https://doi.org/10.32854/agrop.vi.1673

Phenology and quality of habanero pepper fruits (*Capsicum chinense* Jacq.) due to nutrient solution in hydroponics

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ABSTRACT

Objective: To evaluate the phenological development and fruit quality of habanero pepper (*Capsicum chinense* Jacq.) with three nutrient solutions.

Design/Methodology/Approach: In a hydroponic system the nutrient solutions of Steiner, Hoagland and Soria were used to evaluate the phenology, morphology and pungency (spicy-hotness) of the habanero pepper fruits.

Results: It was observed that the nutrient solution of Soria brought flowering 4 d ahead, but it delayed fruiting by 2 d compared to the other treatments. Steiner solution incremented length (4 cm), diameter (2.9 cm), weight (8 g) and moisture content (89%) of the fruit compared to the other nutrient solutions. Capsaicin and dihydrocapsaicin increased in plants watered with Steiner nutrient solutions (24 and 12.5 mg g^{-1}, respectively) and Soria (23 and 12.7 mg g^{-1}, respectively), as well as Scoville units (>538,000).

Study limitations/Implications: Although favorable results were found in some treatments, more studies are required to evaluate the nutrient composition of the different organs of habanero pepper plants, by phenological stages.

Findings/Conclusions: Considering phenology, fruit quality and capsaicinoids content, the Steiner nutrient solution could be a suitable option for cultivating habanero peppers in hydroponic systems.

Keywords: capsaicinoids, flowering, pungency (spicy-hotness).

INTRODUCTION

Applying the appropriate amount of nutrients to plants allows them to perform their basic metabolic functions (Nieves-González *et al*., 2015). In many cases the fertilization of a crop is based on the empirical knowledge of farming producers (Sonneveld and Voogt, 2009) and not on the requirement of the cultivated species. An alternative for the production of vegetables are hydroponic systems, which use balanced nutrient solutions that allow water and nutrients to be efficiently absorbed by the plants (Juárez *et al*., 2006). However, in vegetables such as the habanero pepper (*Capsicum chinense* Jacq.), studies on the use of nutrient solutions in hydroponic systems are scarce (López-Gómez *et al*., 2017).

Agroproductividad: *Vol. 13, Núm. 9, septiembre. 2020. pp: 33-38.*
Recibido: *abril, 2020.* **Aceptado:** *agosto, 2020.*

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The habanero pepper is a crop of great economic importance due to its spicy fruits (Ruíz-Lau *et al*., 2011). Flowering and fruiting depend on strong amounts of macronutrients (N, P, Ca, K and Mg) to produce flowers and fruits (Prado, 2006). Competition for nutrient elements and the production of photoassimilates can modify the phenology of the habanero pepper (Meneses-Lazo *et al*., 2018). Likewise, nutrition influences the size and quality of pepper fruits in hydroponic systems (López-Gómez *et al*., 2017), as well as the capsaicinoids content (Medina-Lara *et al*., 2008). Therefore, the objective of this work was to evaluate the phenological development and quality of the habanero pepper fruits (*Capsicum chinense* Jacq.) responding to different nutrient solutions in a hydroponic system.

MATERIALS AND METHODS

This research was carried out in a greenhouse of the Technological Institute of Conkal. Seeds of habanero pepper (*Capsicum chinense* Jacq.) Orange variety (Geneseeds, Jalisco, Mexico) were sown in 200-cavity polystyrene trays, Canadian moss (SunGro Horticulture, Massachusetts, USA) was used as substrate. At 20 days after sowing (in Spanish, dds) foliar fertilization began (19:19:19 of N:P:K, 1.0 g L^{-1}, twice a week). At 50 dds, the transplant was carried out in 15 L pots and a mixture of tezontle (inert volcanic gravel) and coconut fiber (*Cocos nucifera* L.) was used as the substrate, in a 3:2 v/v ratio, previously steam sterilized. The agronomic management of the crop was that recommended by Soria *et al*. (2002).

