; 0.1 × 0.15; and 0.1 × 0.1 m; the subsubplot (0.5 m^2) consisted of the 2 potato cultivars (Ágata and Asterix), totaling 4 blocks.

The Ágata and Asterix cultivars were used because the tuber shape and skin color are different, facilitating the harvesting and separation in aeroponics, being among the main genotypes currently grown in the

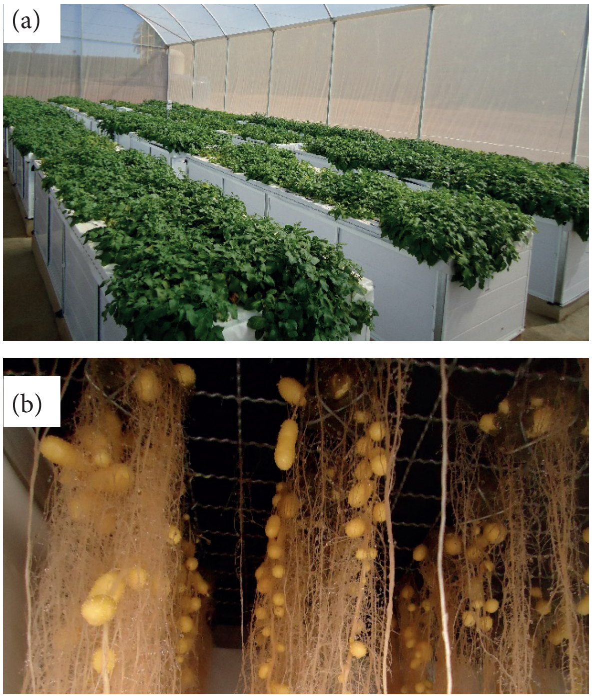
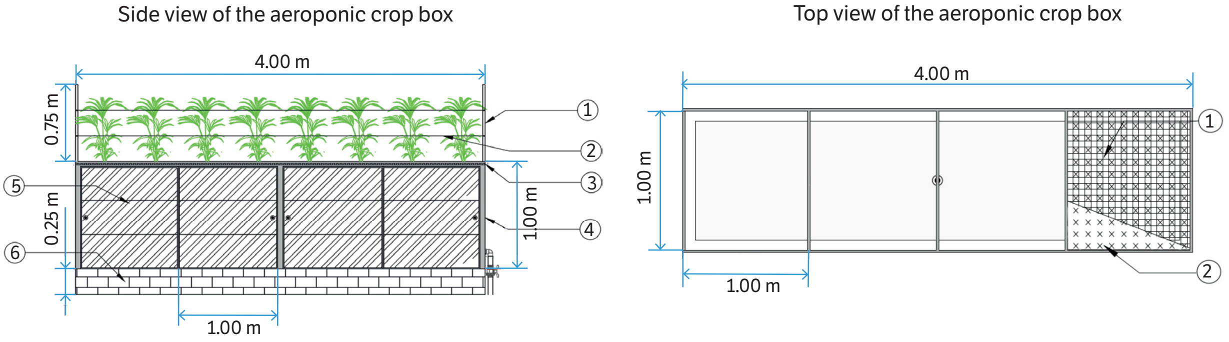


Figure 2. (a) Top view of the crop boxes with the cultivars Ágata and Asterix; (b) Internal view of the crop boxes displaying the roots and stolons of potato plants in full tuberization.



1. Attachment steel brackets
2. Nylon fabric for directing the plants
3. Aluminum profile set with steel spring used for attaching the double-sided plastic
4. Galvanized steel structure
5. Sliding windows
6. Masonry structure

1. Detail of galvanized steel screen
2. Detail of the double-sided polyethylene film

Figure 1. The aeroponics system proposed by Calori et al. (2014). Scale 1:1.

country, commercialized *in natura* and as pre-frozen fries, respectively.

The used nutrient solution was proposed by Factor et al. (2007) and recommended for the cultivation of potatoes in hydroponics with the following nutrient concentrations: 145; 29; 40; 295; 162; 40; 64; 2.0; 0.3; 1.0; 0.3; 0.05; and 0.05 mg·L^{-1} of NO^{-}_{3}, NH_{4}^{+}, P, K, Ca, Mg, S, Fe, Zn, Mn, B, Cu, and Mo, respectively, and EC of approximately 2.0 dS·m^{-1}. Three additional concentrations were prepared and calculated using the 0.5; 1.5; and 2.0 coefficients from the original solution to obtain the different electrical conductivities studied (1.0; 2.0; 3.0; and 4.0 dS·m^{-1}).

The EC was measured daily using a portable digital device (Combo HI 98130 - Hanna®) and corrected when the measured values were 0.1 dS·m^{-1} above or below the initial value. In the first case, water was added to the solution for correction and, in the second, additional volume of nutrient stock solution was added with the same nutrient proportion of the original solution. The pH of the nutrient solution was maintained in the range of 5.5 to 6.5 by adding 6N sulfuric acid or 1N sodium hydroxide.

