Article

Concentration of nutrients in the nutritive solution and yield of "cuatomate" (*Solanum glaucescens* Zucc.)

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Abstract

The cuatomate is a plant that belongs to the Solanaceas family, of the subgenus *Leptostemonum*, also called "spiny Solanaceae", because it has thorns in different parts of the organs of the plant. It is a cultivated and wild species with a high potential to be exploited in new systems of productive reconversion in the Mixteca Baja Poblana region. In order to assess their productive capacity and characterize it agronomically, an experiment was established with a completely random design, with four replications, in Atlixco, Puebla, under controlled conditions of red tezontle as a substrate in hydroponics under shade mesh. The plants evaluated were one year old, the density was one plant per m^2, with a distance between rows of 1.25 m and 1 m between plants. Four concentrations of the universal Steiner solution 25, 50, 75 and 100% were evaluated. The evaluated variables were number of bunches, total number of fruits accumulated and number of fruits harvested, polar and equatorial diameter of fruit, weight of fresh and dry fruit accumulated, as well as the average weight of fresh and dry fruit. The concentration of nutrients clearly influenced the number of fruits harvested and fruits accumulated, as well as the accumulated fresh weight; the other variables were not affected. The conditions of shade and hydroponics can be an alternative to encourage the cultivation of cuatomate and the increase in production; with economic potential for the Mixteca region of Puebla and other parts of the country.

Keywords: biomass, dry matter, hydroponics, Steiner nutrient solution, yield.

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Introduction

It is necessary that agricultural research focus on the study of the genetic diversity of native vegetables in Mexico, since most of these horticultural species provide sustenance and are used to meet the nutritional and economic needs in various regions of the country. Due to their nutritional qualities, vegetables play a transcendental role in the balance of the diet of the world population, since they have a high content of water, fiber, vitamins and antioxidants (Vera *et al*., 2016).

Solanum glaucescens Zucc. it is a plant that is known as Cuatomate. Its fruit is very appreciated as a food, besides it is a component and frequent in the diet of the inhabitants of the Mixteca Baja Poblana, in the form of sauces with which different dishes are accompanied, to improve the flavor of the food and stimulate the appetite (Medina *et al*., 2014). The sauces are prepared with the roasted or boiled fruits, along with “chiltepín” chile fruit (*Capsicum annuum* L.) and is known as “cuatomate sauce” (Gómez, 2014). With the fruits, purées are also prepared, which are used as a base in the preparation of various typical regional stews, such as “chilate”, in which they are ground and added (Gutiérrez *et al*., 2011). Medina *et al*. (2014) indicate that this fruit is an important source of proteins and minerals, such as potassium, calcium and magnesium, as well as vitamin C.

In recent years, the cuatomate has had economic importance due to the increase in demand at the regional level, since it is sold fresh, in small quantities in communities of poblanos in the United States of America, which promotes the consumption of this vegetable (Gutiérrez *et al*., 2011). This Solanaceous grows along with other forest species, backyard and naturally, which give support and shade, or can be associated with other crops, such as *Solanum betaceum* Cav. (Feican *et al*., 2016). In addition, in different municipalities of the region, cuatomate fruit is harvested from wild plants, where it is an important resource for self-consumption and sale (Gutiérrez *et al*., 2011). Its domestication has contributed to agricultural and food production in the region (Candelaria *et al*., 2016).

The characteristics of the Mixteca Baja Poblana region have prolonged periods of drought and limited availability of water, both for human consumption and for the development of agriculture, with an average annual temperature of 26 °C (Guizar *et al*., 2010). The cultivation of cuatomate requires shading and tutoring for its proper development (Vargas, 1998).

In accordance with the above, until today there is no document that refers to the technology for the production of cuatomate in new production systems, especially in the nutritional requirements. In such a way that, in this study, it is considered that knowledge can be generated for this crop in greenhouse conditions with shade mesh and in hydroponics; therefore, the objective of this work was to cultivate it in protected conditions, with shade mesh and hydroponics, using as a red tezontle substrate, and different concentrations of Steiner nutrient solution to determine its effect on the performance of the cuatomate fruit.

Materials and methods

The present investigation was carried out in the Academic Unit Atlixco, belonging to the Postgraduate School Campus Puebla, located at 18° 53’ north latitude and 98° 26’ west longitude, and an altitude of 1 824 m. The experiment was carried out in a monofilament shadow house with

50% shading, with an area of 300 m^2. This with the purpose of having similar environmental conditions, to those in which this species develops naturally. The characteristics of the Mixteca Baja Poblana region according to the agroclimatic description of Köppen, prevails an Aw'o climate; tropical dry with a rainfall of 600 to 700 mm per year with short-term summer rains of about four to five months (Garcia, 2004).

