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Evaluation of guajillo and chile de árbol peppers (*Capsicum annuum* L.) in a hydroponic greenhouse system

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ABSTRACT

Objective: To evaluate the yield of guajillo pepper (CHG) and chile de árbol pepper (CHA) grown in containers with coconut fiber substrate in a hydroponic greenhouse system.

Methodology: Four types of chili peppers were tested: two CHG and two CHA peppers. The CHG peppers with seeds were from two growing areas in the state of San Luis Potosí (SLP), located in the Altiplano Central (high plateau region) of Mexico: one from Las Colonias, Salinas, and the other from El Barril, Villa de Ramos. The CHA peppers were obtained in Yahualica, Jalisco: one in El Salto Verde (CHA-SaltoVerde) and the other in El Faro (CHA-Faro). The chili peppers were established in a hydroponic system with two types of containers (pots (SHM) and slabs (SHB)), in both of which coconut fiber (coir) was used as a substrate. The experimental design was completely randomized with three repetitions and the comparison of means was made with the Tukey test ($p<0.05$).

Results: Significant differences were observed between chile de árbol and guajillo peppers grown in SHM regarding the following variables: plant height and number of leaves, flowers, and peppers. Chile de árbol peppers recorded the highest values for the four variables. There were also significant differences between the chile de árbol and the guajillo peppers regarding the fresh weight and dry weight variables, but, in this case, the guajillo peppers had the highest values. The highest dry weight value (g plant-1) was obtained by CHG-Barril (1,094 g plant^{-1}), followed by CHG-Colonias (866 g plant^{-1}); meanwhile, the lowest values were recorded for CHA-Faro and CHA-SaltoVerde chile de árbol peppers (819 and 258 g plant^{-1}, respectively). The same pattern was observed in the SHB, with significant differences between the chile de árbol —which had the highest values— and guajillo peppers for the following variables: plant height, number of leaves, flowers, and peppers. There were also significant differences in terms of fresh weight between chile de árbol and guajillo peppers, with the latter recording higher values. Finally, CHG-Colonias and CHA-SaltoVerde showed the highest dry weight values with 633 and 595 g plant^{-1}, respectively. Although there were no significant differences between them, there were significant differences with respect to CHG-Barril and CHA-Faro (524 and 483 g plant^{-1}, respectively).

Study Limitations/Implications: The present study has no major limitations.

Conclusions: In general, a better dry yield of chili pepper was obtained with guajillo peppers produced in a pot system. Hydroponic systems in pots and slabs, using a coir substrate, are an alternative in protected agriculture for the production of guajillo and chile de árbol peppers.

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INTRODUCTION

Chili pepper (*Capsicum* spp.) is one of the major crops consumed worldwide. The large amount of nutrients contained in its fruit make it a relevant food. Mexico is the center of origin of *Capsicum*. Chili pepper is an export crop, with great variety and tradition in

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the Mexican gastronomy. It is consumed fresh or dry and, for many years, it has been an essential and typical ingredient of Mexican dishes. It is also rich in vitamin A and a source of β-carotene (Shetty *et al.*, 2013; SAGARPA, 2017).

Mexico has a wide diversity of chili peppers, characterized by their color, smell, flavor, heat, and size. Dehydrated or dry chili peppers (mainly of the *C. Solanaceae*, *C. annuum*, *C. frutescents*, and *C. sinenses* types) are available throughout the year and they have very particular characteristics in each state (Inforural, 2010).

The level of technology used for the chili pepper production varies among the different regions in which it is grown. In the north and northeast region, high technology is used to produce fresh chili pepper, obtaining good yields and productivity. In the Bajío or central region, medium technology is used to produce dry chili pepper (*Capsicum annuum* Linnaeus cv. "Mulato" and "Ancho," *Capsicum annuum* L. var. *annuum* L. cv. "Pasilla", *Capsicum annuum* - "Puya", *Capsicum annuum* var. *annuum* L. "Guajillo") under irrigation. The fruits are harvested when they are completely dry; however, the traditional drying methods result in low dry yields and poor-quality products. This region includes the states of Aguascalientes, Guanajuato, Puebla, San Luis Potosí, Zacatecas and Querétaro. Meanwhile, in the south and southeast region, chili pepper is produced with low technology, resulting in low yields (Caro *et al.*, 2014; Inforural, 2012).