Seedlings of the Ágata and Asterix cultivars derived from tissue culture laboratory (Center for Horticulture of the Agronomic Institute) were transplanted 20 days after pricking out, with 5.0 cm average height and about 2 leaves. The transplant was performed on June 25, 2014, in phenolic foam (0.05 × 0.05 × 0.038 m) and acclimatized on floating-type benches, covered with shade cloth (30%), simulating a mini-greenhouse (3.0 × 3.0 × 2.0 m dimensions) to allow better rooting. The final transplantation to the aeroponics system was carried out 15 days after the seedlings were placed in phenolic foam (DAT). The experiment lasted 95 DAT.

The nutritional status of the plants was evaluated by sampling 1 leaf (third leaf) from the apical tuft, following the recommendation of Trani and van Raij (1997) at 30 DAT. In addition to the nutritional status, the following growth characteristics were evaluated: (a) plant height (PH) (cm); (b) number of stems·plant^{-1} (NS); (c) number of leaves·plant^{-1} (NL); and minitubers production: (d) number of minitubers·plant^{-1} (NMP); (e) number of minitubers·m^{-2} (NMM2), calculated for the area of the aeroponics system (70.4 m^{2}).

The plant growth assessments (a, b, and c) were carried out up to the shoot apex development, observed at 67 DAT. These characteristics were evaluated in samples of 3 plants from each subsubplot, i.e. each treatment.

The production of minitubers (d and e) was evaluated every 7 days, from tuber initiation, observed at 45 DAT. The data of these assessments correspond to the total production of minitubers; samplings were not performed. At harvest, the minitubers in the range of 30 mm of the transverse diameter were harvested, as recommended by Medeiros et al. (2002).

To complement the results, economic feasibility analysis was performed for the different plant densities (25; 44; 66; and 100 plants·m^{-2}) and for both cultivars, according to Mateus-Rodriguez et al. (2013).

The daily average values of temperature (°C) and relative humidity (%) were recorded, using a mini-weather station (model 2470 — Spectrum®). The sensors were positioned at the center of the greenhouse at 1.5 m height.

The results were submitted to analysis of variance and F-test. No interactions were observed between the EC treatments, plant density, and cultivars, but isolated effects were verified for each source of variation. Thus, these were analyzed separately. The nutrient solution EC effect was evaluated by regression analysis, adopting, as a criterion for model selection, the magnitude of the regression coefficients (R^{2}) and their biological significance. Plant density data was submitted to Tukey's test ($p > 0.05$). The statistical software used for analysis of variance was the Project R version 2.15. The regression graphs were prepared using the Origin Pro version 8.

RESULTS AND DISCUSSION

The average temperature during the experimental period was 23 °C, with 33 and 15 °C average maximum and minimum, respectively. The average relative humidity was 52%, with 85 and 22%, representing the maximum and minimum averages, respectively (Figure 3). Similarly to other regions of southeastern Brazil, the winter/spring of the northeastern São Paulo state, in 2014, was considered quite unusual, marked by high temperatures and low humidity.

The average maximum temperature was above 30 °C in most of the experimental period. High temperatures not only reduce the synthesis of photoassimilates and increase maintenance respiration, but also reduce the

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translocation to the tubers as a result, decreasing yield and reducing the tuber dry matter. Complete inhibition of net photosynthesis may happen for temperatures above 30 °C (Burton 1972). Yield reduction of 1% was observed for every 1 °C increase in temperature, between 15 and 25 °C. Furthermore, the productivity of tubers at 30 °C is half of that at 20 °C and even lower than that at 10 °C (Bisognin and Streck 2009).