The plants evaluated were one year old and were obtained through planting by seed. Although the propagation of cuatomate sexually is successful and simple, only 40% of productive plants are obtained through this route (Vargas, 1998). In this species, a floral polymorphism called heterostilia is presented, in which some plants produce flowers with long and fertile styles (females), and others have flowers with short styles, which cannot be fertilized (males). According to Gutiérrez *et al*. (2011), the first are those that were used for the present study.

The plants were developed in black polyethylene bags, caliber 600, of 0.4 x 0.45 m. For the support of the plants red tezontle was used, with a particle size of 5 mm. The separation between rows was 1.25 m and 1 m between plants, with a population density of 1 plant per m^2. A completely randomized experimental design was used, with four repetitions. Four concentrations of Steiner's (1961) nutrient solution were evaluated: 25, 50, 75 and 100%. Each experimental unit was composed of one plant, with four replications, having four plants per treatment.

The application of the concentrations of the nutrient solution to the plants was carried out on July 15, 2016. During the cycle, an average of 1 320 mL of nutrient solution per plant was applied daily in all the treatments. An open hydroponic system was used, with a pH in the nutrient solution of 5.5.

The fruits were harvested 20 days after applying the treatments; when the fruits presented a whitish color of the pulp, in addition to fleshiness and firmness. This type of fruit is recognized for presenting features of larger size and dark green color (Figure 1), called as "chimeco" type (dirty), so opaque in color, nickname given in some areas of the Mixteca of Puebla.

Figure 1. Fruit of cuatomate (*Solanum glaucescens* Zucc.) harvested under shade mesh conditions and hydroponics with Steinar nutrient solution.

Five cuts were made, one every eight days, harvesting all the ripe fruits for each treatment, in total the experiment lasted a month and a half. The crop was developed to free growth, without pruning. The tutoring of the plants was done, when the plants reached a height of one m, for a better management of these. Stakes of 1.4 m long were used for the support and for the conduction of the branches, white plastic mesh was used, with squares 10 x10 cm and 1.5 m wide.

The evaluated variables were number of bunches (NRA), total accumulated fruits (FAT), polar diameter (DPO, cm), equatorial diameter of the fruit (DEC, cm), total of harvested fruits (TFC), accumulated fresh fruit weight (PFAF, g), accumulated dry weight of fruit (PSAF, g), dry weight per fruit (PSxF, g), fresh weight per fruit (PFxF, g). An analysis of variance (ANOVA) was applied to the response variables; the means of each treatment were compared by the Tukey test ($\alpha \leq 0.05$), with the software Statistical Analysis System (SAS), version 9.1 for Windows (SAS, 2002).

Results and discussion

Statistical analysis

The analysis of variance showed that there were highly significant statistical differences between concentrations, for the total of harvested fruits (TFC) and the accumulated fresh weight of fruit (PFAF), and significant for total accumulated fruits (FAT) (Table 1), not so for other components of yield, such as number of accumulated clusters (NRA), polar diameter (DPO) and equatorial (DEC) of the fruit, accumulated dry weight of fruit (PSAF), dry weight per fruit (PSxF) and fresh weight per fruit (PFxF) (Table 1).

The components of yield that had high coefficients of variation were number of accumulated clusters, total accumulated fruits and accumulated fresh weight of fruit (Table 1), this could be due to the fact that the evaluated plants presented some degree of genetic variation. According to the above, Gutiérrez *et al*. (2011) indicate that the cuatomate (*Solanum glaucescens* Zucc.), is a plant in process of domestication.

Table 1. Analysis of variance of nine characters of *Solanum glaucescens* Zucc., grown under shade and hydroponic mesh with four concentrations of Steiner's solution.

FV	NRA	FAT	DPO	DEC	TFC	PFAF	PSAF	PSxF	PFxF
GL trat	3	3	3	3	3	3	3	3	3
SC trat	39.25 ns	4389	0.139	0.103	757.25	448782.6	14.803	0.592	13.234
CM trat	13.08	1463	0.046	0.034	252.41	149594.2	4.934	0.197	4.411
SC error	47.25	3695.5	0.123	0.16	220.25	190361.5	20.689	0.827	34.193
CM error	5.25	410.61	0.013	0.017	24.472	21151.2	2.298	0.091	2.849
F cal	2.49 ns	3.56^{*}	3.4 ns	1.93 ns	10.31^{**}	7.07^{**}	2.15 ns	2.15 ns	1.55 ns
CV	44.7	38.59	2.987	3.395	22.359	30.169	12.889	12.892	7.887

FV= source of variation; Trat= treatments; GL= degrees of freedom; SC= sum of squares of treatments; CM= mean squares of treatments; SC error= sum of squares of the error; CM error= mean error squares; F Cal= F calculated; CV= coefficient of variation; NRA= number of accumulated clusters; FAT= total accumulated fruits; DPO= polar fruit diameter; DEC= equatorial fruit diameter; TFC= total harvested fruits; PFAF= accumulated fresh weight of fruit; PSAF= accumulated dry weight of fruit; PSxF= dry weight per fruit; PFxF= fresh weight per fruit; ns = not significant; *= significant ($p \leq 0.05$); **= highly significant ($p \leq 0.01$).

