Article

Mineral nutrition of chilhuacle in three phenological stages

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Abstract

Chilhuacle (*Capsicum annuum* L.) is one of the most popular chili peppers in Oaxaca. However, the handling and postharvest of the fruits is unknow, this directly affects the yield and quality of the fruit. In order to evaluate different nutrient solutions for each phenological stage, three experiments were established in the experimental field of the Faculty of Agricultural Sciences of the Autonomous University of the State of Morelos. Three concentrations of NO_3^- were evaluated in the vegetative stage, nine NO_3^-:$H_2PO_4^-$:SO_4^{2-} rations in the reproductive stage, and nine NO_3^-:K^+ ratios in the fruiting stage. The treatments were distributed in a completely randomized block design with five repetitions and one plant per experimental unit in black polyethylene containers (15.14 L), in a triangular planting system (50 cm vegetative stage and 75 cm in the reproductive and fruiting stage), drip irrigation system and red tezontle gravel as substrate. The results indicated that the nutrient solutions produced significance in height, stem diameter, root volume, dry matter of stem and of whole plant 14 meq L^{-1} of NO_3^- in the vegetative stage; reduced flower abortion and increased the number of buds per plant with 10:0.75:9.25 meq L^{-1} of NO_3^-:$H_2PO_4^-$:SO_4^{2-} during the reproductive stage and in fruit, the ratio 14:9 meq L^{-1} of NO_3^-:K^+ favored by significantly increasing the equatorial diameter, weight of fresh and dry matter of fruit.

Keywords: fruiting stage, nutrient solutions, phenology.

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Introduction

The black chilhuacle (*Capsicum annuum* L.) is an endemic fruit of San Juan Bautista Cuicatlán, Oaxaca (López *et al*., 2016), it is trapezoidal in shape 10 cm long and 8 cm wide, in an immature state it is intense green in color, in the mature state it is bright brown and black when dehydrated (López and Pérez, 2015), it is marketed mainly dry, used as the main ingredient to make the 'Oaxacan black mole' (García *et al*., 2017), one of the seven most popular moles in the country, where it is cited in the oldest books of gastronomy, also maintains national and international recognition as it is served as a gourmet dish.

In recent years, the price of dried fruit has risen due to the scarcity of chilhuacle producers, increased production costs, particularly due to the excessive use of agrochemicals for pest and disease control (López *et al*., 2016) and the lack of knowledge of crop nutrition, which is of great relevance because a well-nourished plant is more tolerant to pest attack, diseases and viruses (Sieiro *et al*., 2020), which together are a consequence of poor yield. Fertilization only occurs two or three times during the cycle, where foliar fertilization is complementary and more used, if conditions allow it, an estimated harvest of 1 t ha^{-1} is reached (López *et al*., 2016).

The formulation of nutrient solutions in each phenological stage is carried out in order to provide the necessary nutrients to increase plant growth, yield, quality of the organs of interest and in the case of fruit vegetables reduce flower abortion (Moreno-Pérez *et al*., 2019). Nutrient solutions not only induce achieving the maximum productive potential in a crop (Luna-Fletes *et al*., 2021) or reducing the damage caused by the appearance of pathogens that directly affect the commercial quality of the fruits (Fajardo *et al*., 2021), but also have an impact on the development, yield and quality of the fruits (López-Gómez *et al*., 2017).

Of the indispensable macronutrients in crops, nitrogen is the nutrient with the highest demand by plants, it is related to growth, development (Larios-González *et al*., 2021) and crop yields. In the stage of flower formation and fruit set, apart from the need for N, P participates in the formation of roots, flowers, fruits and seed ripening (Taiz and Zeiger, 2010), while S in the form of SO_4^{2-} contributes to the differentiation of flower buds (Corrales-Maldonado *et al*., 2014), stimulates growth, increases the quality and uniformity of the fruits, favoring resistance to cold, tolerance to drought and salts (Nazar *et al*., 2011). In the fruiting stage, potassium (K) is related to crop quality and yield (Pavón *et al*., 2021), increasing vitamin C, the color and taste of fruits, greater size and shelf life.

Due to the specific nutritional requirements during the development of plant species and varieties, the objective of this research was to evaluate the effect of nutrient solutions of different chemical composition in three phenological stages of chilhuacle (vegetative, reproductive and fruiting) in order to favor the growth, yield and quality of the fruits.

