Article

Growth, yield and quality of strawberry by effect of the nutritional regime

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Abstract

The objective of the research was to determine the nutritional regime that favors the growth, yield and physical and biochemical quality of strawberries produced in hydroponics under plastic cover. In 2017, an experiment was carried out in the experimental field of the Faculty of Agricultural Sciences of the Autonomous University of the State of Morelos, in which 27 nutritional regimes made up of the combination of variations in the concentration of NO^-_3 in the vegetative phase (10, 12 and 14 meq L^{-1}), $H_2PO_4^-$ in the reproductive phase (0.75, 1.00 and 1.25 meq L^{-1}) and K^+ in the fruiting phase (5, 7 and 9 meq L^{-1}) were evaluated. Treatments were distributed in a completely randomized experimental block design with four replications per treatment. The experimental unit was a black polyethylene container (15.14 L), with red tezontle as substrate and a strawberry plant. The results indicated that strawberry plants produced in hydroponics with nutritional regimen showed a significantly different response in the relative content of chlorophyll, leaf area, dry biomass of leaves, flower diameter, length and equatorial diameter of the fruit, average weight of the fruit, yield. per plant and concentration of total soluble solids in fruit, depending on the concentrations of NO_3^-:$H_2PO_4^-$:K^+, in the vegetative, reproductive and fruiting phases, respectively. The nutritional regime of 10 meq L^{-1} of NO_3^- in the vegetative phase, 1 meq L^{-1} of $H_2PO_4^-$ in the reproductive phase and 7 meq L^{-1} of K^+ in fruiting, is recommended for producing strawberry in hydroponics because it increased significantly the diameter of the fruit and the yield per plant.

Keywords: fruiting phase, reproductive phase, soilless crops, vegetative phase.

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Introduction

The strawberry (*Fragaria* x *ananassa* Duch.) is in great demand in Mexico and around the world, especially in developed countries; 9 223 815 t are produced in Mexico alone (Romero-Romano *et al*., 2012; FAOSTAT, 2020). The main producing states nationwide are Michoacán, Baja California, Baja California Sur, State of Mexico and Morelos (SIAP, 2020a). Due to the importance of fresh strawberry consumption, the physical and above all biochemical quality is of great importance, due to its large amount of sugars and minerals, in addition to having nutraceutical compounds such as phenols and flavonoids, which have antioxidant properties with capacity to capture free radicals (Vásquez *et al.*, 2007; Luna-Zapien *et al*., 2016). Llacuna y Mach (2012) report that plant products with a high nutraceutical content are important for human health by promoting physiological balance, as well as reducing the risk of developing chronic-degenerative diseases, diabetes and cancer.

To obtain the quality parameters in strawberry, it is of great importance to control the nutritional regime during the cultivation cycle (Jara and Suni, 1999; Avitia-García *et al*., 2014); that is, the supply of macro and micronutrients to the phenological phase. In this investigation, the criteria of Stenier (1984) on the mutual relationships between anions (NO_3^-:$H_2PO_4^-$:SO_4^{2-}) and cations (K^+:Ca^{2+}:Mg^{2+}) were considered, in addition to keeping the total concentration of anions constant (20 meq L^{-1}) and that of cations (20 meq L^{-1}).

N is one of the most limiting nutrients in strawberry production, in such a way that farmers apply high doses of nitrogen fertilization in order to obtain outstanding yields (Cárdenas-Navarro *et al*., 2004), which is why they increase production costs and contamination of groundwater tables by nitrate leaching (Vázquez-Gálvez *et al*., 2008). N has an essential function in the vegetative growth, productivity and quality of the strawberry; its functions are structural and osmotic. This nutrient is absorbed mainly in the form of NO_3^-. If deficiencies are present, the vigor of the plants and the productivity decrease, but the organoleptic quality of the fruit improves; on the other hand, if there is an excess of N, Zn deficiency is induced (Kirschbaum and Bórquez, 2006; Eyal, 2008; Chávez-Sánchez *et al.*, 2014).

P is an essential nutrient for plants, although it is a poorly mobile element in the soil, it benefits the plant by stimulating radical development and flowering, as it is the primary constituent of the systems responsible for energy collection, storage and transfer. It is part of the essential macromolecule structures, such as nucleic acids and phospholipids, so it participates in all physiological processes.