Number of bunches. The four treatments of the Steiner solution applied to cuatomate, did not generate significant statistical differences between these treatments for the number of clusters accumulated during the five cuts. However, the results show a higher number of bunches in the highest concentrations of the nutrient solution (Figure 2), with 75 and 100%, with 6.7 and 6.5 bunches on average, respectively, during the days evaluated. Regarding Moreno *et al*. (2005), applied a nutritious mother solution in the tomato (*Solanum lycopersicum*) crop which increased the number of bunches on average per plant (4 bunches), then the plants treated with vermicompost mixtures plus sand.

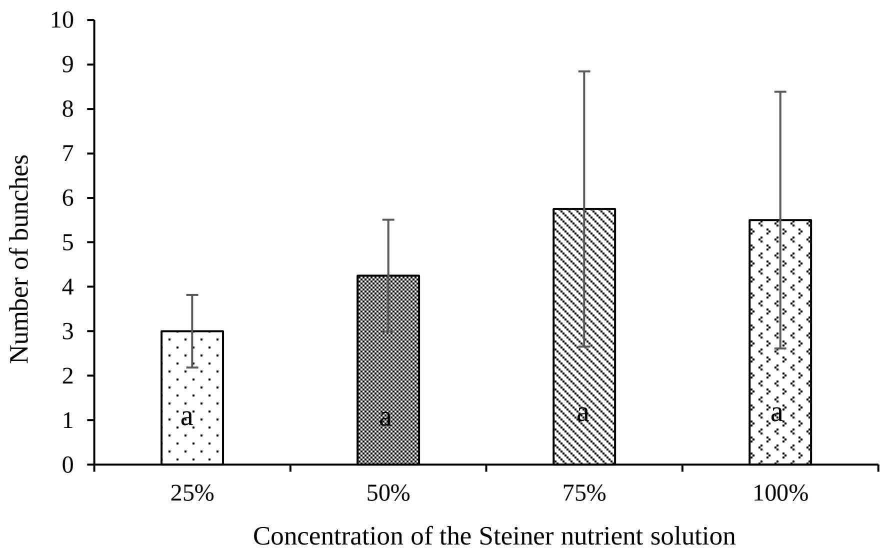

Figure 2. Number of clusters of cuatomate (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 5.05).

In the present study, the Steiner nutrient solution at 75 and 100% registered a higher number of average clusters per plant (5.7 and 5.5 clusters) than the one obtained by Moreno *et al*. (2005). In addition, in the study by Moreno *et al*. (2005) used freshly germinated tomato plants fertilized with the mother solution containing the nutrients necessary for their development, while in the present study one year old growth plants were used that were fertilized with the Steiner nutrient solution containing the necessary nutrients for the development of cuatomate.

On the other hand, Carrillo *et al*. (2003) found, for *Lycopersicon esculentum* Mill., Under controlled greenhouse conditions, a positive correlation for the number of bunches, with respect to yield, which indicates that the higher the number of bunches, the higher the yield. In addition, he mentions that temperature is an important factor that influences the number of bunches harvested, grown under these conditions.

Number of total accumulated fruits. The plants to which the high Steiner nutrient solution was applied (75 and 100%) presented the highest number of accumulated fruits, with 75 and 59 (Figure 3). This may be due to greater availability of nutrients in the nutrient solution. With these results increasing the concentration of the Steiner nutrient solution increases the number of bunches and in turn the number of fruits accumulated.