Materials and methods

Location of experiments

Three experiments were carried out, one for each phenological stage of chilhuacle (vegetative, reproductive and fruiting), in a greenhouse with white polyethylene cover with 30% shade, in the experimental field of the Faculty of Agricultural Sciences of the Autonomous University of the State of Morelos, Cuernavaca, Morelos.

Plant material

Creole seeds of black chilhuacle from producers in Oaxaca were used, which were sown in polyethylene trays of 200 cavities in a commercial peat-based substrate for seedbed (Sunshine3®), the supply of nutrients was carried out with the universal nutrient solution (Steiner, 1984). To obtain seed, fruits of healthy appearance (free of diseases) of the previous cycle, uniform and with average size, usually 6 cm long, 5 cm wide, are selected. The weight of the fruits in fresh state is 40 g and 5.6 g in complete dehydration. The yield per plant is 1.4 kg in fresh fruit and in dried fruit, it oscillates around 250 g plant^{-1}.

Experimental unit

Each experiment was carried out in an open-loop hydroponic system with drip irrigation. Black polyethylene containers (15.14 L), and red tezontle with granulometry less than 0.5 mm in diameter as substrate, were used. In all three cases, there was one black chilhuacle plant per container. The distance between plants varied depending on the phenological stage (50 cm for the vegetative stage and 70 cm for the reproductive and fruiting stages) in a triangular topological arrangement, maintaining three modules for each experiment. The experimental unit in the vegetative stage was made up of six plants (one plant per container), the sampling unit was the two central plants, the lateral plants were discarded to reduce the interaction between them. For the reproductive and fruiting stages, the modules were designed with a distance of 70 cm between plant and plant, where the sampling unit was one plant per container, with five repetitions per treatment.

Management of the experiments

The seedling phase, corresponding to the vegetative stage, had its own agronomic management and was not a reason for evaluation. The transplant time was determined by the number of leaves developed. From the tenth leaf (73 das), the seedlings are within the optimal conditions to be transplanted. In this way, the first experiment (vegetative stage) began on day 74 das (when 50% of the seedlings showed the tenth true leaf with a length of 5 ±1 mm) and ended at 29 dat when 50% of the plants showed the first flower bud (5 ±1 mm).

The second experiment (reproductive stage) began when 50% of the plants visually presented the first flower bud (5 ± 1 mm) and ended at 40 dat (11 days) at the time that 50% of the plants had the first fruit (10 ±1 mm), in this case, the nutrition of the vegetative stage was with the universal nutrient solution (UNS) (Steiner, 1984). The third experiment corresponding to the fruiting stage began at 41 dat when 50% of the plants presented the first fruit and ended at 184 dat until the evaluation of the last harvested fruit, the UNS was applied in the vegetative and flowering stages. The fruits were harvested for 18 weeks, when 100% of the exocarp showed commercial maturity, according to García-Gaytán *et al*. (2017), fruit ripening occurs between 60 and 78 days after anthesis.

Treatments and experimental design

The design of the nutrient solutions evaluated in each phenological stage was carried out considering the universal nutrient solution (Steiner, 1984) as a control and reference for the design of the nutrient solutions. The controls were: 12 meq L^{-1} of NO_3^- in the vegetative stage, 12:1:7 meq L^{-1} of NO_3^-:$H_2PO_4^-$:SO_4^{2-} in the reproductive stage and 12:7 meq L^{-1} of NO_3^-:K^+ in the fruiting one. Steiner's universal nutrient solution maintains the mutual relationships between anions and cations, total ionic concentration and pH, as important factors that will give a positive response in the growth and development of plants, considered as a reference for a general nutrition of any crop.

In the vegetative stage there were three nutrient solutions resulting from modifying the concentration of NO_3^- (10, 12 and 14 meq L^{-1}), in the reproductive stage nine nutrient solutions were generated with different NO_3^-:$H_2PO_4^-$:SO_4^{2-} ratios, which were the result of combining 10, 12 and 14 meq L^{-1} of NO_3^- with 0.75, 1 and 1.25 meq L^{-1} of $H_2PO_4^-$, while in the fruiting stage, nine nutrient solutions as a result of the combination of 10, 12 and 14 meq L^{-1} of NO_3^- with 5, 7 and 9 meq L^{-1} of K^+, were evaluated. In all three experiments, the experimental design was randomized complete blocks, with five repetitions per treatment.

Response variables

In the three experiments (vegetative, reproductive and fruiting), environmental variables such as temperature, relative humidity and luminous intensity were evaluated from transplantation to evaluation, measured with a Hobo® data logger.