Plants absorb it as a primary orthophosphate ion ($H_2PO_4^-$) or as a secondary orthophosphate (HPO_4^{2-}) (Fernández, 2007). P intervenes in biochemical processes such as: biogenesis of glycosides, biosynthesis of lipids, chlorophylls and carotenoid compounds, in glycolysis and the metabolism of organic acids; which translates into the acidity, aroma and color of the fruits (Díaz *et al*., 2017). The deficiency of P diminishes the number and diameter of the flowers causing a reduction of 50% in the yield, the maturation is delayed, the size and firmness of the fruits decreases, and the content of vitamin C decreases; but high levels of P induce Zn deficiency and inactivate Fe (Kirschbaum and Bórquez, 2006; Eyal, 2008; Díaz *et al*., 2017).

K is known as the quality nutrient for its effect on the size, shape, color, flavor and storage resistance that it confers on the fruits (Chávez-Sánchez *et al*., 2014). It is involved in the absorption of water by the roots, influences photosynthesis and regulates the opening of stomata; it is a structural component of lignin and cellulose; it also affects the starch and sugar contents, it is involved in resistance to diseases and insects. It is absorbed by the plant as K^+, it is a mobile element in plants, its availability is critical in leaves and growing fruits. Deficiency induces a decrease in fruit vigor, yield and quality due to affecting pigmentation (Kirschbaum and Bórquez, 2006). K directly affects the quality of the fruit because high levels increase apical rot and reduce the firmness of cell walls (Hernández *et al*., 2009).

Mexico has 14 771 ha of cultivated berries (strawberry, raspberry, blackberry and blueberry) in macrotunel. Of the previous surface, 11 091 ha is strawberry, of which 89.78% is mechanized and 65.63% has plant health technology (SIAP, 2020b). This technified system allows to obtain 50% more yield compared to traditional cultivation (open pit and manual agricultural work), in addition to prolonging the harvest period (SAGARPA, 2016).

Strawberry production in technical systems also allows controlling the nutritional regime; that is, the amount of nutrients for each phenological phase of the strawberry and thereby optimize the development, yield and quality of the fruits (Manqueros-Aviles, 2015). The objective of the investigation was to determine the nutritional regime to favor the growth, yield and physical and biochemical quality of strawberry produced in a system without soil under plastic cover.

Materials and methods

Location

The experiment was carried out in a greenhouse in the experimental field of the Faculty of Agricultural Sciences (18° 58’ 51” north latitude, 99° 13’ 57” west longitude, 1 868 masl) at the Autonomous University of the State of Morelos, Cuernavaca, Morelos, Mexico, in the period from April 2016 to March 2017.

Vegetal material

Plants of *F. x ananassa* var. San Andreas is a neutral day variety of excellent fruit quality, with little need for cold in the nursery, resistant to diseases. It is precocious (autumn planting), its production is stable throughout the cycle, it maintains its size all the time with good production. It produces fewer stolons than the Albion variety when it is in fruit production (Eurosemillas, 2020), this variety was chosen because they produce fruit throughout the entire growing season. These plants are ideal to have them in limited spaces.

Experimental design

To evaluate the growth of the plants, yield and quality of the strawberry according to the nutritional regime, 27 treatments (nutritional regimes) were evaluated, of which treatment 14 was the control, corresponding to the universal nutritive solution (Steiner, 1984; SNU). The treatments (Table 1) were distributed in space according to a randomized complete blocks experimental design with four repetitions per treatment.

Table 1. Nutritional regimes in the production of strawberry in hydroponics under plastic cover.