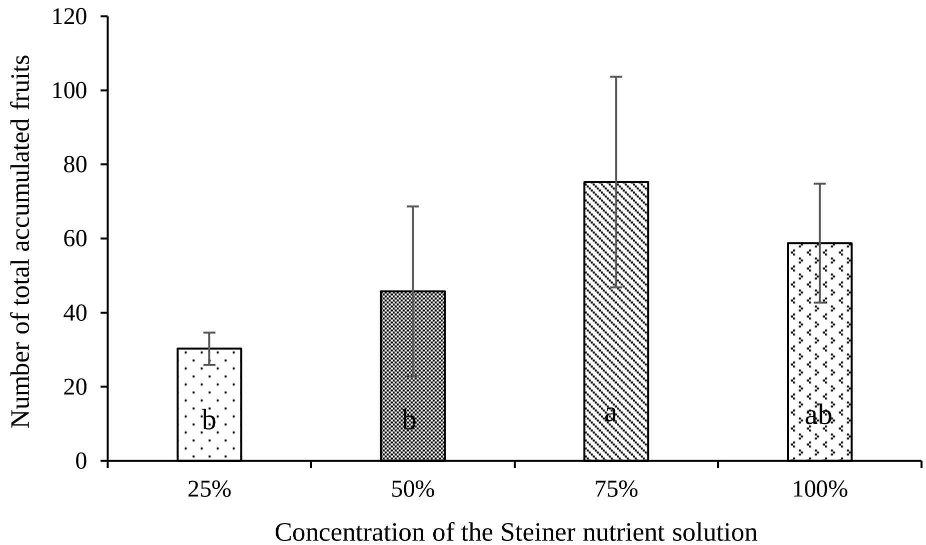

Figure 3. Number of cumulated total fruits of cuatomate (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p\leq 0.05$; 44.731).

In this regard, Maldonado *et al*. (2016) reported 33 fruits per tomato plant (*Solanum lycopersicum* L.), open-pit, with the Steiner solution at 25%, while in the present study 30 fruits were recorded on average per plant of cuatomate (*Solanum glaucescens* Zucc.) Under shade mesh, fertilized with 25% Steiner nutrient solution, which indicates that *S. glaucescens* grown under these conditions produces more fruits.

In another solanaceous (*Capsicum annuum* L.), the highest number of fruits was found in high concentrations of Steiner nutrient solution (75, 100 and 125%) and the lowest number of these in the concentration at 25% (Valentín *et al*., 2013). What coincides with the present study where the higher the concentration, the greater the number of fruits obtained from the cuatomate (*S. glaucescens*). The same effect is reported by Lima *et al*. (2014), who when applying different concentrations of nitrogen and phosphorus, in the form of ammonium sulfate and superphosphate, found answers in high doses, where the number of fruits in the *Solanum melogena* L. crop increased.

Polar diameter of fruit. There was no effect of Steiner nutrient solution concentrations on the polar diameter of the fruit of *S. glaucescens* (3.81 to 4.06) (Figure 4), but this polar diameter was higher than that reported by Vargas (1998) who evaluated a sample of 211 commercial fruits of cuatomate, and found that the polar diameter ranged from 3.65 to 3.69 cm. In addition to other *Solanum* species, the cuatomate fruits harvested in this investigation have a greater polar diameter than *Solanum uncinellum* (1.2 to 2.7 cm) reported by Benítez *et al*. (2011). On the other hand, for another solanaceous such as *Physalis pruinosa*, with the application of algae-based nutrients the polar diameter of green-yellow fruit was 11.57 mm (García *et al*., 2015).

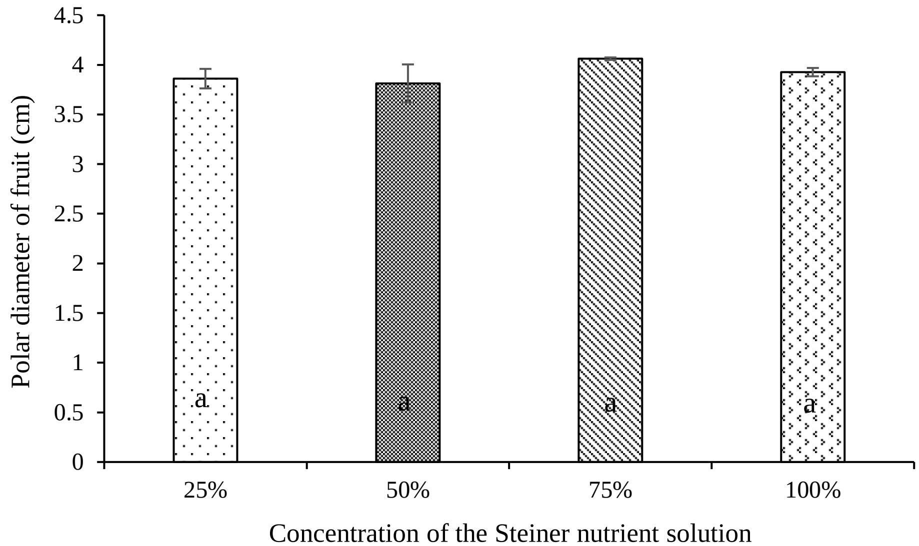

Figure 4. Polar diameter of cuatomate fruit (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 0.26 cm).

