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Article

Evaluation of hydroponic nutrient solutions on potato genotypes in a greenhouse

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Abstract

High densities of potato crops in a greenhouse, genotype, and environmental conditions affect its productivity, and a factor that positively influences is nutritional contribution. The objective of this research was to determine the optimal nutrient solution for the production of minitubers in 12 potato genotypes, 11 generated by INIFAP and the Fianna Dutch variety. The following nutritional solutions N-P-K-Ca (mg L^{-1}) was formulated: a) 200-80-300-100, b) 200-80-350-100, c) 200-80-450-100 and 160-60-250-150 as a control, added with micronutrients, in autumn-winter 2015 and spring-summer 2016. Perlite as a substrate and random complete blocks. The autumn-winter cycle was more productive than the spring-summer cycle. The tallest plants were Granate, Milagros and Modesta. All genotypes exceeded the leaf area index from six to 80 days of cultivation and the SPAD index was different among them. Citlali, Granate and Nau, showed a higher harvest index, 0.79, 0.78 and 0.77, respectively. In contrast, in the rest of the varieties, it was less than 0.7. The varieties with the highest number of tubers per plant were Real 14 and 99-39 with 29.3. For their part, the genotypes with the highest fresh tuber weight per plant were 99-39, Nau, Bajío and Fianna, with 379.3, 349.7, 349.3, and 333.7 g, respectively. The production of minitubers >15 mm was higher in autumn-winter and the 200-80-450-100 solution produced more tubers per plant. Treatments with 350 and 450 mg L^{-1} potassium promoted a greater number of tubers in 10 of the 12 genotypes evaluated.

Keywords:

Solanum tuberosum, greenhouse, hydroponics, minitubers.

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Introduction

In hydroponic crops, efficiency and productivity depend on the constant availability of nutrients, pH, and electrical conductivity of the solution (Chang *et al*., 2008). The nutrient solutions used for potato crops in hydroponics contain macro and micronutrients: N, P, K, S, Ca, Mg, Fe, Mn, Zn, B, Cu, and Mo (Lommen, 2007; Coraspe *et al*., 2008).

On the other hand, Corrêa *et al*. (2008) and Tierno *et al*. (2014) found that the varietal response to the supply of different nutrient solutions is specific, whereas Zheng *et al*. (2018) mention the influence of the C:N ratio. Nutrition in the hydroponic system shows differences because of genotype, environment, and environmental genetic interaction (Corrêa *et al*., 2008; Tierno *et al*., 2014). Chang *et al*. (2011) found that plants developed with low electrical conductivity (EC) values showed inhibition in stem and stolon growth and earlier tuber formation, compared to those that had higher EC values, where tubers were observed 5 to 6 days later.

Potassium and magnesium deficiency decreases the starch and sugar contents in the tuber (Koch *et al*., 2019). Flores *et al*. (2016) mention amounts greater than 200 mg L^{-1} of nitrogen, phosphorus of 60 to 80, and potassium of 350 to 400 mg L^{-1} in the Nevada variety, and Flores *et al*. (2018) determined the optimal K dose of 400 mg L^{-1} in clone 99-39. In accordance with the above, three nutrient solutions were formulated and one was used as a control (Flores *et al*., 2009), the calcium level was reduced to 150 mg L^{-1} in order to determine the productivity of 12 potato genotypes, 11 of them Mexican, generated by INIFAP, and the Dutch variety Fianna as a control in the spring-summer and autumn-winter cycles.

Materials and methods

The study was carried out in two cultivation cycles: cycle 1 autumn-winter, from September 21 to December 18, 2015, and cycle 2 spring-summer, from March 31 to July 4, 2016. The greenhouse used belongs to the Potato Program of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP), for its acronym in Spanish, located at 2 726 masl, 19° 17’ 28” north latitude and 99° 42’ 51” west longitude (Servicio Meteorológico Nacional, 2017).