Vegetative stage

The response variables were evaluated when 50% of the plants presented the first flower bud (5 ± 1 mm). The following were determined: plant height with a tape measure (Pretul®) from the base of the main stem to the apex of the longest stem, main stem diameter a cut was made at a distance of 2 cm above the substrate with a digital vernier (Stainless Hardened®) (López-Gómez *et al*., 2017), relative chlorophyll content (RCC) with a SPAD 502 Plus (Minolta®) in newly matured leaves, leaf area determined with a leaf area integrator (LICOR, LI-3100), length of the longest root measured with a tape measure and root volume by the water-displacement method, dry matter of the organs of the plant (root, stem and leaves), for this a forced air circulation stove (Luzeren, DGH9070A) at a temperature of 65 °C for 72 h and a digital scale were used.

Reproductive stage

The response variables were evaluated when 50% of the plants presented the first fruit with a length of 10 ±1 mm. Plant height, main stem diameter, relative chlorophyll content, leaf area, root volume, weight of dry matter of root, stem and leaves were determined in the same way as in the vegetative stage. In this case, buds per plant, flowers per plant and percentage of flower abortion were also considered.

Fruiting stage

The growth variables of the plants were evaluated at the end of the harvest, in the same way as in the vegetative stage (estimated leaf area, relative chlorophyll content, weight of dry matter of root, stem and leaves). The leaf area and dry leaf matter were estimated considering the internodes from 10 to 15 of the two main stems and the two secondary ones. It was also determined the length and diameter of the fruit, measured with digital vernier (Stainless Hardened®) based on the Standard NNX-FF-107/1-SCFI-2006, exocarp thickness (average of two opposite points in the center of the fruit) with digital vernier (Stainless Hardened®), total soluble solids (°Brix) quantified with a portable refractometer (Atago® , PAL-1 3810), fresh and dried matter of each fruit (similar to the vegetative stage), seeds per fruit, number of fruits per plant, fruits of the main stems, percentage of flower abortion, yield of fresh and dry matter of fruits per plant.

Statistical analysis

The data obtained were subjected to the analysis of variance with the SAS program (version 9.0) and those that presented statistical difference were performed the multiple comparison test of means LSD ($p \leq 0.05$).

Results and discussion

The vegetative stage lasted 29 days, with an average temperature of 21.4 °C and relative humidity of 49.5%, which can be considered short-lived since Azofeifa and Moreira (2004) mention 40 days for jalapeño pepper and Noh *et al*. (2010) indicate 50 days in habanero pepper. Within *C. annuum*, the growth and behavior of non-genetically manipulated varieties can be variable, so in chilhuacle the transplant time may not be constant because of the climatic conditions in which it is grown. In nutrition programs, it is important to consider the duration of the vegetative stage according to the species and variety since some important characteristics are cell division and rapid growth of roots, stems and leaves, involving distribution of biomass to these organs and demand for nutrients (Azofeifa and Moreira, 2004), such as N as it is the element responsible for growth and development (Larios-González *et al*., 2021), especially in the first days after transplantation where growth is accelerated.

Regarding the effect of the concentration of NO_3^- in the nutrient solution on the growth of chilhuacle plants, 10, 12 and 14 meq L^{-1} had a statistically similar effect ($p \leq 0.05$) on the relative chlorophyll concentration (50.35 SPAD units), leaf area (292.4 cm^2) and root length (18 cm), as well as in the accumulation of dry matter of root (0.5 g) and leaf (1.23 g). The variables plant height, main stem diameter, root volume, dry matter of the stem and of the whole plant were affected by the concentration of NO_3^- of the nutrient solution (Table 1). In this sense, with 14 meq L^{-1} of NO_3^-, the plants were 11.51% taller, an increase of 21% more in the stem diameter was observed, in contrast to the plants nourished with 12 meq L^{-1} (control), something similar in root volume, with 14 meq L^{-1} of NO_3^-, the plants presented 30.55% more root volume than with a nutrition with 10 and 12 meq L^{-1} of NO_3^- (Table 1).

In relation to the accumulation of dry matter, in stem it increased 40.50% with 14 meq L^{-1} compared to plants nourished with 12 meq L^{-1} of NO_3^-. When considering total dry matter, plants nourished with 14 meq L^{-1} of NO_3^- produced 22.63% in contrast to a nutrition with 12 meq L^{-1}; however, with 10 meq L^{-1}, dry matter production increased by 10.28% than the control treatment (Table 1).