Equatorial diameter of fruit. Like the polar diameter of the fruit, there was no effect of the concentrations of the Steiner nutrient solution on *Solanum glaucescens* Zucc., registering fruit of 3.92, 3.83, 3.95 and 4.0 cm of equatorial diameter of the fruit with 25, 50, 75 and 100% Steiner nutrient solution (Figure 5). Vargas (1998) collected commercial fruits of cuatomate in the Mixteca Baja Poblana region, in which he found equatorial diameters that varied from 4.10 to 4.12 cm, these diameters indicate that they were slightly higher in the fruits harvested in the solutions at 25, 50 and 100 % and similar with concentration of 75% of the present study (Figure 5). In addition, this same author, of the long/wide relation of the fruit, found that 78% were spherical, while the rest (22%) were slightly oval. In turn, it also reports the absence of channels and curvatures along these.

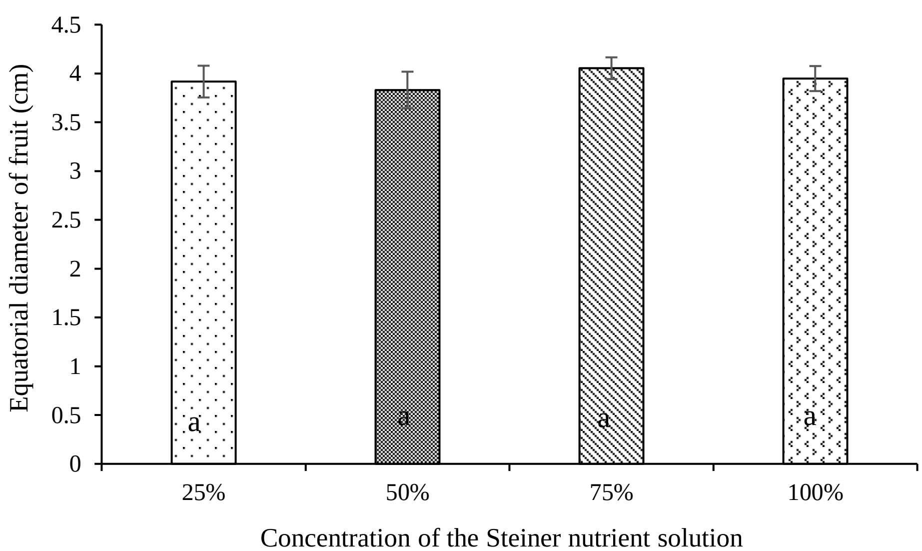

Figure 5. Equatorial diameter of cuatomate fruit (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 0.3 cm).

On another species of *Solanum*, Maldonado *et al*. (2016), reported 4.7 cm of equatorial diameter of *Solanum lycopersicum* L., with a 25% Steiner nutrient solution, which was greater than the equatorial diameter of *S. glaucescens* (3.92 cm) with the same 25% Steiner solution of the present study. Similarly in another solanaceous Rojas *et al*. (2008) report the apple-tree chile (*Capsicum pubescens* R and P), sampled for two years, a fruit width of 4.8 and 4.1 cm with Steiner nutrient solution at 75%, so that the fruits of cuatomate have a smaller width (3.95). cm) treated with the same concentration of Steiner nutrient solution at 75%, compared to the fruits of *C. pubescens*.

Total number of harvested fruits. All the plants treated with concentrations of Steiner nutrient solution presented fruits of commercially acceptable size and color, but there was an effect of these concentrations on the number of harvested fruits, where at a higher concentration of the Steiner nutrient solution (25, 50, 75 and 100%), the greater the number of fruits harvested per plant (15, 17, 24 and 32 fruits, respectively) (Figure 6).