The substrate was horticultural grade perlite, 1.8 L pots and a drip system. Thirty-six plants per square meter with 10 irrigations per day; in addition, the preventive control of pests and diseases was carried out with fungicides and insecticides. The potato genotypes were 11 Mexican cultivars generated by INIFAP: Bajío, Citlali, Milagros, Modesta, Real 14, Cristal, Granate, Sierras, Nevada, Nau, and clone 99-39, all with resistance to potato late blight or tolerance to tuber internal browning or zebra chip, and the Dutch variety Fianna was used as a commercial control (t), which is susceptible to late blight and internal spot of the tuber.

The tubers with a diameter between 15 and 18 mm were planted 10 cm deep, with a single shoot, and were disinfected at the time of planting with fungicides and bactericides. The nutrient solutions evaluated in mg L^{-1}, (N-P-K-Ca), were: 1) 200-80-30-100; 2) 200-80-350-100; 3) 200-80-450-100 and 4) 160-60-250-150 as control (Flores *et al*., 2009); microelements were added in all solutions (Flores *et al*., 2018).

The temperature of the greenhouse was recorded with a Hanna data logger thermometer, HII4ICH model CE IP67®; in the autumn-winter 2015 cycle, the average temperature was 14.3 °C, the maximum of 32 °C, and the minimum of -2 °C and in spring-summer 2016, the average temperature was 22 °C, the maximum of 40 °C, and the minimum of 10 °C. The experimental design was complete randomized blocks with three replications (nested in the nutrient solutions), as a series of experiments (Martinez, 1988).

The significance between cycles, solutions, and genotypes, and the interaction between them was tested. When the analysis of variance showed statistical differences, Tukey test (p< 0.05) was applied with the InfoStat statistical package (Di Rienzo *et al*., 2015).

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The variables were plant height (cm), leaf area index (LAI), greenness index (SPAD values). The number, fresh weight, and diameter of tubers, dry weight of tubers and plant were evaluated at the time of harvest.

Results and discussion

The plants with the highest final height corresponded to the Granate, Milagros, and Modesta varieties. All varieties presented LAI greater than three at 40 dap of the crop and at 80 dap, they already exceeded readings of six; the Sierras, Modesta, and Nevada varieties registered a LAI greater than 7.5. SPAD values showed differences; however, they were probably due to the phenotypic characteristics of the cultivars and not to the fertilization rates or the cultivation cycle (Table 1).

Table 1. Average values of plant height, leaf area index, and greenness index (SPAD) in 12 potato genotypes, for two cultivation cycles, in a hydroponic system in a greenhouse.

Genotype	Plant height (cm)		Leaf area index		SPAD values	
	40 dap	80 dap	40 dap	80 dap	40 dap	80 dap
Bajío	30 g	97.3 cd	3 f	6.61 cde	50.05 ab	44.52 b
Citlali	26 h	98.4 bcd	3.25 cdef	6.77 cd	49.18 abc	42.36 c
Cristal	33.1 fg	93.7 d	3.03 ef	6.4 e	47.83 bcd	44.73 b
Fianna	34.3 ef	91.1 d	3.1 def	6.53 de	48.36 abc	46.08 b
Granate	39.2 cd	109.3 a	3.41 abc	7.43 b	50.7 a	45.39 b
Milagros	40.7 bc	104.9 ab	3.45 abc	7.59 ab	48.65 abc	46.09 ab
Modesta	44.3 a	104.4 abc	3.54 a	7.81 a	49.42 ab	45.73 b
Nau	38.7 cd	91.8 d	3.27 bcde	6.34 e	44.87 e	46.3 ab
Sierras	37.1 de	93.8 d	3.54 a	7.85 a	45.5 de	44.34 bc
Nevada	32.4 fg	95.9 d	3.33 abcd	7.58 ab	47.89 bc	45.39 b
Real 14	42.9 ab	93.2 d	3.52 ab	6.82 c	48.31 bc	48.21 a
99-39	30.4 g	98.1 bcd	3.52 ab	7.45 b	47.05 cde	46.13 ab

Averages with the same letter do not differ statistically ($p< 0.05$), according to Tukey's test.