Nutritional regimen	Vegetative phase NO_3^- (meq L^{-1})	Reproductive phase $H_2PO_4^-$ (meq L^{-1})	Fruiting phase K^+ (meq L^{-1})
1	10	0.75	5
2	10	0.75	7
3	10	0.75	9
4	10	1	5
5	10	1	7
6	10	1	9
7	10	1.25	5
8	10	1.25	7
9	10	1.25	9
10	12	0.75	5
11	12	0.75	7
12	12	0.75	9
13	12	1	5
14	12	1	7
15	12	1	9
15	12	1.25	5
17	12	1.25	7
18	12	1.25	9
19	14	0.75	5
20	14	0.75	7
21	14	0.75	9
22	14	1	5
23	14	1	7
24	14	1	9
25	14	1.25	5
26	14	1.25	7
27	14	1.25	9

Experiment management

The vegetative phase, considered from the transplant until 50% of the plants had 10 true leaves and the first flower appeared, the NO_3^- (10, 12 and 14 meq L^{-1}) was modified keeping the mutual relationships constant SO_4^{2-}:$H_2PO_4^-$ (7:1). In the reproductive phase, since 50% of the plants presented the appearance of the first flower until the appearance of the first fruit (10 ±1 mm in length), the $H_2PO_4^-$ (0.75, 1 and 1.25 meq L^{-1}) was modified, maintaining the mutual relations of NO_3^-:SO_4^{2-} (12:7) are constant.

In the fruiting phase, from the time the first fruit was 10 ±1mm long until the end of the harvest, the K^+ concentration (5, 7 and 9 meq L^{-1}) was varied, keeping the mutual Ca^{2+}: Mg^{2+} (9:4). relationships constant. The nutritive solutions were prepared with running water, after physical-chemical analysis, and with highly soluble fertilizers (potassium nitrate, calcium nitrate, potassium sulfate, monopotassium phosphate and magnesium sulfate); in addition, in each regimen the micronutrients were incorporated: Fe, 8 mg L^{-1} (source Fe-EDTA); H_3BO_3, 2.88 mg L^{-1}; Mn, 0.502 mg L^{-1} ($MnCl_2$); Zn, 0.050 mg L^{-1} ($ZnSO_4$); Cu, 0.045 mg L^{-1} ($CuSO_4$); Mo, 0.01 mg L^{-1} (H_2MoO_4). The pH was adjusted from 5.5-5.8 with H_2SO_4.

The experimental unit was a 15.14 L black polyethylene container (25.5 cm in diameter by 30 cm in height) and a red tezontle with a grain size ≤0.5 cm in diameter was used as the substrate, which is considered chemically inert (Ojodeagua *et al*., 2008). In each experimental unit a strawberry plant with four true leaves was placed. The four irrigations per day were performed using a drip irrigation system (with a Netafim brand self-compensating dropper and a flow rate of 8 L h^{-1}) controlled by a timer. During the experiment, the relative humidity, light intensity and temperature were recorded with the help of a datalogger (Hobo®, Massachusetts, USA).

Response variables

The response variables were: relative chlorophyll content, total number of leaves, leaf area, root volume, dry biomass of leaves and roots, number of flowers per plant, flower diameter, number of fruits per plant, length and diameter of fruit, average weight per fruit, average yield per plant and concentration of total soluble solids.

The relative chlorophyll content was measured with a SPAD-502 (Konica Minolta) from the fourth leaf until the end of the experiment. The total number of leaves was counted at the end of the experiment, the leaf area was determined with a leaf area integrator (LI-COR, LI3-100C). The root volume was determined using the water displacement technique. For this, a 2 L graduated cylinder with a known volume of water was used. The difference in volumes when the root was introduced into the water corresponded to the volume of this organ; to obtain the dry biomass of leaves and roots, these organs were placed in a forced air circulation stove (Lanphan, DHG9070A) at a temperature of 72 °C for 72 h and were subsequently weighed on a digital scale (Ohaus, CS 2000).

The number of flowers per plant and flower diameter were evaluated every week from 60 to 270 days after transplantation (ddt). The fruits began to be harvested at 85 ddt when they presented a deep red color according to NMX-FF-062-SCFI-2002, making one cut per week up to 270 ddt. Once harvested, the fruits were counted and weighed on a digital scale.

The total weight was divided by the number of fruits of each plant and the average weight per fruit was obtained. The length of the fruit was measured from the calyx to the apex with a vernier (Truper) as well as the diameter in the middle part of the fruit; while the yield per plant was obtained with the sum of the harvested up to 270 ddt. In completely red fruits, the total soluble solids concentration (CSST) was determined with a portable refractometer (Pocket refractometer Pal-1, Atago, Tokyo, Japan).