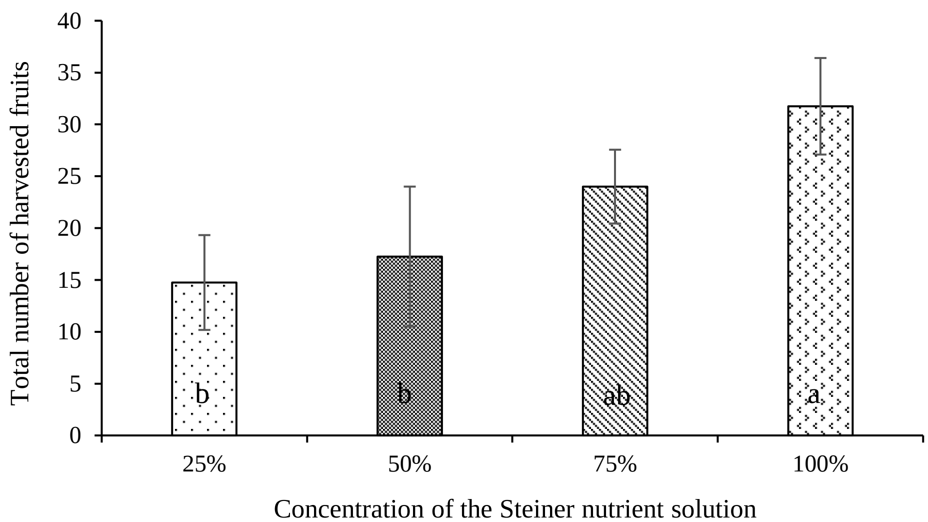

Figure 6. Total number of fruits harvested cuatomate (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 10.9).

Similarly, Gastelum *et al*. (2013) evaluated the same concentrations of the Steiner nutrient solution (25, 50, 75 and 100%) on another solanaceous *Physalis peruviana* L. and these authors concluded that the yield of the crop was affected by the concentration of the Steiner nutrient solution. An increase was observed when increasing the concentration of the solution, obtaining 110 fruits per plant with 100% of Steiner's nutrient solution, while in the present study, at the same concentration of the Steiner solution, 32 fruits of cuatomate were harvested. On the other hand, Valentín *et al*. (2013) found that at higher osmotic concentrations of Steiner nutrient solution applied to water chili (*Capsicum annuum* L.), under protected conditions and hydroponics, the number of fruits increased, reaching 100 fruits per plant with an osmotic concentration of 0.09 MPa of Steiner nutrient solution.

Accumulated total fresh weight of fruit. For *S. glaucescens* grown under shade and hydroponics, increasing the concentration of the Steiner nutrient solution increased the fresh weight of the cuatomate and therefore reflected in higher yield, recording accumulated average weights of 300.25, 363.0, 533.25 and 706.75 g per plant at 25, 50, 75 and 100% Steiner nutrient solution (Figure 7).

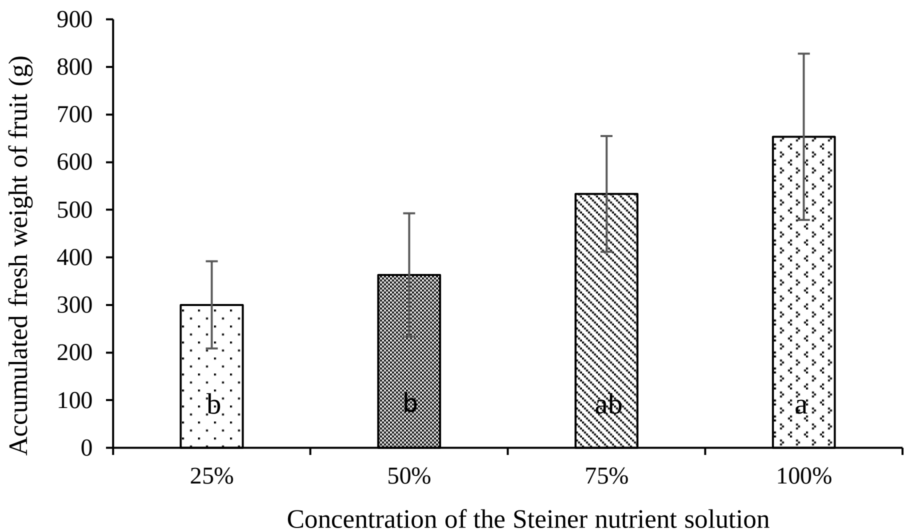

Figure 7. Cumulative fresh weight of cuatomate fruit (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 278.62 g).

This is also observed in another solanaceous such as “water chili” (*Capsicum annuum* L.), where solutions with high concentrations were those that presented higher yield than those with lower concentrations (Valentín *et al*., 2013). Or, *Physalis ixocarpa* Brot., Cultivated under different concentrations of nutrients, the production of fruit increased, according to the availability of nutrients, where the 75% solution reached the maximum production of fruits per plant (3 kg per plant), but from that point the production of fruits per plant decreased (Castro *et al*., 2000).

The use of nutritive solutions with different concentrations has been used in other crops with similar results, such as *Capsicum pubescens* R and P (Pérez and Castro, 2010) and thyme (*Thymus vulgaris* L.) (Guerrero *et al*., 2011).

Accumulated dry weight of fruit. Between the concentrations of the Steiner nutrient solution the accumulated dry weight of cuatomate fruit is maintained, with 11.26, 10.53, 13.11 and 12.12 g at 25, 50, 75 and 100% of the Steiner nutrient solution (Figure 8). A similar effect was reported for "water chili" (*Capsicum annuum* L.) using high osmotic potentials in Steinar nutrient solution, under protected conditions, no differences were observed in the accumulation of dry matter in fruit (Valentín *et al*., 2013).