The production of minitubers with a diameter of #15 mm was better in the autumn-winter cycle than in spring-summer, which is related to the average temperatures recorded in each cycle; in autumn-winter, the average temperature was 14.3 °C, whereas in the spring-summer cycle, the average temperature was 22 °C.

The Citlali variety behaved inversely, with higher production in spring-summer, probably because it adapts better to altitudes below 3 200 masl and presents lower yields in cold climates (Rubio *et al*., 2017). The average production of minitubers per plant in both cycles was higher for the Real 14, Modesta, and Cristal varieties with 32, 31, and 30 tubers, respectively.

Clone 99-39 was equal to Cristal, with an average of 28 minitubers per plant. Likewise, the higher tuber production in the autumn-winter cycle is notable, both for total tubers and for >15 mm in diameter (Figure 1). The results obtained for this variable indicate that the differences found in the two production cycles are probably due to the varietal response; a fact that coincides with what was reported by Corrêa *et al*. (2008); Tierno *et al*. (2014).

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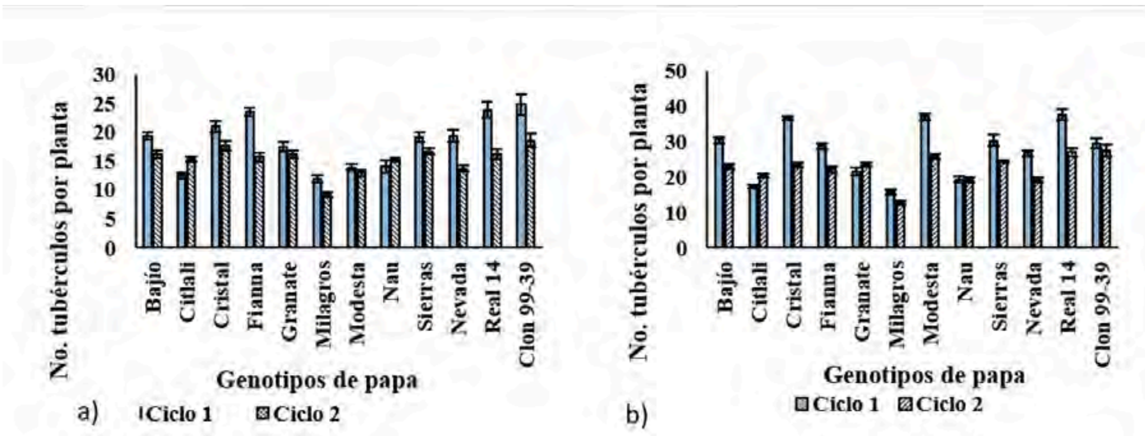
Figure 1. Production of tubers ≥15 mm diameter per plant (a) and total tubers (b) in two production cycles, for twelve potato genotypes, in hydroponics and a greenhouse. Average ± standard error of the mean. Cycle 1: September to December 2015, Cycle 2: March to July 2016.



Late and intermediate varieties produced a greater number of small tubers (Modesta, 18; Real 14 with 13 and Cristal, Sierras and Bajío, with 10, 9 and 9).

The highest fresh weight of tubers recorded during the two cycles evaluated was with the Nau variety, with an average of 340 g per plant. Genotypes 99-39, Fianna and Bajío showed statistically equal yields, with an average of 314, 313 and 309 g plant^{-1}. Milagros presented the lowest yield per plant, with 151 g, considering the late cycle of this genotype. All genotypes showed similar responses in both production cycles (Figure 2), since each of the genotypes under study present different yield potential and in the genotype-by-cycle interaction, as indicated by Corrêa *et al*. (2008); Tierno *et al*. (2014).