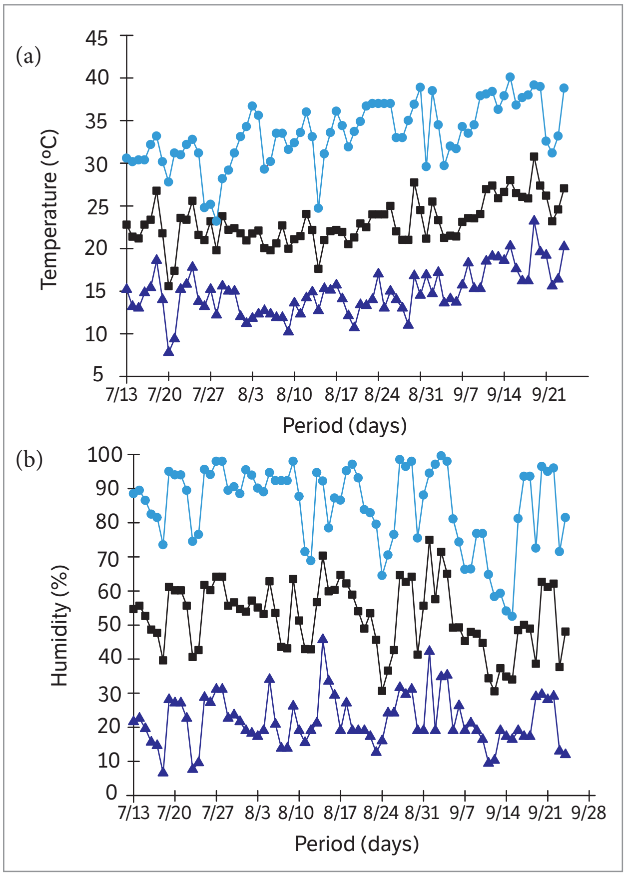

Figure 3. (a) Temperature (°C); (b) Relative humidity (%) during the experimental period (winter/spring).

No significant interaction was observed between the treatments for all analyzed characteristics. Thus, the results are shown and discussed separately.

Electrical conductivity of nutrient solution

For both potato cultivars, foliar nutrient content was significantly influenced by the nutrient solution EC (Table 1). For most of the nutrients, increasing EC increased the foliar content, except for K, which was the opposite. Potassium influences plant osmotic regulation, especially as counter-ions of inorganic anions such as chloride and nitrate (Epstein and Bloom 2006). Thus, the increase in nitrogen levels may have contributed to the reduction of leaf potassium levels (Table 1), also verified by Resende et al. (2009). According to Savvas e Adamidis (1999), large amounts of nutrients in the nutrient solution can lead to osmotic stress and ions toxicity, as suggested by the means for higher EC (4.0 dS·m^{-1}) (Table 1).

Despite the influence of the EC on the foliar nutrients, the values remained within the range recommended by Lorenzi et al. (1997). The exceptions were sulfur (6.9 g·kg^{-1}) in the 4.0 dS·m^{-1} EC for 'Asterix', above the suggested value (2.5 to 5.0 g·kg^{-1}), and nitrogen (39 g·kg^{-1}) in the 1.0 dS·m^{-1} EC for 'Ágata', below the value recommend by the same authors (40 – 50 g·kg^{-1}) (Table 1), which was confirmed by the yellowing of older leaves (chlorosis) in this treatment. The N is directly related to plant growth and shoot development, i.e. the deficiency of N commonly causes pale and yellowish leaves (Epstein and Bloom 2006).

Regarding the growth characteristics, the EC significantly affected all growth variables (PH, NS, and NL) of both cultivars (Figure 4). For 'Ágata', PH increased as EC increased up to 2.2 dS·m^{-1}, and the highest value

Table 1. Foliar content of macronutrients for the cultivars Ágata and Asterix, 30 DAT, for the studied electrical conductivities of the nutrient solution.

EC (dS·m^{-1})	Nutrient											
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
	g·kg^{-1}						g·kg^{-1}					
	'Ágata'						'Asterix'					
1.0	39	4	54	17	3	3	42	4	46	18	3	5
2.0	46	5	59	15	3	3	49	5	40	17	3	4
3.0	46	5	50	15	3	3	51	5	40	17	3	4
4.0	48	5	47	17	3	6	55	6	37	18	3	7
F-test	**	**	**	*	ns	**	**	**	**	*	ns	**

**Significant ($p < 0.01$); *Significant ($p > 0.05$); EC = Electrical conductivity; ns = Non-significant.

observed was 42.9 cm (Figure 2a), with a subsequent decrease, fitting a quadratic polynomial regression model. The same trend was observed for the NS and NL variables, with the highest values of 4.4 and 41.5 cm, respectively, for the 2.3 dS·m^{-1} EC (Figure 4b,c).

For the Asterix cultivar, the highest PH (40.7 cm) was observed for the 2.6 dS·m^{-1} EC (Figure 4a). The maximum NS and NL values were 2.9 and 34.6, respectively, for 2.9 dS·m^{-1} EC (Figures 4b,c). The largest EC values may be related to increased nutritional requirements of 'Asterix' cultivar compared to 'Ágata' (Table 1), supported by Fernandes et al. (2011) in their nutrient absorption studies and highlighted by Chang et al. (2005). These authors stated that the optimal response to EC might differ between cultivars.

On the other hand, the greater development of the shoot of the 'Asterix' cultivar for increasing EC did not necessarily increased tuber multiplication rate, as the largest values of 20.4 for NMP and 1,014.4 for NMM2 were obtained for 2.3 and 2.1 dS·m^{-1} ECs, respectively (Figure 5a,b). The contrast between ECs that provided greater plant growth and tuber yield can be related to nitrogen metabolism. In the potato crop, several factors have been shown to affect the formation of the tuber, especially nitrogen levels, temperature, and light (Jackson 1999). In early stages, the N may favor the development of the shoot, but excess N at the time of tuberization can prevent tuber initiation and filling (Oparka et al. 1987; Goins and Yorio 2004). In addition, the high temperatures that occurred during the experimental period (Figure 3) may have favored the synthesis of gibberellin (Figueiredo-Ribeiro et al. 2004), reducing tuberization and the number of tubers per plant (Tavares and Lucchesi 1999). The increased air temperature is sufficient to modify the length of the developmental stages of the potato cultivar 'Asterix' (Streck et al. 2006) as well as its productivity.