The chile de árbol pepper originated in tropical and subtropical regions of the Americas, but it can adapt to semi-arid and temperate environments with a clearly identifiable winter. It has an annual cycle. It develops from sea level up to 2,000 m.a.s.l. (Jaramillo, 2010). It responds to short days and neutral days (*i.e.*, less than 12 hours to 14 hours of light). It is a plant that requires a lot of light (Japón, 1980). It thrives at average temperatures of 24 °C (minimum 16 °C and maximum 30 °C), with at least 3 months of warm weather required for good crop development (Jaramillo, 2010). According to Martínez (2007), it tolerates temperatures from 10 °C to 32 °C. The optimum temperature ranges from 15 °C to 26 °C. It does not grow well under cold conditions, but temperatures above 32-34 °C can cause flower abscission and fertilization and fruit set problems. It grows well with 600 to 1,250 mm of rainfall per year and is favored by a range of 55 to 90% relative humidity (Jaramillo, 2010). A $\approx$75% relative humidity is favorable (Chávez, 2001). It requires 50 to 150 cm depth soils. It develops well in somewhat sandy to clayey soils; however, the production is higher in the former. It prefers soils with a clay-loam or sandy-loam texture, with good drainage (Japón, 1980). Soils with 6-6.5 pH are favorable for its development (Jaramillo, 2010).

Unlike other kinds of chili, fresh and dry chile de árbol peppers share the same name. They can be used regardless of their state (fresh or dry). This variety is the most used for making salsas, given its high heat. The main chili-producing states are: Jalisco, Nayarit, Aguascalientes, Zacatecas, Chihuahua, and Guanajuato (Aguirre and Muñoz, 2015).

Given its production volume, guajillo pepper is included among the four most important chili peppers in the country. From 2000 to 2009, the apparent consumption averaged 1,584,000 tonnes; however, in 2008 and 2009, it was below the average. In 2000, one out of every ten tonnes was exported, but currently only four tonnes are exported. The harvested area registered an average annual growth rate of -0.4 % in the 2000-2009 period; therefore, it decreased from 145,674 ha in 2000 to 140,424 ha in 2009 (COFUPRO, 2010).

The production of dry guajillo pepper has three main destinations: direct consumption, the production of mole and salsas, and the production of dyes. Almost 50% of the guajillo pepper produced is destined for direct consumption and the preparation of mole. They include first and second quality peppers, while the remaining 50% (poor-quality peppers) is destined for industrial consumption (production of salsas and mole) (COFUPRO, 2010).

The guajillo pepper has a particular flavor, resulting from its aroma and fleshiness, and is used to prepare mole, adobo, and salsa (SIAP, 2022).

The guajillo pepper has a heat of 2,500 to 5,000 Scoville units, while the chile de árbol pepper reaches 15,000 to 30,000 units (SIAP, 2017).

One of the main horticultural crops in the Altiplano Potosino is the guajillo or mirasol pepper. The area sown in that region reaches 5,000 ha and a 1.2 t ha^{-1} yield is produced with 80 days of work per ha, providing approximately $36 million MXN for the state. Its production requires the extraction of subsoil water, which is increasingly scarce. Likewise, a more efficient application of fertilizer will allow producers to obtain better yields that enable them to pay production costs and use water more efficiently. Ferti-irrigation is an alternative to improve the use of water and fertilizers in the cultivation of mirasol pepper. Ferti-irrigation can increase the production of dry chili pepper by more than 100%, speed up the harvest by 15 to 20 days, and pay the investment in the drip irrigation and ferti-irrigation systems with the first year's production (INIFAP, 2002).