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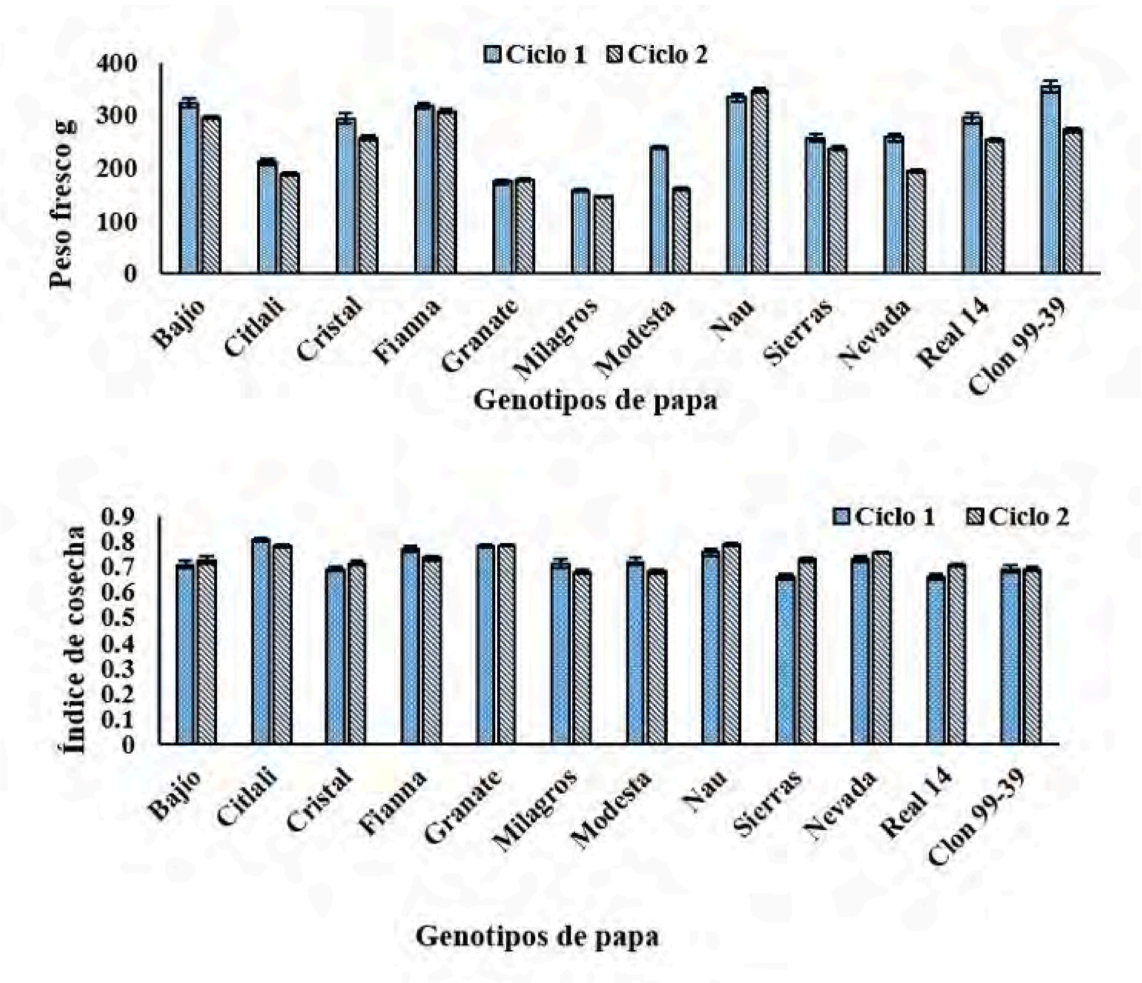
Figure 2. Fresh weight of tubers per plant (a) and harvest index (b) for 12 potato genotypes, in two cultivation cycles, in hydroponics and a greenhouse. Average ± standard error of the mean. Cycle 1: September to December 2015, Cycle 2: March to July 2016.