Nutrient solutions

The nutrient solutions of Steiner (1984), Hoagland and Arnon (1950), and Soria *et al*. (2002) were used, and each solution was a treatment. The Steiner (T1) and Hoagland (T2) nutrient solutions were chosen because they are balanced universal solutions that include all the essential macronutrients (N, P, K, Ca, Mg, S), while the solution of Soria *et al*. (2002) was chosen as the control (T3) because it is of the customary use in Yucatán, México by pepper and habanero producers. However, the sources of N and P for this solution were modified. In the place of urea (46% N), ammonium nitrate (33% N) was used to avoid microorganisms which convert urea to ammonium; and, instead of phosphoric acid, monopotassium phosphate was used (to avoid a very acidic pH).

Thus, Steiner solution was formulated with: 9, 3, 4, 3 and 1 meq L^{-1} of $Ca(NO_3)_2$, KNO_3, $MgSO_4$, K_2SO_4, KH_2PO_4, respectively. Hoagland & Amon's with 1, 8, 6, 4, and 1 meq L^{-1} of NH_4NO_3, $Ca(NO_3)_2$, KNO_3, $MgSO_4$, KH_2PO_4, respectively. And that of Soria was formulated according to the requirements of four pepper phenological stages: transplant (7.9, 4.9 and 2. 6 meq L^{-1} de NH_4NO_3, KH_2PO_4 y KNO_3, respectively); growth and flowering (2.7, 1.2 and 2.5 meq L^{-1} de NH_4NO_3, KH_2PO_4 y KNO_3, respectively); fruiting (0.7 and 1.2 meq L^{-1} de NH_4NO_3 y KH_2PO_4, respectively); and production (0.3 and 1.4 meq L^{-1} de KH_2PO_4 y KNO_3, respectively). Micronutrients (30 mg L^{-1}) were added to the three nutrient solutions (treatments).

Reproductive phenology and fruit morphology

The time to flowering and fruiting was calculated, a stage was considered as flowering or fruiting when 50% + 1 of the evaluated plants presented flowers or fruits (Garruña-Hernández *et al*., 2012). The fruits were weighed with an analytical balance and the pericarp thickness, length and diameter of the fruit were determined with a Vernier caliper.

Ash content and moisture percentage in fruits

To determine the ash content, the fruits were weighed fresh, dried in an oven at 60 °C for 5 d, and ground until obtaining fine powder. In addition, crucibles were placed in an oven at 150 °C for 4 h, then they were placed in a drying hood to lower the temperature and the weight of the empty crucible was determined, in each crucible 1 g of dried fruit powder was placed and they were put in a muffle furnace at 600 °C for 5 h to obtain the weight of crucible with ash. To determine the weight of ash, to the weight of the crucible with ash was subtracted the weight of the empty crucible. To determine the percentage of ash, the ash weight was divided by the sample weight in grams and multiplied by one hundred.

Capsaicinoid content

For determination of capsaicinoids the fruits were placed in an oven at 60 °C for 5 d, ground, and 1 g of dried and powdered fruit was weighed and placed in a 250-mL flask. Three replicates were generated by treatment. To each flask, 25 mL of acetonitrile were added and placed in a shaker at 60 °C for 4 h in the dark, with stirring at intervals of 20 min. Subsequently, the samples were filtered and the filtrate obtained was placed in flasks that were made up to 25 mL with acetonitrile. The samples were homogenized and 2 mL were placed in dark vials for reading on high resolution liquid chromatography. The data were expressed in content (mg g^{-1}-of PS, Spanish for DW) and pungency (Scoville heat units, SHU). One

SHU is equivalent to 0.015 mg g^{-1} of capsaicinoids dry weight.

A randomized complete block experimental design with five replications was used. Three treatments were evaluated (T1=Steiner nutrient solution; T2=Hoagland & Amon nutrient solution; T3=Soria *et al.*, modified nutrient solution). Twenty-five plants were established per treatment. An analysis of variance (ANOVA, $p \leq 0.05$) and a Tukey test ($\alpha = 0.05$) were performed on the data. The data in percentages were transformed by the square root of the arc sine.