Statistical analysis

All data were analyzed for variance with the SAS program (version 6.12) and the Tukey multiple comparison test of means ($p \leq 0.05$) was applied to those that showed significant statistical difference.

Results and discussion

The analysis of variance ($p \leq 0.05$) carried out on the variables of growth, production and fruit quality indicated that at least one nutritional regime exerted statistically significant differences from the rest of the regimes in the relative content of chlorophyll, leaf area, dry biomass of leaves, flower diameter, length and diameter of the fruit, average weight of the fruit, yield per plant and concentration of total soluble solids in the fruit.

The variables that did not show significant statistical differences ($p \leq 0.05$) were the number of leaves, root volume, dry root biomass and number of flowers per plant (unpublished data), which indicates that these characteristics are more influenced by the genetic component than the nutritional one, since all the treatments were in the same physical-chemical environment (temperature, light intensity, relative humidity, availability of nutritive solution in the substrate, among others).

Regarding the relative content of chlorophyll expressed in SPAD units, the nutritional regime (in meq L^{-1}) 14:1.25:9 of NO_3^-:$H_2PO_4^-$:K^+ in the vegetative, reproductive and fruiting phases, respectively, was 47.71 , 8.03% higher than in plants with the 10:0.75:7, regime, which presented the lowest value of 44.16, in the other treatments, including the control, presented similar value (46.39% on average) (Table 2). The relative content of chlorophyll is an indicator between the relationship of the degree of supply and availability of nutrients, Juárez-Rosete *et al*. (2007) report readings of up to 43.23 SPAD, nourishing the plant with the Steiner nutritive solution, also mention that as the cultivation cycle passed, the SPAD readings decreased in the different phenological phases of strawberry cv. Chandler.

Regarding the leaf area, with 12:0.75:7 it was 1 819.92 cm^2, 165% more with respect to the plants that received 10:1.25:5 and 12:1.25:5 (686.75 cm^2, on average) (Table 2). This result differs from that obtained by Caso *et al*. (2010) who report a leaf area of 920.52 cm^2 in strawberry cultivated in pumice substrate (100%) and with La Molina nutrient solution. For their part, Casierra-Posada and Poveda (2005) obtained a leaf area of 600 cm^2 when cultivating the strawberry var. Camarosa with highly soluble compound fertilizer. From the diversity of values in the reported strawberry leaf area, the effect of both nutrition and variety can be inferred, aspects to consider in the case of establishing a commercial crop.

Table 2. Morphological characteristics and biomass accumulation in strawberry plants in response to the nutritional regime.