When different concentrations of nutrients are applied to a crop, there may be the possibility that these are directed to different bodies, mainly those of demand, and not to sites of the plant of commercial interest. Peil and Galvez (2005) indicate that there is interest in that a maximum proportion of assimilated be allocated to the fruits; However, there are limits in the fraction of those assimilated that can deviate from these, since the plants need to allocate a sufficient amount for the other organs.

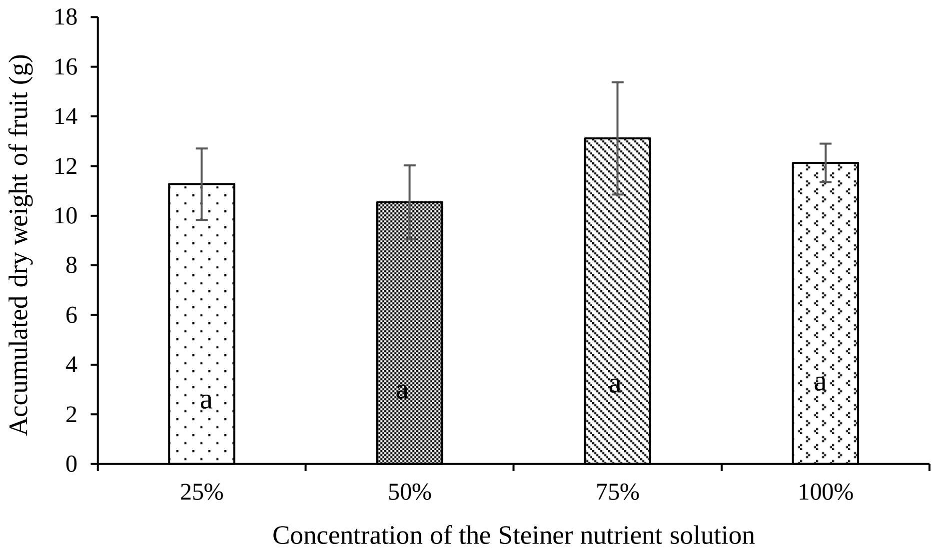

Figure 8. Accumulated dry weight of cuatomate fruit (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p\leq 0.05$; 3.35 g).

Dry weight per fruit. Like the accumulated dry weight of fruit, the dry weight per fruit (2.25, 2.1, 2.62 and 2.42 g) does not increase in the cultivation of cuatomate (*Solanum glaucescens* Zucc.), Evaluated under a shading system and hydroponics with different Steiner nutrient solution concentrations (25, 50, 75 and 100%) (Figure 9). On the other hand, the percentage of dry matter accumulated in fruit of cuatomate was about 11% of the fresh weight of the fruit for the different concentrations of Steiner solution, in comparison with that reported by Peña *et al*. (2013) in *Solanum lycopersicum*, cultivated in greenhouse and hydroponics, found values of 4.5 and 5.4% of fresh weight of fruit, which indicates that the percentages were lower in comparison with the accumulated dry matter of fruits of *S. glaucescens* Zucc. found in the present study.

Fresh weight per fruit. The harvested fruits of cuatomate (*Solanum glaucescens* Zucc.) presented similar fresh weights (between 20 and 23 g, approximately) in plants treated with nutrient solution Steiner at 25, 50, 75 and 100% (Figure 10). In a previous study, the plants of cuatomate registered an average weight of 12.27 g of fresh fruit weight, large fruits (30 g) and boys (5.87 g), both from two municipalities (Tehuitzingo and Izúcar of Matamoros) (Vargas, 1998), which indicates that the fruits obtained under these conditions in the cultivation of cuatomate have higher average weights than those obtained by this author.

On the other hand, Gastelum *et al*. (2013) report that as the concentration increases from 25 to 50 and 75% Steiner solution increases the weight of the fruit of gooseberry (*Physalis peruviana* L.), but this weight of the fruit decreases to 100% of Steiner solution, except in plants with density of 8 plants per m, where the highest weight of cuatomate fruits was recorded. In contrast, in the present study increasing the concentration of Steiner nutrient solution increased the weight of cuatomete fruits.