RESULTS AND DISCUSSION

Times to flowering and fruiting

The habanero pepper plants advanced flowering 4 d ahead with the Soria solution (72 dds), followed by the plants with Hoagland's, and Steiner solutions (76 dds) (Figure 1A). According to Medina-Lara *et al.* (2008), flower production depends more on N concentrations than those of K. The Soria solution has high doses of N in growing and flowering stages; thus, it is probable that the increase in the concentrations of N and K in the Soria solution favored the precocity of flower buds in the plants. Similarly, the increase in P concentrations in the nutrient solution can favor flower production (Coutinho *et al.*, 2014). Plants with Soria solution had high doses of P during the transplant stage (4.9 meq L^{-1}), it is probable that this also contributed to early flowering.

Plants irrigated with Steiner and Hoagland solutions brought the fruiting stage 2 d ahead (90 DAP) compared to plants watered with Soria solution (92 dap). But, at 90 dds, the plants with Hoagland solution (52%) had a lower percentage of plants with fruits than the plants watered with Steiner (68%) (Figure 1B).

In this regard, Medina-Lara *et al.* (2008) reported that the application of N with 15 meq L^{-1} promotes fruit production in habanero pepper. Similarly, Nieves-González *et al.* (2015) mentioned that the application of P with 1.5 meq L^{-1} increased the production of habanero pepper fruits. Steiner and Hoagland solutions supply similar concentrations of NO_3^- and $H_2PO_4^-$ constantly in the crop, which probably avoided competition for nutrients during fruit formation. In addition, the formulation of both solutions included other elements such as Ca, Mg and S, which are also important for plant and fruit growth (Barker and Pilbeam, 2014).

Fruit morphology

The habanero pepper fruits watered with Steiner nutrient solution had greater length and diameter (4.0 and 2.9 cm, respectively) compared to fruits watered with Hoagland (3.2 and 2.4 cm, respectively) and Soria (3.8 and 2.4 cm,) solutions (Figure 2A and 2B). The fruits of the Steiner treatment were visually more robust (Figure 3A-3C) and with better appearance (Figure 3D-3F).

Similarly, the fruits of the plants watered with Steiner solution presented greater weight (8 g) compared to those of Hoagland (5.5 g) and Soria (6.5 g) solutions (Figure 2D). However, the fruits of the treatment with the Soria nutrient solution had greater pericarp thickness (2.2 mm) than the other treatments (Steiner: 2.04 mm, and Hoagland: 2.02 mm) (Figure 2C and 3G-I). Some authors mention that in hydroponic cultivation the habanero