Therefore, supplying 10 and 14 meq L^{-1} increases the dry matter available in the organs of chilhuacle plants, where this parameter indicates the amount of cumulative matter in the evaluated organs. The outstanding plants in relation to height, stem diameter, root volume, dry matter of stem and of whole plant (Table 1) allocated 45% of their dry matter to the leaves, 37% to the stem and 18% to the root, a balanced distribution of dry matter between the aerial part in greater proportion and less to stems and roots (Peil and Gálvez, 2005).

Table 1. Effect of the concentration of NO_3^- of the nutrient solution supplied during the vegetative stage of chilhuacle on morphological variables and dry matter production of plants.

Concentration of NO_3^- (me L^{-1})	PH (cm)	MSD (mm)	RV (cm³)	DSM (g)	DMTOT (g)
10	32.3 ab	4.57 ab	7 b	0.96 ab	2.68 ab
12*	30.4 b	4.14 b	7.4 b	0.79 b	2.43 b
14	33.9 a	5.01 a	9.4 a	1.11 a	2.98 a
LSD	1.92	0.71	1.36	0.15	0.42
CV (%)	6.43	16.82	18.51	17.58	17.01

Means with the same literal in the column are statistically equal according to the LSD test ($p\leq 0.05$). PH= plant height; MSD= main stem diameter; RV= root volume; DSM= dry stem matter; DMTOT= dry matter of the whole plant; LSD= least significant difference; CV= coefficient of variation; *= control treatment (12 meq L^{-1}).

According to the analysis of variance ($p\leq 0.05$) plant height, main stem diameter, relative chlorophyll content and leaf area, the chilhuacle plants nourished with 10:0.75:9.25 and the control (12:1:7) were statistically similar in terms of growth during the period in which they were cultivated.

The $NO_3^-:H_2PO_4^-:SO_4^{2-}$ ratios supplied to the chilhuacle during the flowering stage had a statistically different effect on the variables of growth and accumulation of dry matter (Table 2). In the flowering stage, the most important variables were the number of flowers and buds. On average, chilhuacle plants had 3.4 flowers/plant regardless of the nutritional ratio with which they were treated. As for the number of buds per plant, the ratio $NO_3^-:H_2PO_4^-:SO_4^{2-}$ 10:0.75:9.25 meq L^{-1} and the control were statistically similar ($p\leq 0.05$), presenting the same number of buds in 30.55% more with respect to the ratio with 14:0.75:5.25 meq L^{-1}.

In this same sense, by increasing the number of buds per plant we do not ensure the development of fruits, but the flower abortion decreases by at least 2.05% (Table 2). Therefore, N and P at 10 and 0.75 meq L^{-1} and 9.25 meq L^{-1} of S reduces the percentage of abortion and increases the number of buds per plant, finding that the availability of N in the plant depends on the formation of buds and the development of flowers, in addition, SO_4^{2-} participates in the formation of flower buds (Corrales-Maldonado *et al*., 2014). Therefore, as the concentration of NO_3^- increases, the flower abortion increases, and the number of fruits produced per plant decreases.

Table 2. Effect of the NO_3^-:$H_2PO_4^-$:SO_4^{2-} ratios of the nutrient solution supplied in the reproductive stage of chilhuacle on morphological variables and dry matter production of plants.

Ratios NO_3^-:$H_2PO_4^-$:SO_4^{2-} (meq L^{-1})	PH (cm)	MSD (mm)	RCC	LA (cm²)	RV (cm³)	NBP	PFA	DRM (g)	DSM (g)	DLM (g)	DMTOT (g)
10:0.75:9.25	48.92ab	6.39a	57.04ab	844.8ab	10c	14a	2.05	1.51ab	4.1ab	3.84a	9.46ab
10:1:9	44.66b	5.77ab	56.82ab	790.4ab	11c	12ab	2.83	1.28b	3.52b	3.45ab	8.26b
10:1.25:8.75	48.12ab	6.4a	59.5a	921.8ab	15.6ab	13.2ab	2.64	1.98a	4.43a	3.97a	10.4a
12:0.75:7.25	48.06ab	6.03ab	58.06ab	761ab	14abc	12.6ab	5.11	1.45b	3.76ab	3.6ab	8.82ab
12:1:7*	49.72a	5.96ab	54.94b	959a	16.8a	14.2a	7.03	1.59ab	4.18ab	3.99a	9.77ab
12:1.25:6.75	48.22ab	6.11ab	56.46ab	808.1ab	11.6abc	11.6ab	7.17	1.31b	3.92ab	3.55 ab	8.8ab
14:0.75:5.25	48.62ab	6 ab	58.1ab	711.8b	14.6abc	10.8b	4.13	1.45b	4.26ab	3.65ab	9.37ab
14:1:5	46.62ab	6.24ab	55.7ab	718.1b	11.8bc	11.8ab	6.61	1.25b	3.63ab	3.13b	8.03b
14:1.25:4.75	45.08ab	5.51b	58.88ab	759.3ab	9.6c	11.8ab	5.53	1.33b	3.58ab	3.33ab	8.26b
MSD	4.92	0.76	4.05	200.54	5.24	2.99	nd	0.48	0.88	0.77	1.81
CV (%)	8.03	9.81	5.49	19.25	31.83	7.1	nd	25.77	17.37	16.72	15.6