The Citlali, Granate, and Nau varieties showed the highest harvest index, with 0.79, 0.78, and 0.77, respectively; that is, the dry weight of their tubers contributes 77% or more of the total dry weight of the plant. The above is because of the earliest cycle and due to the fact that, in the period of 80 days, they were closer to the end of the cultivation cycle. The cultivars with the lowest harvest index during the two cycles were Real 14 (0.68), 99-39 (0.69), and Sierras (0.69), which are later genotypes (Figure 2).

In general, six genotypes had a higher harvest index in the spring-summer season than in the autumn-winter, which does not agree with what was pointed out by Beukema and Van der Zaag (1990), who indicate greater accumulation of biomass in the tubers in cold seasons, which only occurred in four of the genotypes, Citlali, Fianna, Milagros, and Modesta, under study (Figure 2).

The response in the fresh weight yield of tubers per plant showed similar results to that obtained in the number of tubers. In general, the highest fresh weight was obtained with the solution of 450 mg L^{-1} potassium, with statistically significant differences (p< 0.05) among treatments (Figure 3). The above is because of the greater availability of this element, which is involved in the speed of opening and closing of stomata, as well as in photosynthesis, which affects the photosynthetic rate and production of assimilates, in addition to the transport of sugars from the source to the demand organ and the activation of several enzymes involved in the general metabolism of the plant.

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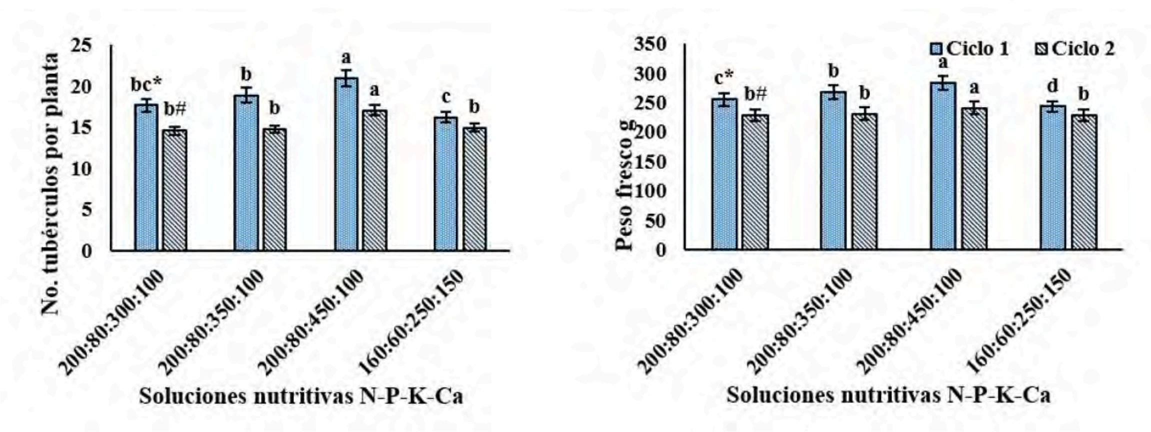
Figure 3. Response in number of minitubers >15 mm and fresh weight of 12 potato genotypes with four nutrient solutions, in two cultivation cycles in a greenhouse. *#= averages with the same letter do not differ statistically (p< 0.05), according to Tukey's test. Cycle 1: September to December 2015, Cycle 2: March to July 2016.



The cycle x solution x genotype interaction was highly significant. The nutrient solutions evaluated in the autumn-winter cycle promoted the production of minitubers in a statistically equal way in seven of the twelve genotypes. Nevertheless, Nau, Sierras, Nevada, Real 14, and clone 99-39 did present statistical differences compared to the control and within the solutions studied (Table 2), where Nau presented a higher yield in number of tubers in the control solution with less nitrogen, phosphorus, and potassium, which may be due to the fact that it is a varietal characteristic.