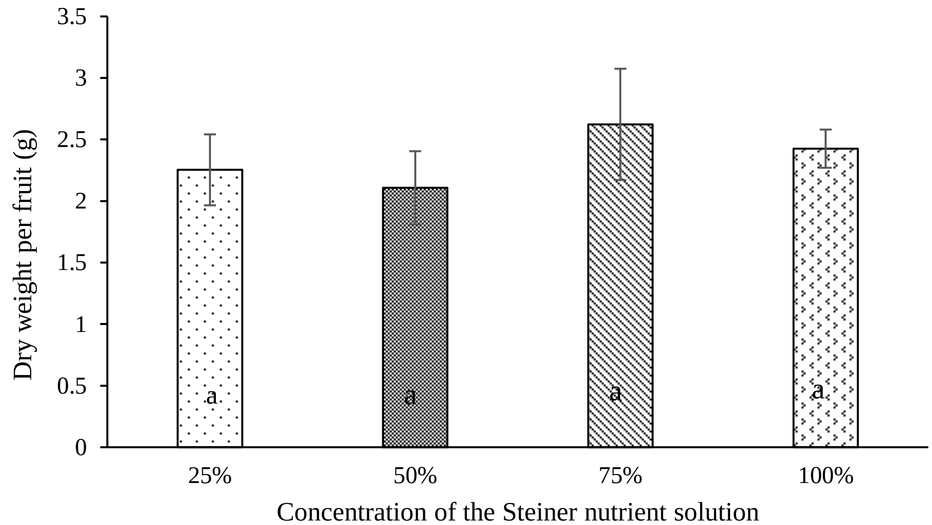

Figure 9. Dry weight per fruit of cuatomate (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 0.66 g).

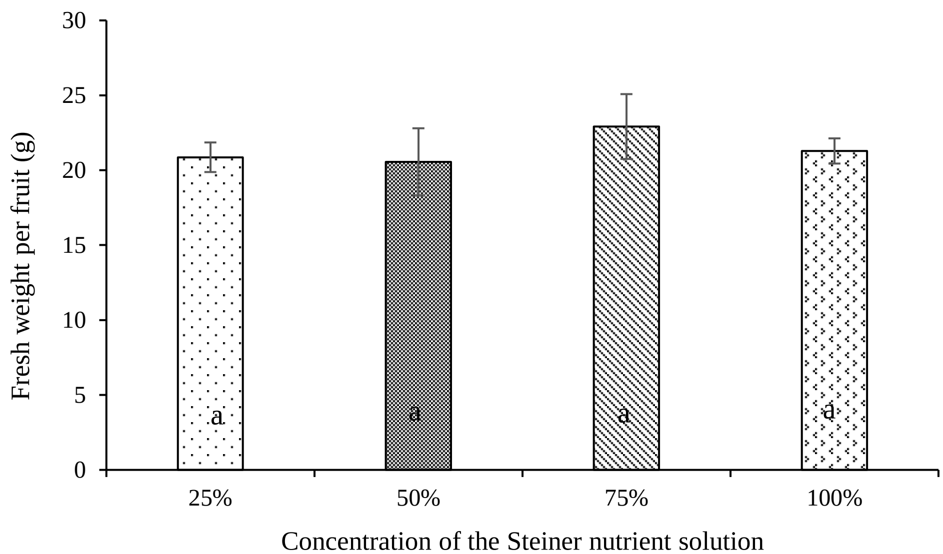

Figure 10. Fresh weight of cuatomate fruit (*Solanum glaucescens* Zucc.) grown under shade mesh in Atlixco, Puebla, 2016 (Tukey $p \leq 0.05$; 3.77 g).

Muñoz (2009) points out that excessive applications of nitrogen in tomato in greenhouse, increase the possibility of appearing a ripening disorder in the fruit, called "green shoulder", while Castellanos (2009) indicates that the excess of nitrogen in the crop of tomato (*Solanum lycopersicum* L.) makes it very vegetative, in addition to appearing in the floral bouquet leaves, characteristic of excess vigor in the plant.

In the present study in cuatomate, this characteristic did not appear in the flowering stage, it appeared after the third cut, when the fruits were harvested in the treatment with 100% concentration of Steiner solution. With all these results, it is necessary to determine the optimum concentration of the nutritive solution to ensure the best fruit weight of the agricultural crops, to avoid that an excess concentration of the fertilization affects the yield of the crop and commercial economic price.

Conclusions

The concentration of nutrients in the nutrient solution influenced the number of fruits harvested and fruits accumulated, as well as in the accumulated fresh weight, in the cultivation of cuatomate, cultivated in shade mesh and hydroponics. The variables number of bunches, polar diameter and equatorial fruit diameter, accumulated dry fruit weight, fresh and dry weight per fruit were not affected by the concentration of nutritive solutions. The conditions of shade and hydroponics can be an alternative to promote the cultivation of cuatomate and the increase in production, with a great economic potential to be developed in the Mixteca Baja Poblana region and other parts of the country.

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