In the Altiplano Potosino, 2-4 dry tonne yields are obtained per cycle, when guajillo or mirasol pepper is grown in the traditional way —mainly an open-air sowing for a period of 4 to 5 months after transplanting, combined with weeding and rolling or drip irrigation (INIFAP, 2002).

According to Reyes *et al.* (2006), a larger cultivated property generally means a greater use of technology and higher yield. Therefore, the levels of technology have a direct influence on the production volume. They also consider that the profitability and income of producers may increase as a result of the improved chances and conditions that they have to adopt technology. In short, as the size of the property and the application of technology increase, the yield per hectare will be higher and profitability levels will increase.

The use of medium and low technology is a common denominator in the cultivation of chili pepper in the whole country and some of its regions (*e.g.*, the north central region). This situation causes low yields of guajillo pepper and poor-quality fruits and seeds. Given the need to innovate the production systems, the hydroponic greenhouse production system can be an alternative to increase the yield potential and the quality of fruits and seeds.

MATERIALS AND METHODS

The experiment was carried out in a double tunnel greenhouse located in the "La Huerta" Experimental Unit, of the San Luis Potosí Campus (22° 62' N and 101° 71' W). Four types of chili peppers were tested: two from CHA, Salto Verde (CHA-SaltoVerde) and El Faro (CHA-Faro); and two from CHG, Las Colonias (CHG-Colonias) and El Barril (CHG-Barril). The seeds came from different places in the Altiplano Central of

Mexico: the chile de árbol peppers came from Yahualica, Jalisco; and the guajillo peppers came from Las Colonias, Salinas, SLP, and from El Barril, Villa de Ramos, SLP. The experiment was established in a hydroponic system with two types of containers: pots (SHM) and slabs (SHB). Both containers included coconut fiber as substrate, and they were irrigated with drippers on stake. Each type of container was evaluated independently. The experimental design was completely randomized with three repetitions. Before the experiment was established, the chili peppers with the best characteristics (size and seed weight) were selected. To determine which was the best seed to sow, 1,000 seeds were weighted with 5 repetitions, according to the following procedure: the seeds of 10 chili peppers were counted and weighed with 5 repetitions; the peel was also weighed; and the length, tip, and end of all the collected chili peppers were measured.

Sowing the seeds. Two seeds were sown per cavity at a 1-cm depth, in seedbeds with a peat moss substrate.

Irrigation system. It was installed in order to uniformize the pressure in both systems (slabs and pots). A 2,500-L water tank was installed to store the irrigation water with nutrient solution (NS); another 450-L water tank was used for the application of fungicides, pesticides, or rooting products. The water tanks were connected to a one-inch PVC tube and a ¼ HP pump. In order to control the water flow, a 16 mm hose was connected to the main line and a stopcock was placed at each of the hose's water outlets that irrigate the pots and slabs. In each line, 4 L h^{-1} drippers were installed, making a small hole in the hose. To avoid spilling water and consequently to distribute the irrigation evenly in each pot and slab, each dripper was assembled using a 5-outlet drip irrigation manifold with a micro tubing and 4 drippers on stake. Finally, a stopcock was installed at the outlet of each line to allow drainage and, therefore, to prevent the blockage of the drippers.

Placement and preparation of pots and slabs. A sketch with accurate measures was prepared in order to evenly distribute the pots and slabs. These containers were filled with commercial coconut fiber substrate (Germinaza) and perforated to place the plants. Both pots and slabs were placed in parallel lines and moistened for two days and two nights before the transplanting (February 26, 2018).

The transplanting was carried out 50 days after germination, once the substrate of pots and slabs was completely humid.

Nutrient solutions. The nutrient solution recommended by Hewit and Smith and modified by Gómez-González *et al.* (2019) was used. Two solutions (an initial and a final) with the exact requirements for the chili pepper crop was applied to 1,000 L of water and adjusted to 2,500 L.