Table 2. Productivity of 12 Mexican potato genotypes in two cultivation cycles, cycle 01 September to December 2015 and cycle 02 March to July 2016, with four nutrient solutions. Genotype/solution interac tion. Number of tubers ≥15 mm in diameter, average per plant.

Genotype	Cycle 1: solutions (N-P-K-Ca)				Cycle 2: solutions (N-P-K-Ca)			
	1	2	3	4 (t)	1	2	3	4 (t)
Bajío	20 a*	18.3 a	21.3 a	17.6 a	16.3 a	16.3 a	17.3 a	14.6 a
Citlali	12.6 a	12 a	13.3 a	12 a	15.6 a	14.3 a	16 a	15.3 a
Cristal	21.3 a	24.3 a	21.3 a	17 a	15.6 a	16.6 a	21.6 a	17 a
Fianna	21 a	24 a	26 a	23 a	13 a	16 a	18 a	15.6 a
Granate	16.6 a	16 a	22 a	15 a	16.3 a	15.6 a	18 a	15 a
Milagros	9.6 a	13.6 a	13.3 a	11 a	7.3 a	10 a	10.6 a	8.6 a
Modesta	14 a	13.6 a	15.3 a	12.6 a	12 a	13.3 a	13 a	13.6 a
Nau	11 b	11.3 b	15.3 ab	18.6 a	15 a	14 a	15.6 a	16.3 a
Sierras	19.3 a	21.3 a	20.6 a	15.3 b	17 a	16.6 a	18 a	15 a
Nevada	19 ab	19.6 ab	24 a	15 b	13.3 a	13.6 a	15 a	13 a
Real 14	23.3 bc	26 ab	29.3 a	17 c	17 a	14.6 a	17.3 a	15.6 a
99-39	23.7 b	26 ab	29.3 a	20.3 c	16 bc	15.3 bc	24 a	19 ab

Solution 1= 200-80-300-100; solution 2= 200-80-350-100; solution 3= 200-80-450-100; control= 160-60-250-150. *= averages with the same letter, within the same cultivation cycle, do not differ statistically (p< 0.05), according to Tukey's test. It applies to the values of each genotype, not among genotypes.

In the autumn-winter cycle, the solutions with doses of 350 and 450 mg L^{-1} of potassium promoted a greater number of tubers >15 mm in the Real 14, Sierras, and Nevada genotypes and clone 99-39, with significant differences compared to the control, whereas the Bajío, Citlali, Cristal, Fianna,

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Granate, Milagros, and Modesta genotypes, with no statistically significant difference between the solutions, show an increase in tubers in solutions formulated with higher nitrogen, phosphorus and potassium contents.

This confirms that the genotype factor strongly influences productivity in greenhouses as well as in the field. This agrees with what has been reported in similar studies (Chang *et al*., 2008). Concentrations of 350 and 450 mg L^{-1} of potassium produced more tubers in autumn-winter than in spring-summer in 10 of the 12 genotypes evaluated, which is consistent with what was indicated by Flores *et al*. (2016 and 2018); Morales *et al*. (2016). In contrast, Citlali and Nau presented a greater number of tubers in spring-summer.

Likewise, in this spring cycle, only clone 99-39 presented a statistical difference between solutions, with 24 tubers per plant in solution three (200, 80, 450, 100), whereas in the rest of the genotypes, there was no statistical difference; however, there is a trend of a greater number of tubers in treatment 3 compared to the control (Table 2).

In general, in the solution with 450 mg L^{-1} of potassium, in 11 of the 12 genotypes evaluated, they produced 1 and up to 4 more tubers per plant than the control, which is important to note since if they are tubers larger than 15 mm in diameter, they are useful to take to the field and if they are smaller than this diameter, they can be used as reproductive material within the greenhouse for production of pre-basic seed II.