Nutritional regimen (meq L^{-1}) $NO_3^-:H_2PO_4^-:K^+$	CRC (SPAD)	NH	AF (cm^2)	VR (cm^3)	BSH (g)	BSR (g)
10:0.75:5	45.14 ab	5.6 a	922.1 ab	116.25 a	20.75 ab	29.5 a
10:0.75:7	44.16 b	5.36 a	1099.85 ab	97 a	22 ab	20.75 a
10:0.75:9	45.94 ab	5.84 a	1118.21 ab	137 a	17 abc	36.5 a
10:1.00:5	45.25 ab	5.37 a	1074.76 ab	140.25 a	21 abc	32.25 a
10:1.00:7	44.79 ab	5.89 a	1306.5 ab	132.25 a	25 ab	30.25 a
10:1.00:9	45.35 ab	5.4 a	1044.93 ab	140 a	20 abc	37.75 a
10:1.25:5	45.07 ab	5.64 a	706.05 b	100 a	16.5 abc	26 a
10:1.25:7	45.18 ab	4.94 a	1183.06 ab	102.5 a	20.5 abc	24.75 a
10:1.25: 9	45.43 ab	5.12a	936.44 ab	121.5 a	21.5 abc	32.25 a
12:0.75:5	44.43 ab	5.2 a	925.98 ab	97.5 a	16.5 abc	24.25 a
12:0.75:7	44.5 ab	5.75 a	1819.92 a	125 a	21 abc	33.75 a
12:0.75:9	44.6 ab	5.97a	1461.48 ab	145 a	18.5 abc	37.75 a
12:1.00:5	44.69 ab	6.13 a	1037.43 ab	78.25 a	12.25 bc	20.5 a
12:1.00:7*	46.39 ab	5.55 a	1338.85 ab	122.75 a	18.5 abc	31.25 a
12:1.00:9	46.22 ab	5.78 a	953.76 ab	95 a	15.75 abc	23.25 a
12:1.25:5	46.69 ab	5.76 a	667.46 b	90 a	10.75 c	22.75 a
12:1.25:7	46.23 ab	5.63 a	1243.37 ab	120 a	18 abc	30.25 a
12:1.25:9	46.43 ab	5.62 a	925.02 ab	120 a	14.5 abc	30 a
14:0.75:5	45.3 ab	5.34 a	1165.36 ab	112.5 a	18 abc	36 a
14:0.75:7	46.07 ab	6.06 a	1303.46 ab	95 a	20.75 abc	20.5 a
14:0.75:9	46.74 ab	5.86 a	1310.71 ab	127.5 a	22.25 abc	33.25 a
14:1.00:5	46.34 ab	5.69 a	1100.25 ab	117.5 a	20.25 abc	29 a
14:1.00:7	46.44 ab	5.75 a	1407.53ab	115 a	26.75 a	26.75 a
14:1.00:9	46.32 ab	5.56 a	1141.36 ab	120 a	18.25 abc	26.25 a
14:1.25:5	45.74 ab	5.75 a	1032.7 ab	117.5 a	18.5 abc	25.25 a
14:1.25:7	45.66 ab	5.42 a	963.13 ab	85 a	15.25 abc	19.25 a
14:1.25:9	47.71 a	5.47 a	1137.51 ab	110 a	20.5 abc	24.5 a
DMSH	3.38	1.33	1023.6	7.21|	12.93	22.79
CV (%)	2.73	8.8	33.6	23.33	25.22	29.68

Regimen corresponding to the control treatment; CRC= relative chlorophyll content; NH= number of leaves per plant; AF= leaf area per plant; VR= root volume; BSH= dry leaf biomass; BSR= dry root biomass; DMSH= honest minimal significant difference; CV= coefficient of variation. Means with the same column literal are statistically equal according to the Tukey test ($p \leq 0.05$).

In relation to biomass accumulation, as a parameter to quantify growth (Urrestarazu *et al*., 1999; Villegas-Torres *et al*., 2005), a significant difference was found in leaves. The nutritional regime that led to this variable (26.75 g) was 14:1:7, which represented an increase of 148% compared to plants (10.75 g) fed with the 12:1.25:5 regime (Table 2). Caso *et al*. (2010) reported dry biomass of leaves of 3.8 g, this in strawberries grown with the pumice substrate and La Molina hydroponic solution.

Regarding the flower size, the 14:0.75:7 regime favored the plants to present larger flowers (2.37 cm in diameter), a difference of 37.79% with respect to the flower diameter of strawberries fed with 10:1.25:5. Fruiting started ten days after flowering, while the harvest lasted 185 days. The 14:0.75:9 regimen induced the strawberry to produce the greatest number of fruits per plant (12.67), the difference was 66.05% greater with respect to the plants fed with 10:0.75:7 (Table 3).

Table 3. Yield components and concentration of total soluble solids in strawberry fruits by effect of the nutritional regime.