Means with the same literal in column are statistically equal according to the LSD test ($p\leq$ 0.05). PH: plant height; MSD= main stem diameter; RCC= relative chlorophyll content in SPAD units; LA= leaf area; RV= root volume; NBP= number of buds per plant; PFA= percentage of flower abortion; DRM= dry root matter; DSM= dry stem matter; DLM= dry leaf matter; DMTOT= dry matter of the whole plant; LSD= least significant difference; CV= coefficient of variation; nd= not determined; *= control treatment.

The fruiting stage of chilhuacle lasted 184 days with an average temperature of 20.9 °C. In this period, the components of the yield and quality of the fruit are important. As for the first, the different NO_3^-:K^+ ratios evaluated had a statistically similar effect ($p\leq$ 0.05) on the number of fruits per plant (53), yield of fresh (1.416 kg $plant^{-1}$) and dry (0.253 kg $plant^{-1}$) matter of fruits (Table 3). The number of fruits on the main stems varied significantly. In this sense, with the ratio NO_3^-:K^+ 14:5 meq L^{-1}, the plants had the highest number of fruits in the main stems (20.4), which represented 54.54% more than the control plants (12:1:7 meq L^{-1}).

The same results reported in habanero pepper, where the ratio 14:5 meq L^{-1} increased by 15.5% the number of fruits per plant, while the ratio 12:1:7 meq L^{-1} increased the yield by 66.4%, harvesting up to 1 054 g $plant^{-1}$ (López-Gómez *et al*., 2017). The chilhuacle plants did not show differences due to the effect of nutrition, but due to the effect of populations on yield and number of fruits, harvesting up to 274.14 g $plant^{-1}$ and 13.58 fruits in red chilhuacle and 434.43 g $plant^{-1}$ with 29.67 fruits $plant^{-1}$ in black chilhuacle (Urbina-Sánchez *et al*., 2020).

In the case of plants nourished with 14:5 meq L^{-1}, compared to the ratio 14:9 meq L^{-1} of NO_3^-: K^+, it is interesting to consider that with the same concentration of NO_3^- (14 me L^{-1}) but different in K^+ (5 and 9), it was statistically similar in RCC (63.81 SPAD units), total soluble solids (9.03 °Brix) and weight of dry root matter (31.1 g). Although the plants nourished with the ratio NO_3^-:K^+ 14:5 had 50% more fruits on the main stems compared to the plants that received 14:9, these produced fruits with greater equatorial diameter (5.28%), with a tendency to produce more weight of fresh (7.59%) and dry (8.68%) matter. This ratio favors chilhuacle plants, where the concentration of NO_3^- remains constant and demanding (Larios-González *et al*., 2021) during all their stages, while the contribution of K^+ increases the quality and yield of the crop (Pavón *et al*., 2021).

Regarding the percentage of flower abortion, with none of the NO_3^-:K^+ ratios evaluated in this experiment the reduction below 50% was achieved, since the variation was from 50.41% (10:5 me L^{-1} of NO_3^-:K^+) to 70.42% (12:9 meq L^{-1} of NO_3^-:K^+). With the ratio 12:7 (control), the percentage of flower abortion was 65.70, while with 14:9, it was 60.85 (unpublished data). As for the quality of the fruits, the fruit length (60.76 mm), exocarp thickness (2.99 mm) and number of seeds (131) were statistically similar (p< 0.05) regardless of the different NO_3^-:K^+ ratios with which the plants were treated.