Irrigation frequency. For one week after the transplanting, a flood-like irrigation was applied to avoid dehydration stress. For the initial phenological stage of the crop seven 5-min irrigations were programmed using a timer. Subsequently, eight irrigations (three 5-min and five 8-min irrigations) were scheduled for a more advanced phenological stage, in order to keep the plants well hydrated and with good drainage. The amount of water applied per plant was determined with ***control drippers***. The percentage of solution that was actually applied to each pot was observed in the ***drainage trays***, which were emptied daily.

Plant tutoring. The plants were attached to a steel cable using raffia. A hook, a clamp, and a plastic ring were used to fix a point of the stem and the base of the plant, in order to prevent them from falling. The raffia was as taut as possible.

Pests and diseases were controlled with the irrigation and spraying of various fungicides and insecticides. A 15-L sprayer was used to apply 1 mm of the product per 1 L of water. The "Muralla" insecticide was applied to control aphids, while the "Raley" fungicide was used to control downy mildew.

For **the harvest**, only ripe chili peppers or those that had signs of maturation were cut, counted, and weighed individually. Afterwards, they were stored in paper bags and dried. Two cuts were made (July 9 and 27, 2018).

Fruit drying. The samples were put in paper bags. The first cut of chili peppers was dried in ovens at a temperature of 60 °C. One part of the second cut was dried in an oven and the other in a greenhouse dryer.

Study variables

The following variables were measured: steam diameter, number of leaves, flowers, and fruits, plant height, and dry weight. The ***stem diameter*** was measured with a vernier, from the beginning of the crop until the end of the experiment. The ***leaves, flowers, and fruits*** were counted individually as they appeared on the plant, throughout the experiment, in order to determine their ***number***. ***Plant height*** was measured with a measuring tape, from the base of the stem to the tip, taking the highest leaf as reference. Each freshly cut fruit was weighed to determine the ***fresh weight***, considering only the fruits of the sampled plants. The ***dry weight*** was determined when the plants reached a constant weight during drying, in order to find the average weight of the sample.

Statistical analysis

The measured variables were subjected to an analysis of variance for a completely randomized model with three repetitions. The comparison of means was performed using Tukey's test ($p<0.05$).

RESULTS AND DISCUSSION

The analysis of variance for the types of chili peppers produced in the hydroponics system (with both containers) showed significant differences between the treatments (the four types of peppers evaluated). The comparison of means also showed significant differences between the evaluated variables.

In the case of the ***hydroponic system with pots***, the statistical analysis of the means test shows the results detailed below for the studied variables.

Regarding the plant height, number of leaves, and number of flowers variables, Table 1 shows that there were no significant differences ($p<0.05$), neither between one chile de árbol pepper and the other (CHA-SaltoVerde and CHA-Faro), nor between one guajillo pepper and the other (CHG-Colonies and CHG-Barril). However, significant differences were observed between chile de árbol peppers (CHA) and guajillo peppers (CHG). The

CHA recorded the highest values for plant height, number of leaves, and number of flowers. The CHG had a much lower value in these three variables.

Like the previous variables, the average number of chili peppers in the last sampling does not show significant differences (Table 2), neither between chile de árbol peppers (CHA-SaltoVerde and CHA-Faro), nor between guajillo peppers (CHG- Colonias and CHG-Barril). However, there are significant differences between the means of both types of peppers (CHA and CHG). Meanwhile, there are significant differences between the fresh weight of chile de árbol peppers (CHA) and guajillo peppers (CHG). However, guajillo peppers: CHG-Colonias (5,435 g plant^{-1}) and CHG-Barril (5,147 g plant^{-1}) had similar fresh weight, while there were significant differences between CHA-SaltoVerde (428 g plant^{-1}) and CHA-Faro (954 g plant^{-1}).