Nutritional regimen (meq L^{-1}) $NO_3^-:H_2PO_4^-:K^+$	DF (cm)	NFRU	LF (cm)	DFR (cm)	PPF (g)	RPP (g)	CSST (°Brix)
10:0.75:5	1.93 abc	10.17 abc	2.65 bc	2.44 abc	8.06 bcd	149.34 abc	9.2 abc
10:0.75:7	1.98 abc	7.63 c	3.28 abc	2.85 a	12.37 ab	147.32 abc	7.05 a-e
10:0.75:9	1.96 abc	10.61 ab	2.76 abc	2.4 abc	7.82 bcd	139.35 abc	9.13 a-e
10:1.00:5	2 abc	10.06 abc	2.96 abc	2.53 abc	9.33 a-d	188.4 abc	7.47 a-e
10:1.00:7	1.75 bc	9.94 abc	3.34 abc	2.91 a	11.97 a-d	289.28 a	6.59 a-e
10:1.00:9	2.04 abc	9.45 abc	2.83 abc	2.46 abc	8.31 bcd	127.43 abc	7.44 a-d
10:1.25:5	1.72 c	9.73 abc	2.62 bc	2.17 c	6.13 d	82.12 bc	6 a-e
10:1.25:7	1.91 abc	7.82 bc	3.59 a	2.96 a	15.15 a	128.67 abc	10.13 ab
10:1.25: 9	1.79 abc	9.69 abc	3.11 abc	2.61 abc	10.14 a-d	146.13 abc	6.95 a-e
12:0.75:5	2.08 abc	8.37 abc	3.15 abc	2.78 abc	11.29 a-d	261.2 ab	6.23 a-e
12:0.75:7	1.98 abc	8.89 abc	3.18 abc	2.76 abc	11.03 a-d	227.65 abc	6.05 a-e
12:0.75:9	1.82 abc	10.16 abc	3.14 abc	2.63 abc	10.19 a-d	163.01 abc	3.37 cde
12:1.00:5	2.17 abc	8.35 abc	3.37 ab	2.94 a	12.18 abc	260.18 ab	5.63 b-e
12:1.00:7*	1.9 abc	10.01 abc	3.11 abc	2.66 abc	10.17 a-d	219.9 abc	6.22 a-e
12:1.00:9	2.18 abc	9.62 abc	2.95 abc	2.61 abc	9.55 a-d	218.57 abc	6.85 a-e
12:1.25:5	1.8 abc	8.48 abc	2.46 c	2.18 abc	6.33 dc	83.07 bc	4.19 cde
12:1.25:7	1.98 abc	8.7 abc	3.2 abc	2.83 ab	12.31 abc	198.88 abc	6.96 a-e
12:1.25:9	1.9 abc	10.49 abc	2.57 bc	2.42 abc	7.56 bcd	127.25 abc	4.67 b-e
14:0.75:5	1.88 abc	10.55 abc	3.03 abc	2.56 abc	9.2 a-d	135.55 abc	7.07 a-e
14:0.75:7	2.37 a	8.48 abc	3.3 abc	2.94 a	12.64 ab	127.93 abc	3.99 cde
14:0.75:9	1.91 abc	12.67 a	3.06 abc	2.62 abc	9.48a-d	174.09 abc	5.69 b-e
14:1.00:5	2.14 abc	10.36 abc	3 abc	2.52 abc	9.36 a-d	146 abc	1.45 e
14:1.00:7	2.31 ab	12.36 ab	3.12 abc	2.63 abc	10.36 a-d	192.81 abc	5.15 b-e
14:1.00:9	1.97 abc	11.3 abc	3.08 abc	2.47 abc	8.48 bcd	68.51 c	9.1 bcde
14:1.25:5	1.98 abc	9.47 abc	2.94 abc	2.42 abc	8.01 bcd	107.49 abc	11.75 a
14:1.25:7	1.93 abc	8.98 abc	2.98 abc	2.49 abc	9.21 a-d	151.1 abc	3.91 cde
14:1.25:9	1.93 abc	11.78 abc	2.73 abc	2.47 abc	8 bcd	163.92 abc	3.41 de
DMSH	0.58	4.71	0.88	0.66	6.02	185.4	5.81
CV (%)	10.99	17.76	10.77	9.41	22.66	41.7	34.02

Regimen corresponding to the comtrol treatment; DF= flower diameter; NFRU= number of fruits per plant; LF= fruit length; DFR= fruit diameter; PPF= average weight per fruit; RPP= average yield per plant; CSST= concentration of total soluble solids; DMSH= honest minimal significant difference; CV= coefficient of variation. Means with the same column literal are statistically equal according to the Tukey test ($p\leq 0.05$).

Caso *et al*. (2010) reported 68.17 fruits per plant over a period of 270 days in strawberries grown in pumice using the La Molina hydroponic nutrient solution. The amount of fruit produced by plants can vary since temperatures of 24 to 32 °C cause abortion of fruits in some plants, therefore, the amount of fruit decreases (Taylor, 2002; Romero-Romano *et al*., 2012).