Furthermore, 'Ágata' cultivar had the highest averages, 33.0 for NMP and 1,723.0 for NMM2 in the 2.2 dS·m^{-1} EC (Figure 5a,b). Novella et al. (2008) also observed a quadratic polynomial effect for different ECs used to produce seed potato minitubers of the cultivar 'Macaca' in aeroponics system, but the best productivity responses were obtained in the range of 2.8 to 3.0 dS·m^{-1} EC. On the other hand, Chang et al. (2011) obtained the best results for lower EC (1.8 dS·m^{-1}) for the cultivar 'Haryeong', also in aeroponics. Moreover, Müller et al. (2007), in a hydroponics system, used sand as substrate and obtained, on average, 435.0 minitubers·m^{-2} in 2.5 dS·m^{-1} EC, similarly to the value of EC obtained in this study.

Plant density

Different plant densities affected significantly plant growth variables, especially PH and NL for cultivar Ágata and NS for cultivar Asterix (Table 2).

The highest NL values were obtained at lower plant densities (25 to 44 plants·m^{-2}) for 'Ágata' while the highest

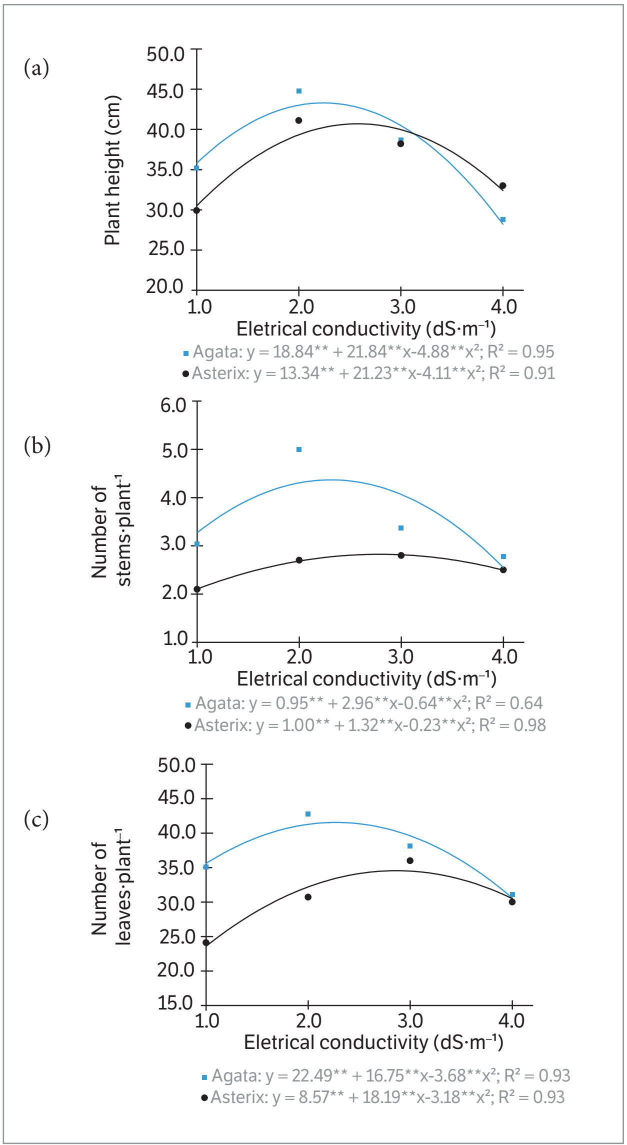

Figure 4. (a) Plant height; (b) Number of stems per plant; (c) Number of leaves per plant for the studied ECs of the potato cultivars Ágata and Asterix grown in aeroponics.

NS values were also observed at lower densities (25; 44; and 66 plants·m^{-2}) for the cultivar Asterix. The opposite effect was observed for the variable PH for cultivar Ágata, when the greatest height, 40.8 cm, was observed in the highest density (100 plants·m^{-2}), statistically different from the other densities.

This inverse effect between PH × NL and NS may be attributed to the high-density cultivation, i.e. as the density is increased, intraspecific competition also increased, especially for light, causing most of the photoassimilates to be directed to stem elongation in detriment of leaf emergence (Oliveira 2000). Increased plant height at the expense of the number of leaves at higher densities has also been verified by Dellai et al. (2005) for the cultivar Macaca grown in field conditions.