The equatorial diameter of the fruit was significantly affected by the NO_3^-:K^+ ratios (Table 3). The ratio 14:9 meq L^{-1} caused the plants to have a diameter with 5.64% more than the control (12:7), among other ratios of NO_3^-:K^+ (10:7, 12:5, 12:9, 14:5, 14:7). As for the weight of the fresh matter of the same organ, the plants nourished with 14:9 of NO_3^-:K^+ had fruits 12.88% heavier than those produced with 10:7 and 12:9. The ratio NO_3^-:K^+ 14:9 also caused the fruits to present greater dry matter compared to plants whose nutrient solution was 10 and 12 meq L^{-1} (Table 3), which confirms that throughout the production cycle of chilhuacle, it demands N (14 meq L^{-1}) and K to favor the formation and quality of the fruits (Taiz and Zeiger, 2010).

Chilhuacle fruits are marketed dry, so the size and weight of the dry matter are important. In this regard, the plants nourished with the ratio 14:9 of NO_3^-:K^+ presented a statistical trend to have a greater equatorial diameter, as well as dry matter (Table 3). López-Gómez *et al*. (2017) reported that, in habanero pepper *var* Jaguar, the ratio 14:5 meq L^{-1} of NO_3^-:K^+ in the nutrient solution supplied in the fruiting stage increased the yield and weight of fresh matter of the fruit. This difference in the demand for K^+, with the same concentration of NO_3^- (14 meq L^{-1}), can be attributed to the high demand for N and K required by *Capsicum*, so in *C. chinense*, one of the most studied chili peppers, the demand it required was lower than chilhuacle.

In this same sense, Urbina-Sánchez *et al*. (2020) fertilized chilhuacle plants with ammonium in concentrations of 0, 1.5 and 3 meq L^{-1}, the results showed that, statistically, the fresh and dry weight of fruit was not significant but between populations of black chilhuacle (18.66 and 2.13 g) and red chilhuacle (23.22 and 2.2 g).

The content of total soluble solids presented significant differences due to the effects of nutrient solutions, the control treatment (12:7 meq L^{-1} of NO_3^-:K^+) increased this content, compared to the plants that were treated with the ratio 12:5 meq L^{-1}, where said increase was 9.46% more than the fruits of the plants nourished with a different nutrition. As for the content of total soluble solids (TSS), Urbina-Sánchez *et al*. (2020) reported higher content in red chilhuacle, where at 0 meq L^{-1}

of NH_4^-, it produced 10.2 ºBrix, while at 3 meq L^{-1} of NH_4, the TSS content was 10 ºBrix. In black chilhuacle, they presented on average 9.5 ºBrix with a contribution of 3 meq L^{-1} of NH_4, same results obtained in this study.

Regarding plant growth, there were no statistical differences ($p \leq 0.05$) in the estimated leaf area (1 384 cm^2 $plant^{-1}$) and accumulation of dry matter in leaves (12.6 g), but it was different in terms of the relative chlorophyll content. Plants nourished with 14:9 of NO_3^-:K^+ presented relative chlorophyll content statistically similar to that of the control (12:7) but 30.21% less compared to those nourished with 10:9. The above data indicate that the increase in the concentration of N-NO_3^- in the nutrient solution does not directly increase chlorophyll since its effect was modified by the level of K^+ (Table 3). In relation to the above, the availability of N modifies the relationship with K, as in habanero pepper a concentration of 12 and 7 meq L^{-1} increased the chlorophyll content in the leaves, while it decreased when the plants were irrigated with 10 meq L^{-1} of NO_3^-:K^+ (López-Gómez *et al*., 2017).

Although chlorophyll in plants is important because it is the pigment responsible for the capture of light energy during the process of photosynthesis and its concentration is directly related to the intensity of the green color (Rincón and Ligarreto, 2010), photosynthetic efficiency and the partitioning of photoassimilates is also fundamental, favoring the organ of interest. Regarding the production of dry matter, in leaves, stems and in the whole plant, it was statistically similar ($p \leq 0.05$) between treatments with values of 12.6 g, 124.4 g and 164.9 g, respectively, in root, with the ratio NO_3^-:K^+ 10:7, the plants accumulated 74.78% compared to the root of the plants nourished with the ratio 12:7 (Table 3). It is considered that the effect of the different treatments observed in the plants was due to the ratio NO_3^-:K^+ of the nutrient solution since all the plants were randomized in the same greenhouse.

Table 3. Effect of the NO_3^-:K^+ ratios of the solution supplied at the fruiting stage of chilhuacle on the relative chlorophyll content, weight of dry root matter, number of fruits and quality of the fruit.