Regarding the average dry weight (g plant^{-1}) yields, differences were recorded between the means of each type of chili pepper and in the comparison of CHG with CHA. For example, CHG-Barril and CHG-Colonias had a yield of 1,094 and 866, respectively. For their part, CHA peppers had major differences: the CHA-Faro had the highest weight (819), while CHA-SaltoVerde recorded the lowest yield (258). Due to the type of fruit produced by each type of chili pepper, the CHG —which has a lower number of fruits than CHA— achieves a greater weight per plant in production.

Through the management systems, the dry weight of the fruit tended to have an inverse relationship with the number of fruits per plant —*i.e.*, a greater number of fruits observed represented a lower dry weight of the fruit. Although this was not the case for the CHA, the CHG did show this behavior. Differences between the types of chili peppers are also shown. The same response was observed by Olutolaj and Makine (1994) in chili peppers of

Table 1. Average height, number of leaves, and number of flowers, in the pot system.

Chili types	Height (cm)	Leaves (number)	Flowers (number)
CHA-Salto Verde	252.25 a	452.00 a	315.06 a
CHA-Faro	251.93 a	452.71 a	313.34 a
CHG-Colonias	175.56 b	331.43 b	110.25 b
CHG-Barril	174.31 b	330.15 b	107.03 b

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

Table 2. Average number of chili peppers, fresh weight, and dry weight, in the pot system.

Chili types	Fruit (number)	Fresh weight (g planta^{-1})	Dry weight (g planta^{-1})
CHA-Salto Verde	113.96 a	428.27 c	257.84 c
CHA-Faro	116.96 a	953.78 b	819.09 b
CHG-Colonias	60.40 b	5,435.07 a	865.81 b
CHG-Barril	60.40 b	5,146.96 a	1,094.02 a

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

the *C. annuum* and *C. frutescens* species, which indicates that it is a species-specific response. As observed in this study, some types of chili peppers experience a gradual increase in the number of flowers, number of fruits, and fruit weight, followed by a decrease in the reproductive organs. Nevertheless, in this study, the decrease occurred alternately according to the reproductive attribute and not in the same way that was reported by Olutolaj and Makine (1994).

Regarding the hydroponic system with slabs, the comparison of means shows that there were no significant differences in the plant height and number of flowers between chile de árbol peppers (CHA-SaltoVerde and CHA-Faro). However, there were significant differences between the number of leaves (Table 3). The number of leaves per plant was significantly higher for CHA-SaltoVerde than for CHA-Faro. On the contrary, none of the three variables of the CHG —which have very similar mean values— show significant differences. The means of the CHA have significant differences with respect to the CHG, since the former has higher height, number of leaves, and number of flowers.

The average number of chili peppers per plant in the last sampling was 122.68 (CHA-SaltoVerde) and 120.75 (CHA-Faro); meanwhile the CHG recorded averages of 66.21 (CHA-Colonias) and 65.71 (CHA-Barril) (Table 4). There are no significant differences in means, neither between chile de árbol peppers (CHA-SaltoVerde and CHA-Faro), nor between guajillo peppers (CHG-Colonias and CHG-Barril). On the contrary, there were significant differences between chile de árbol peppers (CHA) and guajillo peppers (CHG).

Table 4 shows that, regarding the fresh weight yield, significant differences were found between the guajillo peppers: CHG-Colonias recorded an average of 5,396 g plant^{-1}, while CHG-Barril registered 2,415 g plant^{-1}. On the contrary, there were no significant differences between both chile de árbol peppers: CHA-SaltoVerde obtained an average of

Table 3. Average height, number of leaves, and number of flowers, in the slab system.

Chili type	Height (cm)	Leaves (number)	Flowers (number)
CHA-Salto Verde	239.25 a	452.65 a	343.65 a
CHA-Faro	238.12 a	436.62 b	338.81 a
CHG-Colonias	181.81 b	334.75 c	116.00 b
CHG-Barril	181.06 b	333.53 c	115.00 b

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

Table 4. Average number of chili peppers and fresh and dry weight, in the slab system.