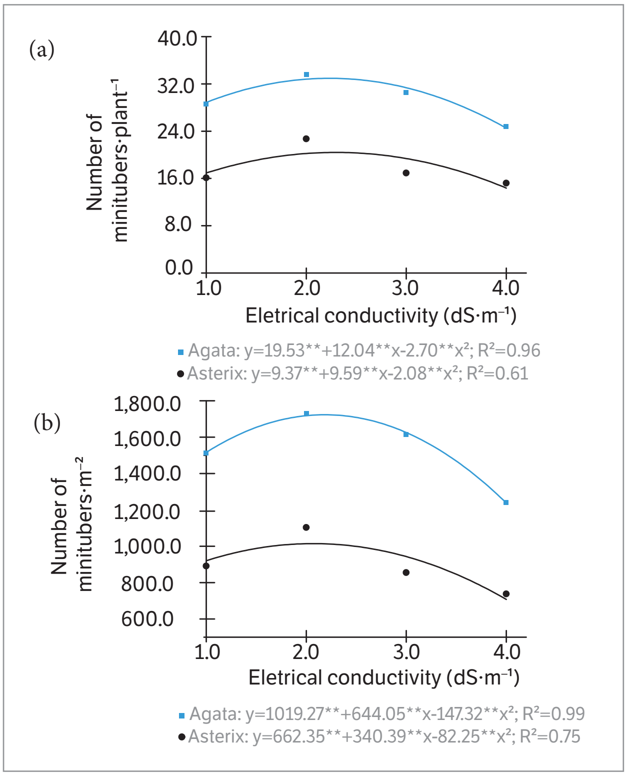

Figure 5. (a) Number of minitubers per plant; (b) Number of minitubers per m2 for the studied ECs of the cultivars Ágata and Asterix grown in aeroponics.

Regarding minituber production, higher average NMP were obtained at lower density (25 plants·m^{-2}) for both cultivars Asterix (27.0) and Ágata (38.3), but did not differ from the density of 44 plants·m^{-2}. Larger numbers of tubers per plant were also obtained for lower plant densities by Abdullateef et al. (2012) in aeroponics, Santos and Rodriguez (2008) in pots, as well as Kim et al. (2008) and Corrêa et al. (2007) in boxes containing substrates.

The results for NMP obtained in this study are higher than those reported by Tierno et al. (2014), 12.5 NMP for the cultivar Monalisa, and lower than those observed by Factor et al. (2007), 40.3 and 46.6 NMP for 'Ágata' and Asterix cultivars, respectively, both in aeroponics system. It is noteworthy, however, that the aeroponics system of this research is larger than the prototype described by Factor et al. (2007) and, therefore, closer to the commercial systems used and feasible to be adopted by the productive sector without many adaptations. Also, during the trial period, the temperatures, especially maximum, were above those recommended for potato culture (Figure 2) according to Burton (1972), which may have contributed to the lower yield of seed potato minitubers obtained in this study.

As for NMM2, higher yields were obtained at the highest density (100 plants·m^{-2}) for both Asterix (1,240.4) and Ágata (1,942.5) cultivars, but did not differ from the density of 66 plants·m^{-2} (Table 3). Although not significant, the difference of 277.4 NMM2 (66 to 100 plants·m^{-2}) is sufficient to cover expenses and generate a positive balance of US$ 8,943.22 (MRR — 25%) for the highest density (Table 4). In addition, for both cultivars, the highest plant density (100 plants·m^{-2}) provided higher internal rate of return (IRR) and shorter payback period (simple and discounted payback) compared with other densities (25; 44; and 66 plants·m^{-2}). Also, the higher plant density was the only economically feasible for the Asterix cultivar (Table 4). It is important to note, however, that the economic figures presented here are the data relative to a single crop cycle. At high altitudes 1,000 m and mild temperatures, it is possible to

Table 2. Plant height, number of stems per plant and number of leaves per plant for plant density of the potato cultivars Ágata and Asterix grown in aeroponics .

Density (plants·m^{-2})	Características					
	PH (cm)	NS	NL	PH (cm)	NS	NL
	‘Ágata’			‘Asterix’		
100	40.8 a[1]	3.1	30.4 b	35.7	2.0 b	26.0
66	38.2 b	3.1	31.0 b	35.8	2.7 a	29.6
44	35.1 c	3.9	39.1 ab	36.6	2.7 a	32.0
25	33.3 d	4.1	46.7 a	34.1	2.8 a	33.2
F-test	176.0**	3.9	948.4**	17.4	1.9**	161.9
CV (%)	4.4	33.0	25.5	16.5	21.7	34.7

[1] Means followed by the same letter in the column do not differ by Tukey's test ($p > 0.05$); **Significant ($p < 0.01$). CV = Coefficient of variation; PH = Plant height; NS = Number of stems per plant; NL = Number of leaves per plant.

produce up to 3 crop cycles per year, which would certainly contribute to maximize the economic return. The results of the economic study observed for the Ágata cultivar at higher plant density were similar to those reported by Mateus-Rodriguez et al. (2013) in Peru and Ecuador. According to Karafyllidis et al. (1997), a higher number of minitubers and productivity are expected at high densities compared to lower ones. However, the density increase is beneficial up to the moment when competition and damage to plant development are not very high, since, after that, productivity decreases, a fact that was not observed in this research.