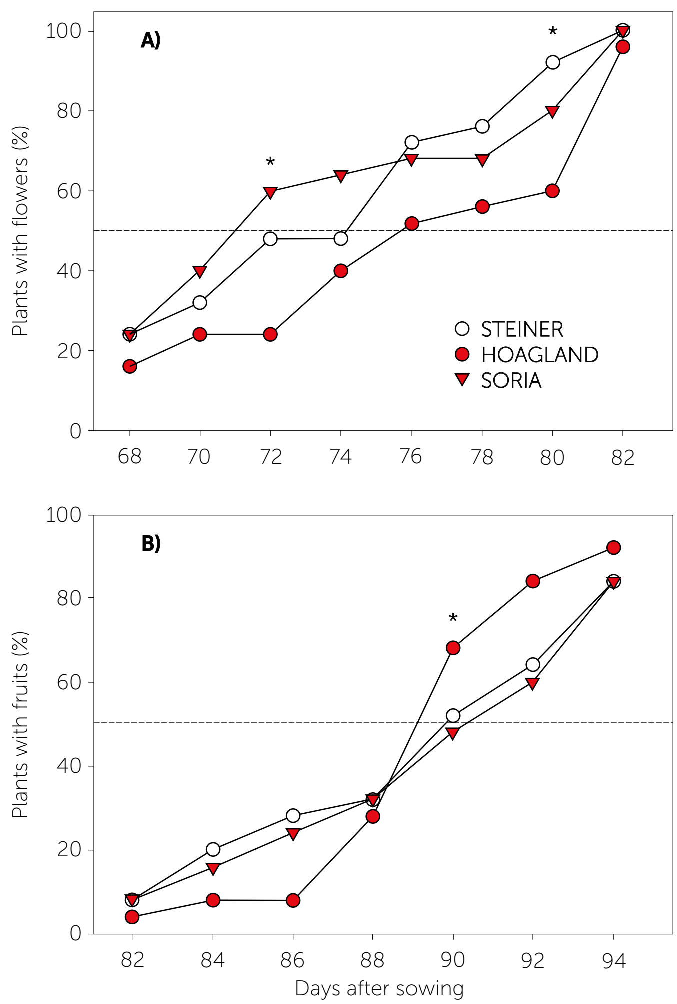

Figure 1. Time to flowering (A) and fruiting (B) of habanero pepper plants (*Capsicum chinense* Jacq.), fertilized with different nutrient solutions (Steiner, Hoagland and Soria) in a hydroponic system. The dotted line indicates 50% of individuals with flowers or fruits. The values represent the means ± standard error, *=statistical differences (ANOVA, $p \leq 0.05$); n=25.