Chili types	Fruit (number)	Fresh weight (g planta^{-1})	Dry weight (g planta^{-1})
CHA-SaltoVerde	122.68 a	732.99 c	594.69 a
CHA-Faro	120.75 a	853.76 c	483.02 b
CHG-Colonias	66.21 b	5,396.49 a	632.60 a
CHG-Barril	65.71 b	2,414.72 b	523.60 b

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

733 g plant^{-1}, while CHA-Barril recorded 854 g plant^{-1}. As proven by their averages, the differences between CHAs and CHGs are significant.

Significant differences were recorded for the dry weight of chile de árbol peppers (Table 4): CHA-SaltoVerde had an average of 595 g plant^{-1}, while CHA-Faro had 483 g plant^{-1}. Likewise, the differences between the guajillo peppers were significant: the average for CHG-Colonias and for CHG-Barril was 633 g plant^{-1} and 524 g plant^{-1}, respectively. Chile de árbol and guajillo peppers show no clear difference regarding this variable, since CHA-SaltoVerde was significantly higher than CHG-Barril, while CHG-Colonias was significantly higher than CHA-Faro.

The maximum number of flowers and the final number of established or set fruits of guajillo pepper recorded in this study matched the results of Marcelis and Baan (1997) and Guardiola (1997) —given that the number of flowers is usually greater than the number of fruits, although the difference between these two attributes in guajillo pepper was not so excessive. An important fact in this study is the percentage of fruit set —*i.e.*, the number of ripe fruits in relation to the maximum number of flowers—, which had a 38-100% fluctuation in the management systems. For their part, Dahal *et al.* (2006) reported that up to 19% of chili pepper fruits had set.

The initial decrease in the number of flowers match the gradual increase in the number of fruits as a result of the diversion of photoassimilates towards the formation of fruits (Azofeifa and Moreira, 2004). However, a continuously low production of buds and flowers due to the lower accumulation of carbohydrates suggests the existence of a competition for assimilates between all vegetative and reproductive organs, including leaves (Aloni *et al.*, 1996) and seeds, whose growth also demands a high amount of carbohydrates (Marcelis and Baan, 1997). Regarding the behavior of the evaluated variables in relation to the type of production system (pots and slabs), there is a very similar behavior in both systems in terms of the following variables: plant height, number of flowers, number of leaves, and number of fruits (Figure 1). With regard to the fresh weight and dry weight of the fruits, the

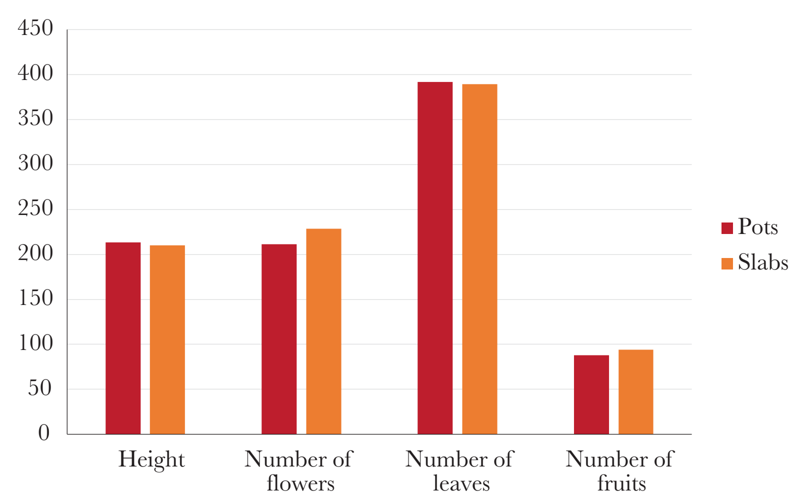

Figure 1. Response of the plant height (cm), number of flowers, number of leaves, and number of fruits variables to the production systems (pots and slabs).

potted system showed a superiority in both variables in relation to the system with slabs (Figure 2).