There were also significant statistical differences in length and diameter in strawberry fruits var. San Andreas, the regime that favored both variables (3.59 and 2.96 cm respectively) was 10:1.25:7. Chávez-Sánchez *et al*. (2014) reported values in the length of strawberry fruits 3.68 cm and for the diameter 2.73 cm applying a concentration of NO_3^- of 9 milliMol (mM) in the nutritive solution. Caso *et al*. (2010) obtained in the diameter and length values of 2.99 cm and 4.11 cm, respectively, in strawberry fruits with the rice husk substrate and La Molina hydroponic solution.

The nutritional regime 10:1.25:7 had a significant effect ($p \leq 0.05$) on the average weight per fruit (15.15 g), which was 147% higher than the fruits (6.13 g) of plants fed with 10:1.25:5. In this case, the variation in the response was due to the concentration of SO_4^{2-} in the fruiting phase. Casierra-Posada and Poveda (2005) obtained fruit weights of up to 10.7 g, however, they also mention that radiation and photoperiod affect the weight of strawberry fruits.

Regarding the yield of fruits per plant, the outstanding value (289.28 g) was registered with the regime (in meq L^{-1}) 10:1:7, which was 322.24% higher than that registered in plants fed with 14:1:9 (Table 3). Moor *et al*. (2004) reported fruit yield of 252 g per plant, fertilizing with the Kemfos® and Kemira Ferticare® products in the different phenological phases of strawberry var. Bounty, while Romero-Romano *et al*. (2012) obtained 189.42 g using organic-mineral nutrition (chemical fertilizer + fulvic acids + growth regulator + vermicompost), while Furlani and Fernández (2007) indicated yields of 50 to 300 g.

In relation to the nutritional regime, it would be expected that with the highest concentration of NO_3^- (14 meq L^{-1}) in the vegetative phase and K^+ (9 meq L^{-1}) in the fruiting phase, the fruit yield per plant was higher than with the lower values of both nutrients: 10 and 7, respectively; however, the data showed otherwise. From the above, it follows that the relationships between the concentration of NO_3^- in the vegetative phase and that of K^+ in the fruiting phase is more important than the absolute value of each of the nutrients involved.

The physical characteristics of the fruit are important, but so is the degree of sweetness, among other biochemical attributes (Juárez-Rosete *et al*., 2007). Table 3 shows that the regime that favored the CSST was (in meq L^{-1}) 14:1.25:5, with a value of 11.75 °Brix, in relation to that obtained in fruits of plants fed with 14:1.00:5, was 710% higher (Table 3). Roudeillac and Trajkovski (2004) point out that the strawberry must be between 7 and 12 °Brix, to be among the post-harvest quality recommendations. Giraldo (2006) reported 9.3 °Brix in strawberry fruits, while Martínez-Bolaños *et al*. (2008) reached values of up to 8.48 °Brix with the Mexican strawberry cultivar CP-Roxana. Núñez-Castellano *et al*. (2012) evaluated strawberry fruits where the result was 9.50 °Brix with the treatment without calcium immersion, with plastic cover.

It is important to note that with the decrease of $H_2PO_4^-$ in the flowering phase, with the same concentration of NO_3^- and K^+ in the vegetative and fruiting phases, respectively, the CSST decreased significantly, which may indicate that, in the metabolism of sugars, organic acids, among others, the participation of $H_2PO_4^-$ is important as is its relative concentration with the other two ions (NO_3^- and K^+).

Conclusions

Strawberry plants produced in hydroponics with nutritional regimen showed a significantly different response in the relative content of chlorophyll, leaf area, dry biomass of leaves, flower diameter, length and equatorial diameter of the fruit, average fruit weight, yield per plant and concentration. of total soluble solids in fruit, depending on the relative concentrations between NO_3^-:$H_2PO_4^-$:K^+, in the vegetative, reproductive and fruiting phases, respectively.

The nutritional regime of 10 meq L^{-1} of NO_3^- in the vegetative phase, 1 meq L^{-1} of $H_2PO_4^-$ in the reproductive phase and 7 meq L^{-1} of K^+ in fruiting, is recommended to produce strawberry in soilless system because the diameter of the fruit and the yield per plant increased significantly.

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