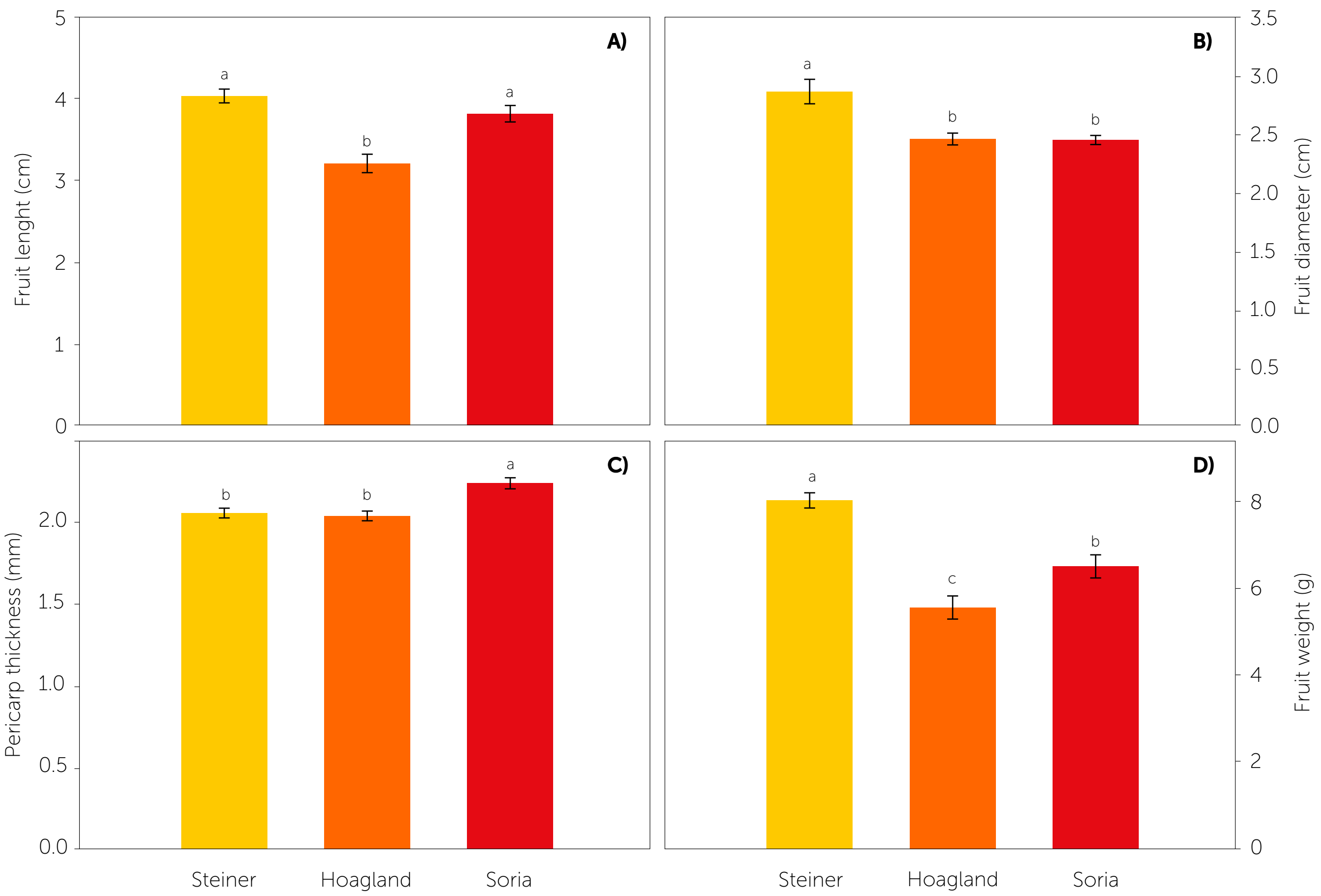

Figure 2. Fruit length (A), fruit diameter (B), pericarp thickness (C) and fruit weight (D) of habanero pepper plants (*Capsicum chinense* Jacq.), fertilized with different nutrient solutions (Steiner, Hoagland and Soria) in a hydroponic system. Data are means ± standard error; different letters indicate statistical differences between treatments (Tukey, α=0.05); n=100.