Table 3. Number of minitubers per plant and number of minitubers per m^2 for plant density of the cultivars Ágata and Asterix grown in aeroponics.

Densidades (plantas·m^{-2})	Variables			
	NMP	NMM2	NMP	NMM2
	‘Ágata’		‘Asterix’	
100	19.3 c	1.942.5 a	12.4c[1]	1.240.4a
66	26.3 b	1.665.1 ab	12.9bc	849.1b
44	33.7 a	1.483.8 b	18.6b	820.6b
25	38.3 a[1]	1.006.5 c	27.0a	675.5b
Teste F	835.1**	1.857.951.9**	20.4**	15.9**
CV (%)[2]	14.9	19.8	29.4	23.4

[1] Means followed by the same letter in the column do not differ by Tukey’s test ($p > 0.05$); **Significant ($p < 0.01$); *Significant ($p < 0.05$). NMP = Number of minitubers per plant; NMM2 = Number of minitubers per m2; CV = Coefficient of variation.

The productivity results obtained in this study were higher than the values reported by Factor et al. (2007) (874.0 minitubers·m^{-2}) and Farran and Mingo-Castel (2006) (802.0 minitubers·m^{-2}) in aeroponics, in the densities of 44 and 60 plants·m^{-2}, respectively.

CONCLUSION

The highest productivity of seed potato minitubers was observed for 2.2 and 2.1 dS·m^{-1} EC of the nutrient solution for the potato cultivars Ágata and Asterix, respectively, regardless of plant density.

For both cultivars, the density of 100 plants m^{-2} provided the greatest productivity (NMM2) and economic viability of production.

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Table 4. Economic indicators for the studied plant densities of the cultivars Ágata and Asterix grown in aeroponics (additional content).

Economic indicators	Plant density (plants·m^{-2})							
	100	66	44	25	100	66	44	25
	‘Ágata’				‘Asterix’			
IRR (%) – 10% per year	37	28	24	9	13	2	2	–2
NPV (US$)	44,588.08	35,644.86	29,765.26	10,373.48	13,658.08	–302.85	548.94	3,943.92
PBS (years)	1.8	2.1	2.3	3.4	3.1	4.6	4.5	5.3
DPBP (years)	2.5	3.0	3.4	5.1	4.3	6.5	6.3	7.5
MRR (%)	25	20	187	--	4.610	–155	114	--

IRR = Internal rate of return; NPV = Net present value; PBP = Simple payback; DPBP = Discounted payback period 10% per year; MRR = Marginal rate of return, calculated based on NPV; 1US$ 1.00 = R$ 3.89, exchange rate on 03/02/2016.

REFERENCES

Abdullateef, S., Bohme, M. H. and Pinker, I. (2012). Potato minituber production at different plant densities using an aeroponic system. Acta Horticulturae, 927, 429-436. http://dx.doi.org/10.17660/ActaHortic.2012.927.53.

Análise das Informações de Comércio Exterior (2015). Ministério, Indústria e Comércio Exterior, Secretaria de Comércio Exterior; [accessed 2015 Dec. 27]. http://aliceweb.mdic.gov.br/

Bisognin, D. A. and Streck N. A. (2009). Desenvolvimento e manejo das plantas para alta produtividade e qualidade da batata. Itapetininga: Associação Brasileira da Batata.

Boersig, M. R. and Wagner, S. A. (1988). Hydroponic system for production of seed tubers. American Potato Journal, 65, 470-471.

Burton, W. G. (1972). The response of potato plant and tuber to temperature. In A. R. Rees, K. E. Cockshull, D. W. Hand and R. G. Hurd (Eds.), Crop processes in controlled environments (p. 217-233). New York: Academic Press.

Calori, A. H., Factor, T. L., Feltran, J. C. and Purquerio, L. F. V. (2014). Aeroponia pode inovar a produção de minitubérculos de batata no Estado de São Paulo. O Agronômico, 43-51, 64-66.

Chang, D. C., Cho, I. C., Suh, J. T., Kim, S. J. and Lee, Y. B. (2011). Growth and yield response of three aeroponically grown potato cultivars (*Solanum tuberosum* L.) to different electrical conductivities of nutrient solution. American Journal of Potato Research, 88, 450-458. http://dx.doi.org/10.1007/s12230-011-9211-6.

Chang, D. C., Park, C. S., Kim, S. Y. and Lee, Y. B. (2012). Growth and tuberization of hydroponically grown potatoes. Potato Research, 55, 69-81. http://dx.doi.org/10.1007/s11540-012-9208-7.

Chang, D. C., Park, C. S., Lee, J. G., Lee, J. H., Son, J. M. and Lee, Y. B. (2005). Optimizing electrical conductivity and pH of nutrient solution for hydroponic culture of seed potatoes (*Solanum tuberosum*). Journal of the Korean Society for Horticultural Science, 46, 26-32.