Ratios NO_3^-: K^+ (meq L^{-1})	RCC	WDRM (g)	NFMS	EDF (mm)	WFFM (g)	WDFM (g)	TSS (°Brix)
10:5	70.78 cd	39.8 ab	18.8 ab	53.59 ab	39.82 ab	6.87 ab	8.73 ab
10:7	75.48 abc	41.6 a	14.8 bcd	52.01 b	37.09 b	6.75 ab	8.78 ab
10:9	89.36 a	31 ab	14.8 bcd	53.14 ab	39.47 ab	6.82 ab	8.99 ab
12:5	83.5 ab	33.4 ab	18.4 abc	51.77 b	38.92 ab	6.69 ab	8.56 b
12:7*	59.32 d	23.8	13.2 cd	51.87 b	39.08 ab	7.03 ab	9.37 a
12:9	58.8 d	26.4 ab	11.6 d	51.01 b	36.74 b	6.51 b	8.86 ab
14:5	65.26 cd	35 ab	20.4 a	52.05 b	38.71 ab	6.68 ab	9.21 ab
14:7	62.36 cd	29 ab	16.4 abcd	51.86 b	38 ab	6.64 ab	9.26 ab
14:9	62.36 cd	27.2 ab	13.6 bcd	54.8 a	41.65 a	7.26 a	8.85 ab
LSD	14.79	16.82	5.28	2.63	4.05	0.73	0.76
CV (%)	16.47	40.92	9.76	3.9	8.11	8.3	6.58

Means with the same literal in column are statistically equal according to the LSD test ($p \leq 0.05$). RCC= relative chlorophyll content in SPAD units; WDRM= weight of root dry matter; NFMS= number of fruits on main stems; EDF= equatorial diameter of fruit; WFFM= weight of fresh fruit matter; WDFM= weight of dry fruit matter; TSS= total soluble solids; LSD= least significant difference; CV= coefficient of variation; *= control treatment.

Conclusions

In the vegetative stage, the concentration with 14 meq L^{-1} of NO_3^- favored the height, stem diameter, root volume, dry matter of the stem and of the whole plant. In the reproductive stage, the NO_3^-:$H_2PO_4^-$:SO_4^{2-} ratios of the nutrient solution significantly modified the number of buds per plant. With 10:0.75:9.25 and 12:1:7 meq L^{-1} (control), the largest amount was obtained; however, 10:0.75:9.25 meq L^{-1} caused the lowest percentage of flower abortion. In the fruiting stage, the ratio 14:9 meq L^{-1} of NO_3^-:K^+ had a different influence on the quality of the chilhuacle fruits in presenting a greater diameter, as well as the weight of the fresh and dry matter.

Cited literature

Azofeifa, Á. y Moreira, M. A. 2004. Análisis de crecimiento del chile jalapeño (*Capsicum annuum* L. *cv* Hot), en Alajuela, Costa Rica. Agron. Costarr. 28(1):57-67. http://www.redalyc.org/pdf/436/43628106.pdf.

Corrales-Maldonado, C. G.; Vargas-Arispuro, I.; Vallejo-Cohén, S. y Martínez-Téllez, M. A. 2014. Deficiencia de azufre en suelos cultivables y su efecto en la productividad. Biotecnia. 16(1):38-44. http://www.repositorioinstitucional.uson.mx/handle/unison/4265.

Fajardo-Rebollar, E.; Estrada, K.; Grande, R.; Ek Ramos, M. J.; Ruiz, V. G.; Villegas-Torres, O. G. and Camino, C. D. 2021. Bacterial and fungal microbiome profiling in chilhuacle negro chili (*Capsicum annuum* L.) associated with fruit rot disease. Plant Dis. https://doi.org/10.1094/PDIS-09-20-2098-RE.

García-Gáytan, V.; Gómez, M. F. C.; Trejo, T. L. I.; Baca, C. G. A. and Garcia, M. S. 2017. The chilhuacle chili (*Capsicum annuum* L.) in Mexico: description of the variety, its cultivation, and uses. Inter. J. Agron. 2017. https://www.hindawi.com/journals/ija/2017/5641680/.

IICA. 2019. Instituto Interamericano de Cooperación para la Agricultura. Guía para la identificación y análisis de las posibilidades de negocios de la Bioeconomía. Costa Rica. 200 p.

Larios-González, R. C.; García, C. L.; Ríos, M. J.; Avalos, E. C. D. S. y Castro, S. J. R. 2021. Pérdidas de nitrógeno por volatilización a partir de dos fuentes nitrogenadas y dos métodos de aplicación. Siembra. 8(2): e2575. https://doi.org/10.29166/siembra.v8i2.2475.