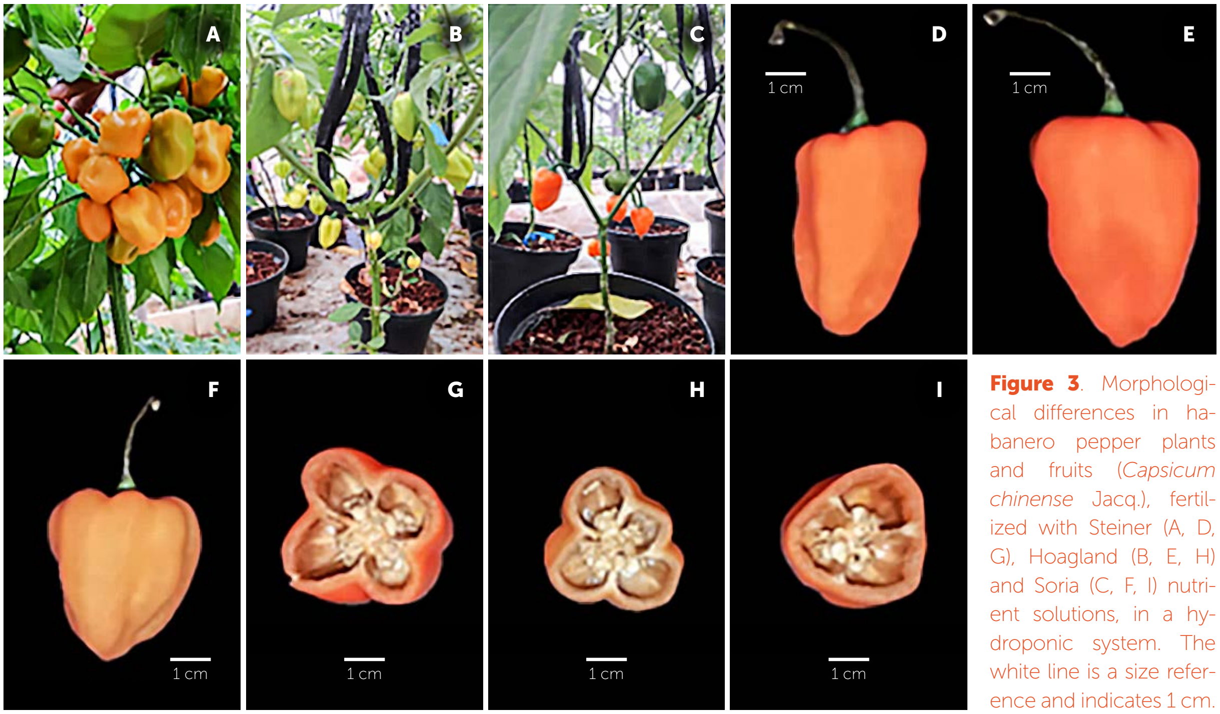

Figure 3. Morphological differences in habanero pepper plants and fruits (*Capsicum chinense* Jacq.), fertilized with Steiner (A, D, G), Hoagland (B, E, H) and Soria (C, F, I) nutrient solutions, in a hydroponic system. The white line is a size reference and indicates 1 cm.

pepper can reach a length between 3.5 and 3.6 cm, with diameters between 2.3 and 2.5 cm (Tucuch-Haas *et al*., 2012; López-Gómez *et al*., 2017).

Fruit weight was statistically different among treatments, and no statistical differences were found in the weight of ash. However, the Steiner and Soria solutions presented a higher percentage of ash in the fruit (8.76 and 8.89%, respectively), respect to the Hoagland solution (8.26%). On the other hand, the fruits with Steiner solutions had a higher percentage of humidity (89%) compared to the fruits of the plants watered with Hoagland and Soria solutions (84 and 86%, respectively) (Table 1). The percentage of ash is an indicator of the accumulation of biomass in plants, a product of their photosynthetic activity (Azcón-Bieto and Talón, 2013). It is probable that the plants, watered with Steiner and Soria solutions, allocated more photo-assimilates to the fruits, which favored their size and increased the percentage of ash and moisture.

Table 1. Weight and percentage of ashes and moisture content of habanero fruits (*Capsicum chinense* Jacq.) grown with three nutrient solutions.

Treatments	Ash weight (g)	Ash (%)	Moisture content (%)
Steiner	0.921±0.002	8.76±0.04 a	89±0.2 a
Hoagland	0.923±0.002	8.26±0.09 b	84±0.4 c
Soria	0.920±0.002	8.89±0.03 a	86±0.1 b

* Data are means±standard error; different letters in columns indicate statistical differences among treatments (Tukey, α=0.05); n=9.

Physicochemical characteristics of the fruit

Capsaicin (CAP) in the fruits of the plants watered with Steiner and Soria solutions (23.94 and 23.27 mg g^{-1} respectively) was statistically higher compared to the fruits of the treatment with Hoagland (19.26 mg g^{-1}) (Table 2). In dihydrocapsaicin (DHCAP), the fruits with the Soria solution (12.65 mg g^{-1}) were statistically superior to the fruits with the Hoagland solution (10.31 mg g^{-1}) (Table 2). Likewise, it was observed that the fruits with the Steiner and Soria solutions had a higher content of total capsaicinoids (total CAP's) (36.42 and 35.92 mg g^{-1}, respectively) compared to the Hoagland treatment (29.58 mg g^{-1}). According to Aldana-Iuit *et al*. (2014) there is a positive correlation between the concentration of NO_3^- and the accumulation of capsaicinoids in the placentas of habanero pepper. However, Medina-Lara *et al*. (2008) mention that the supply of N in high concentrations can decrease the capsaicin content in the fruits. In this case, the application of N, throughout the entire cultivation, led to contrasting effects on the accumulation of capsaicinoids between the Steiner and Hoagland solutions, probably as a result of the difference in the concentration of N (Steiner: 12 meq L^{-1} of NO_3^-; Hoagland: 14 meq L^{-1} of NO_3^- y 1 meq L^{-1} of NH_4^+). The treatment with more N (Hoagland) decreased the spicy-hotness (pungency) of the fruits. It is probable that the increase in the pungency of the fruits with the Soria solution is due to a greater distribution of photo-assimilates in the fruits than in the rest of the plant, caused by the decrease in nutrients in the production stage (nutritional deficit), which would cause stress in the plant. Then the plant, in response, would channel the photo-assimilates to sites where they are most required (Azcón-Bieto and Talón, 2013). In the Scoville units (SHU) the fruits of the treatments with the Steiner and Soria solutions (546,000 and 538,800 SHU, respectively) statistically surpassed the fruits watered with the Hoagland solution (443,550 SHU) (Table 2).