Chiipanthenga, M., Maliro, M., Demo, P. and Njoloma, J. (2012). Potential of aeroponics system in the production of quality potato (*Solanum tuberosum* l.) seed in developing countries. African Journal of Biotechnology, 17, 3993-3999. http://dx.doi.org/10.5897/AJB10.1138.

Corrêa, R. M., Pereira-Pinto, J. E. B., Pereira-Pinto, C. A. B., Faquin, V., Reis, E. S., Monteiro, A. B. and Dyer, W. E. (2008). A comparison of potato seed tuber yields in beds, pots and hydroponic systems. Scientia Horticulturae, 17-20. http://dx.doi.org/10.1016/j.scienta.2007.10.031.

Corrêa, R. M., Pereira-Pinto, J. E. B., Reis, E. S., Monteiro, A. B., Pinto, C. A. B. P. and Faquim, V. (2007). Densidade de plantas e métodos de colheita na multiplicação de batata-semente em vasos. Horticultura Brasileira, 25, 270-274. http://dx.doi.org/10.1590/S0102-05362007000200028.

Daniels, J., Pereira, A. S. and Fortes, G. R. L. (2000). Verticalização da produção de batata-semente por produtores de agricultura familiar no Rio Grande do Sul. Pelotas: Embrapa Clima Temperado.

Dellai, J., Trentin, G., Bisognin, D. A. and Streck, N. A. (2005). Filocrono em diferentes densidades de plantas de batata. Ciência Rural, 35, 1269-1274. http://dx.doi.org/10.1590/S0103-84782005000600007.

Epstein, E. and Bloom, A. (2006). Nutrição mineral de plantas: princípios e perspectivas. Londrina: Editora Planta.

Factor, T. L., Kawakami, F. P. C. and Iunck, V. (2007) Produção de minitubérculos básicos de batata em três sistemas hidropônicos. Horticultura Brasileira, 25, 82-87. http://dx.doi.org/10.1590/S0102-05362007000100016.

Farran, I. and Mingo-Castel, A. (2006). Potato minituber production using aeroponics: effect of plant density and harvesting intervals. American Journal of Potato Research, 83, 47-53. http://dx.doi.org/10.1007/BF02869609.

Fernandes, A. M., Soratto, R. P. and Silva, B. L. (2011). Extração e exportação de nutrientes em cultivares de batata: I – Macronutrientes. Revista Brasileira de Ciência do Solo, 35, 2039-2056.

Figueiredo-Ribeiro, R. C. L., Chu, E. P. and Almeida, V. P. (2004). Tuberização. In G. B. Kerbauy (Ed.), Fisiologia vegetal. Rio de Janeiro: Editora Guanabara.

Furlani, P. R., Silveira, L. C. P., Bolonhezi, D. and Faquin, V. (1999). Cultivo hidropônico de plantas. Campinas: Instituto Agronômico.

Goins, G. D. and Yorio, N. C. (2004). Influence of nitrogen nutrition management on biomass partitioning and nitrogen use efficiency indices in hydroponically grown potato. Journal of the American Society for Horticultural Science, 129, 134-140.

Jackson, S. D. (1999). Multiple signaling pathways control tuber induction in potato. Plant Physiology, 119, 1-8. http://dx.doi.org/10.1104/pp.119.1.1.

Karafyllidis, D. I., Georgakis, D. N., Stavropoulos, N. I., Nianiou, E. X. and Vezyroglou, L. A. (1997). Effect of planting density and size of potato seed-minitubers on their yielding capacity. Acta Horticulturae, 462, 943-949. http://dx.doi.org/10.17660/ActaHortic.1997.462.150.

Kim, C. W., Song, C. K., Park, J. S., Mun, H. K., Kang, Y. K. and Kang, B. K. (2008). Effects of medium and planting density on growth and yield of seed potatoes grown in a wick hydroponic system. Korean Journal of Crop Science, 53, 251-255.

Lommen, W. J, M. and Struik, P. C. (1992). Production of potato minitubers by repeated harvesting: plant productivity and initiation, growth and resorption of tubers. Netherlands Journal of Agricultural Science, 40, 342-359. http://dx.doi.org/10.1007/BF02357598.

Lorenzi, J. O., Monteiro, P. A., Miranda Filho, H. S. and van Raij, B. (1997). Raízes e tubérculos. In B. van Raij, H. Cantarella, J. A. Quaggio and A. M. C. Furlani (Eds.), Recomendações de adubação e calagem para o Estado de São Paulo. 2. ed. revised and updated (p. 221-229). Campinas: Instituto Agronômico/Fundação IAC. Boletim 100.