In autumn-winter, the Bajío, Nau, Sierras, Nevada, and Real 14 varieties and clone 99-39 presented statistically a higher weight of tubers with the use of the solution with 450 mg L^{-1} of potassium compared to the control solution; even though the Nau variety produced a greater number of tubers per plant in this cycle with the control nutrient dose (Table 2), it presented a higher weight of tubers with solutions two and three (Table 3). For the rest of the genotypes (Citlali, Cristal, Fianna, Granate, Milagros, and Modesta), the nutritional dose that was supplemented was irrelevant, so in these varieties, in the autumn-winter cycle, it could be better to use the control solution if only the fresh weight is considered, not if the number of tubers is considered.

Table 3. Fresh weight of tubers (g) per plant in twelve Mexican potato genotypes in cycle 01 from September to December 2015, cycle 02 March to July 2016, with four nutrient solutions. Genotype x solution interaction. Weight of tubers ≥ 15 mm in diameter, average per plant.

	Cycle 1				Cycle 2			
Genotype	**1**	**2**	**3**	**4 (t)**	**1**	**2**	**3**	**4(t)**
Bajío	304.3 b*	325.7 ab	349.3 a	291.7 b	278.3 a*	288 a	304.7 a	288.3 a
Citlali	185.3 a	204.3 a	217 a	224.3 a	183.3 a	181.7 a	195 a	184.3 a
Cristal	289 a	290.3 a	316.3 a	234 a	242.7 b	253 ab	274 a	241.7 b
Fianna (t)	297 a	314.7 a	333.7 a	312.7 a	311.3 ab	293.7 ab	317.3 a	282.3 b
Granate	164.3 a	174.7 a	164.3 a	185.3 a	169.7 a	166.3 a	178.7 a	178 a
Milagros	148.7 a	159.7 a	163.7 a	144 a	138.7 a	144.4 a	146 a	147 a
Modesta	233.3 a	234 a	233 a	219 a	156.7 a	148.7 a	154.7 a	145 a
Nau	217.7 c	343.7 a	349.7 a	293.3 b	335 a	354.7 a	331 a	359 a
Sierras	241 ab	247.3 ab	279.3 a	227.7 b	225 a	241.3 a	243.7 a	222 a
Nevada	264.7 ab	238 b	278.7 a	225 b	180.3 a	191.3 a	204.7 a	186.3 a
Real 14	251 c	311.3 b	324.7 a	260 c	245.3 a	249 a	256.7 a	241 a
99-39	365 a	364.3 a	379.3 a	297.3 b	271.3 a	255.7 a	282 a	257.3 a

*= averages with the same letter do not differ statistically (p< 0.05), according to Tukey's test. It applies to the values of each genotype, not between genotypes, and in each season separately.

In a potato tuber-seed multiplication scheme, the most important thing is the number of minitubers with potential to be used in the field. These results show that not all genotypes respond in the same way to nutrition with nitrogen, phosphorus, and potassium and that the response could be varietal, as observed by other authors (Chang et al., 2011; Tierno et al., 2014).

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In contrast, in spring-summer, it is observed that doses with 350 and 450 mg L^{-1} of potassium promoted greater weight in the tubers of the Cristal and Fianna varieties and for both, nutrition with the control solution was the one with the lowest weight of tubers per plant. In the rest of the varieties, no differences were detected between the solutions evaluated. The above is possibly due to temperatures of up to 40 °C during the day in the spring-summer cycle, as opposed to optimal temperatures of 10 to 25 °C for the crop (Rubio *et al*., 2000).

Conclusions

The differential response of greenhouse potato crop in different cultivation cycles (spring-summer and autumn-winter) was confirmed. The genotype strongly influences the productivity of the crop in a greenhouse, with some genotypes being more efficient with a higher harvest index in both cultivation cycles.

There are varieties that require less nutrient input, such as the Nau variety. Higher concentrations of nitrogen, phosphorus, and potassium (200-80-350) in a hydroponic crop in perlite recorded higher yields in number and weight of tubers.

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