According to Canto-Flick *et al*. (2008), the degree of pungency in habanero pepper can vary considerably due to genetic or environmental factors. In this regard, Garruña-Hernández *et al*. (2013) report 15.9 mg g^{-1} of capsaicinoids with 238,500 SHU in ripe habanero pepper fruits, in a high CO_2 environment (760 mg kg^{-1}). In this study, it is probable that the difference in the degree of pungency of the peppers is due both to environmental conditions and to the nutrition applied to the plants; favoring the obtention of fruits with differences in the content of capsaicinoids and in the SHU values.

Table 2. Contents of capsaicin (CAP), dihydrocapsaicin (DHCAP), total capsaicinoids (total CAP's) and Scoville units (SHU) in habanero pepper fruits (*Capsicum chinense* Jacq.), evaluated with three nutritional solutions.

Treatments	CAP (mg g^{-1})	DHCAP (mg g^{-1})	Total CAP's (mg g^{-1})	SHU
Steiner	23.94±0.72 a	12.48±0.23 ab	36.42±0.94 a	546,300±14,000 a
Hoagland	19.26±0.21 b	10.31±0.48 b	29.58±0.66 b	443,550±9,900 b
Soria	23.27±0.27 a	12.65±0.13 a	35.92±0.36 a	538,800±5,400 a

Data are means±standard error; different letters in each column indicate statistical differences among treatments (Tukey, α=0.05); n=3.

CONCLUSIONS

Steiner nutrient solution advanced the fruiting stage and improved fruit morphology, by producing larger and heavier fruits. The most spicy-hot (pungent) habanero pepper fruits were obtained with the nutrient solutions of Steiner and Soria. Considering the phenology and the quality of the fruits, Steiner nutrient solution may be an option for cultivating habanero peppers in hydroponic systems.

ACKNOWLEDGEMENTS

To the Consejo Nacional de Ciencia y Tecnología (CONACYT, México) for the scholarship granted to the first author for her postgraduate studies.

REFERENCES

Aldana-Iuit, J.G., Sauri-Duch, E., Miranda-Ham, M.L., Castro-Concha, L.A., Cuevas-Glory, L.F. and F.A. Vázquez-Flota. (2015). Nitrate promotes capsaicin accumulation in *Capsicum chinense* immobilized placentas. BioMed Research International. Art. ID: 794084; http://dx.doi.org/10.1155/2015/794084

Azcón-Bieto, J. y M. Talón. (2013). Fundamentos de fisiología vegetal. 2ª Ed. McGraw Hill Interamericana. Madrid, España. 651 p.

Barker, A. V. and D. J. Pilbeam. (2015). Handbook of plant nutrition. 2nd Ed. CRC Press. Taylor and Francis Group, L. L. C. New York, U. S. A. 743 p.

Canto-Flick, A., Balam-Uc, E.; Bello-Bello, J.J., Lencona-Guzmán, C., Solís-Marroquín, D., Avilés-Viñas, S., Gómez-Uc, E., López-Puc, G., Santana-Buzzy, N. and L.G. Iglesias-Andreu. (2008). Capsaicinoids content in Habanero pepper (*Capsicum chinense* Jacq.): Hottest known cultivars. HortScience. 43(5): 1344-1349.

Coutinho E., L. M.; Orioli J., V.; Silva E., J.; Coutinho N., A. M. y S. Cardoso S. (2014). Nutrición, producción y calidad de frutos de tomate para procesamiento en función de la fertilización con fósforo y potasio. Agrociencia Uruguay, Vol. 18(2): 40-46.