Additionally, a simple calculation of the value of dry chili pepper production that would be obtained per greenhouse ha was carried out, estimating the yields from the average dry weight (g plant^{-1}) of the different types of chili pepper (Table 5). The calculation was based on the density of 3 plants m^{-2} and a cost of $150,000 MXN per tonne of dry guajillo pepper and $180,000 MXN per tonne of chile de árbol pepper.

Given that the estimated yields of dry chili pepper (except for the CHA-SaltoVerde) were higher under the production system in pots, the highest production values were obtained under this production system. The highest production value of chili pepper was obtained with CHG-Barril, whose estimated dry yield was 32.82 t ha^{-1} which had a value

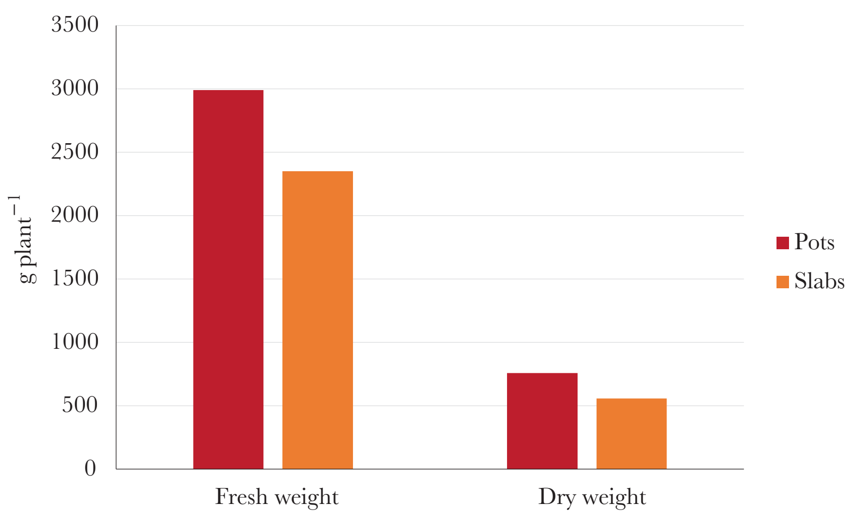

Figure 2. Response of the fresh weight and dry weight variables to the production systems (pots and slabs).

Table 5. Value of the estimated yields (per ha) based on the dry weight of the different types of chili pepper.

Chili type	Dry yield (g planta^{-1})	Yield* (kg m^{-2})	Yield (t ha^{-1})	Value per ha** ($)
	Potted production system			
CHG-Barril	1094.02	3,282.06	32.82	4’923,000
CHG-Colonias	865.81	2,597.43	25.97	3’895,500
CHA-Faro	819.09	2,457.27	24.57	4’422,600
CHA-SaltoVerde	257.84	773.52	7.73	1’391,400
	Pen production system			
CHG-Barril	523.60	1,570.80	15.71	2’356,500
CHG-Colonias	632.60	1,897.80	18.98	2’847,000
CHA-Faro	483.02	1,449.06	14.96	2’692,800
CHA-SaltoVerde	594.69	1,784.07	17.84	3’211,200

* With a density of 3 plants m^{-2}. ** Considering a price of $150,000 MXN (USD$ 7,500.00) per ton for guajillo pepper and $180,000 MXN (USD$ 9,000.00) per ton of chile de árbol pepper.

of \$4,923,000 MXN (USD\$246,150) (considering a price of USD\$7,500 ton). In second place, CHA-Faro recorded an estimated dry yield of 24.57 t ha^{-1}, which amounts to \$4,422,600 MXN (USD\$221,130) (considering a price of USD\$9,000 ton).

CONCLUSIONS

Except for chile de árbol pepper from Salto Verde (CHA-SaltoVerde), the production of dry chili peppers showed a better response in the production system with pots. Under that production system, the guajillo pepper from El Barril (CHG-Barril) obtained the highest dry weight yield and is therefore the chili pepper from which the greatest profitability would be obtained. The hydroponic greenhouse production of guajillo and chile de árbol peppers (using pots and slabs) is a good alternative for protected agriculture.

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