Mateus-Rodriguez, J. R., Haan, S., Andrade-Piedra, J. L., Maldonado, L., Hareau, G., Barker, I., Chuquillanqui, C., Otazú, V., Frisancho, R., Bastos, C., Pereira, A. S., Medeiros, C. A., Montesdeoca, F. and Benítez, J. (2013). Technical and economic analysis of aeroponics and other systems for potato mini-tuber production in Latin America. American Journal of Potato Research, 90, 357-368. http://dx.doi.org/10.1007/s12230-013-9312-5.

Medeiros, C. A. B., Ziemer, A. H., Daniels, J. and Pereira, A. S. (2002). Produção de sementes pré-básicas de batata em sistemas hidropônicos. Horticultura Brasileira, 20, 110-114. http://dx.doi.org/10.1590/S0102-05362002000100022.

Müller, D. R., Bisognin, D. A., Andriolo, J. L., Dellai, J. and Copetti, F. (2007). Produção hidropônica de batata em diferentes concentrações de solução nutritiva e épocas de cultivo. Pesquisa Agropecuária Brasileira, 42, 647-653. http://dx.doi.org/10.1590/S0100-204X2007000500006.

Novella, M. B., Andriolo, J. L., Bisognin, D. A., Cogo, C. M. and Bandinelli, M. G. (2008). Concentration of nutrient solution in the hydroponic production of potato minitubers. Ciência Rural, 38, 1529-1533. http://dx.doi.org/10.1590/S0103-84782008000600006.

Oliveira, C. A. S. (2000). Potato crop growth as affected by nitrogen and plant density. Pesquisa Agropecuária Brasileira, 35, 939-950. http://dx.doi.org/10.1590/S0100-204X2000000500011.

Oparka, K. J., Davies, H. V. and Prior, D. A. M. (1987). The influence of applied N on export and partitioning of current assimilate by field-grown potato plants. Annals of Botany, 59, 484-488.

Otazú, V. (2010). Manual on quality seed potato production using aeroponics. Lima: International Potato Center.

Resende, G. M., Alvarenga, M. A. R., Yuri, J. E., Souza, R. J., Mota, J. H., Carvalho, J. G. and Rodrigues Júnior, J. C. (2009). Rendimento e teores de macronutrientes em alface tipo americana em função de doses de nitrogênio e molibdênio em cultivo de verão. Ciência e Agrotecnologia, 33, 153-163. http://dx.doi.org/10.1590/S1413-70542009000100022.

Ritter, E., Angulo, B., Riga, P., Herrán, J., Relloso, J. and San Jose, M. (2001). Comparison of hydroponic and aeroponic cultivation systems for the production of potato minitubers. Potato Research, 44, 127-135. http://dx.doi.org/10.1007/BF02410099.

Rolot, J. L. and Seutin, H. (1999). Soilless production of potato minitubers using a hydroponic technique. American Journal of Potato Research, 42, 457-469. http://dx.doi.org/10.1007/BF02358162.

Santos, B. M. and Rodriguez. P. R. (2008). Optimum in-row distances for potato mini tuber production. Hortechnology, 18, 403-406.

Savvas, D. and Adamidis, K. (1999). Automated management of nutrient solutions based on target electrical conductivity, pH, and nutrient concentration ratios. Journal of Plant Nutrition, 22, 1415-1432. http://dx.doi.org/10.1080/01904169909365723.

Streck, N. A., Lago, I., Alberto, C. M. and Bisognin, D. A. (2006). Simulação do desenvolvimento da batata cultivar asterix em cinco cenários de mudanças climáticas em Santa Maria, RS. Bragantia, 65, 693-702. http://dx.doi.org/10.1590/S0006-87052006000400021.

Tavares, S. and Lucchesi, A. A. (1999). Reguladores vegetais na batata cv. Monalisa, após a tuberização. Scientia Agricola, 56, 975-980. http://dx.doi.org/10.1590/S0103-90161999000400027.

Tibbitts, T. W. and Cao, W. (1994). Solid matrix and liquid culture procedures for growth of potatoes. Advanced Space Research, 14, 427-433.

Tierno, R., Carrasco, A., Ritter, E. and Galarreta, J. I. R. (2014). Differential growth response and minituber production of three potato cultivars under aeroponics and greenhouse bed culture. American Journal of Potato Research, 91, 346-353. http://dx.doi.org/10.1007/s12230-013-9354-8.

Trani, P. E. and van Raij, B. (1997). Raízes e tubérculos: composição mineral, amostragem de folhas e diagnose foliar. In B. van Raij, H. Cantarella, J. A. Quaggio and A. M. C. Furlani, (Eds.), Recomendações de adubação e calagem para o Estado de São Paulo. 2. ed. revised and updated. Campinas: Instituto Agronômico/Fundação IAC. Boletim 100.

Wheeler, R. M., Mackowiak, C. L., Sager, J. C., Knott, W. M. and Hinkle, C. R. (1990). Potato growth and yield using nutrient film technique (NFT). American Potato Journal, 67, 177-187. http://dx.doi.org/10.1007/BF02987070.