Garruña-Hernández, R., Canto, A., Mijangos-Cortés, J.O., Islas, I., Pinzón, L. and R. Orellana. (2012). Changes in flowering and fruiting of Habanero pepper in response to higher temperature and CO2. Journal of Food, Agriculture and Environment. 10 (3&4): 802-808.

Garruña-Hernández, R., Monforte-González, M., Canto-Aguilar, A., Vázquez-Flota, F. and R. Orellana. (2013). Enrichment of carbon dioxide in the atmosphere increases the capsaicinoids content in Habanero pepper (*Capsicum chinense* Jacq.). Journal of the Science of Food and Agriculture, Vol. 93: 1385-1388.

Hoagland, D. R. and D. I. Arnon. (1950). The water-culture method for growing plants without soil. California Agricultural Experiment Station. Circular 347. The College of Agriculture, University of California, Berkeley. 32 p.

Juárez H., M. J.; Baca C., G. A.; Aceves N., L. A.; Sánchez G., P.; Tirado T., J. J.; Sahagún C., J. y M. T. Colinas de León. (2016). Propuesta para la formulación de soluciones nutritivas en estudios de nutrición vegetal. Interciencia, Vol. 31(4): 246-253.

López-Gómez, J. D., O. G. Villegas-Torres, H. Sotelo N., M. Andrade R., P. Juárez L., y E. Martínez F. (2017). Rendimiento y calidad del chile habanero (*Capsicum chinense* Jacq.) por efecto del régimen nutrimental. Revista Mexicana de Ciencias Agrícolas, Vol. 8(8): 1747-1758.

Medina-Lara, F., Echevarría-Machado, I., Pacheco-Arjona, R., Ruíz-Lau, N., Guzmán-Antonio, A. and M. Martínez-Estévez. (2008). Influence of nitrogen and potassium fertilization on fruiting and capsaicin content in Habanero pepper (*Capsicum chinense* Jacq.). HortScience, Vol. 43(5): 1549-1554.

Meneses-Lazo, R., Garruña-Hernández, R., Latournerie-Moreno, L., Andrade-Torres, J.L. y A. Pérez-Gutiérrez. (2018). Caracterización fenológica y fisiológica de variedades experimentales de chile habanero con alto potencial agronómico. Revista Fitotecnia Mexicana, Vol. 41(1): 67-74.

Nieves-González, F., Alejo-Santiago, G., Luna-Esquivel, G., Lemus-Flores, C., Juárez-López, P. y E. Salcedo-Pérez. (2015). Extracción y requerimiento de fósforo en chile habanero (*Capsicum chinense* Jacq.) 'Big Brother'. Interciencia, Vol. 40(4): 282-286.

Prado U., G. (2006). Tecnología de Producción Comercial de Chile Habanero (*Capsicum chinense* Jacq.). Gobierno del Estado de Tabasco. 35 p.

Ruíz-Lau, N., Medina L., F. y M. Martínez E. (2011). El chile habanero: su origen y usos. Revista Ciencia - Academia Mexicana de Ciencias, Vol. 62(3): 70-77.

Sonneveld, C. and W. Voogt. (2009). Plant nutrition of greenhouse crops. Ed. Springer. New York, U. S. A. 471 p.

Soria, M.; Trejo, J.; Tun, J. y R. Terán. (2002). Paquete tecnológico para la producción de chile habanero (*Capsicum chinense* Jacq.). Secretaría de Educación Pública. Subsecretaría de Educación e Investigación Tecnológicas (SEP-SEIT-ITA). Instituto Agropecuario No. 2, Conkal, Yucatán, México.

Steiner, A. A. (1984). The universal nutrient solution. pp. 633-650. In: Proceedings 6th International Congress on Soilles Culture. Wageningen, The Netherlands.

Tucuch-Haas, C. J., G. Alcántar-González, V. M. Ordaz-Chaparro, J. A. Santizo-Rincón, y A. Larqué-Saavedra. (2012). Producción y calidad de chile habanero con diferentes relaciones NH_4^+ / NO_3^- y tamaño de partícula de sustratos. Terra Latinoamericana, Vol. 30: 9-15.