López, L. P. y Pérez, D. B. 2015. El chile Huacle (*Capsicum annuum* sp.) en el estado de Oaxaca, México. Rev. Agroproductividad. 8(1):35-39. http://www.revista-agroproductividad.org/index.php/agroproductividad/article/view/636.

López, L. P.; Rodríguez, H. R. y Bravo, M. E. 2016. Impacto económico del chile Huacle (*Capsicum annuum* L.) en el estado de Oaxaca. Rev. Mex. Agron. 20(38):317-328. Doi:10.22004 / ag.econ.239292.

López-Gómez, J. D.; Villegas, T. O. G.; Nava, H. S.; Rodríguez, M. A.; López, P. J. y Fernández, E. M. 2017. Rendimiento y calidad del chile habanero (*Capsicum chinense* Jacq.) por efecto del régimen nutrimental. Rev. Mex. Cienc. Agríc. 8(8):1747-1758. http://www.redalyc.org/articulo.oa?id=263153822009.

Luna-Fletes, J. A.; Cruz-Crespo, E. y Can-Chulim, Á. 2021. Piedra pómez, tezontle y soluciones nutritivas en el cultivo de tomate Cherry. Terra Latinoam. 39:1-12. https://doi.org/10.28940/terra.v39i0.781.

Moreno-Pérez, E. C.; Sánchez-Del Castillo, F.; Gaspar, F. J. M.; Ramírez-Árias, A. y Beryl-Colinas-León, M. T. 2019. Rendimiento de pimiento morrón (*Capsicum annuum* L.) por poda floral selectiva y despunte de yemas laterales en la cuarta bifurcación. Agrociencia. 53(5):697-707. https://agrociencia-colpos.mx/index.php/agrociencia/article/view/1837.

Nazar, R.; Iqbal, N.; Masood, A.; Syeed, S. and Khan, N. A. 2011. Understanding the significance of sulfur in improving salinity tolerance in plants. Environ. Exp. Bot. 70(2-3):80-87. https://doi.org/10.1016/j.envexpbot.2010.09.011.

Noh, M. J.; Borges, G. L.; y Soria, F. M. 2010. Composición nutrimental de biomasa y tejidos conductores en chile habanero (*Capsicum chinense* Jacq.). Trop. Subtrop. Agroecosys. 12(2):219-228. https://www.redalyc.org/articulo.oa?id=93913070003.

Pavón, T. L. D.; Fernández, B. J. A. y Graupera, G. X. J. 2021. Efectos de fertilización potásica en el cultivo de pimiento (*Capsicum annum* L.) *var* híbrido Nathalie. Alfa Rev. de Investigación en Ciencias Agronómicas y Veterinaria. 5(13):78-90. https://doi.org/10.33996/revistaalfa.v5i13.99.

Peil, R. M. y Gálvez, J. L. 2005. Reparto de materia seca como factor determinante de la producción de las hortalizas de fruto cultivadas en invernadero. Agrociencia 11(1):05-11. http://dx.doi.org/10.18539/CAST.V11I1.1171; https://periodicos.ufpel.edu.br/ojs2/index.php/CAST/article/view/1171/966.

Rincón, C. Á. y Ligarreto, G. A. 2010. Relación entre nitrógeno foliar y el contenido de clorofila, en maíz asociado con pastos en el Piedemonte Llanero colombiano. Corpoica. Ciencia y Tecnología Agropecuaria. 11(2):122-128. http://www.redalyc.org/pdf/4499/449945029003.pdf.

Sieiro, Miranda, G. L.; González Marrero, A. N.; Rodríguez Lema, E. L.; Rodríguez Regal, M. 2020. Efecto de los macroelementos primarios en la susceptibilidad a enfermedades. Centro Agrícola. 47(3):66-74. http://scielo.sld.cu/scielo.php?pid=S0253-57852020000300066&script=sci_abstract&tlng=es.

Steiner, A. A. 1984. The universal solution. ISOSC. *In*: Proceedings of 6th International Congress on Soilles Culture. Lunteren, The Netherlands. 633-649 pp.

Taiz, L. and Zeiger, E. 2010. Plant physiology 5th (Ed.). Sunderland. Sinauer Assoc, Inc., Publishers, Sunderland Masschusetts. 764 p.

Urbina-Sánchez, E.; Cuevas-Jiménez, A.; Reyes-Alemán, J. C.; Alejo-Santiago, G.; Valdez-Aguilar, L. A.; Vázquez-García, L. M. 2020. Solución nutritiva adicionada con NH_4^+ para producción hidropónica de chile huacle (*Capsicum annuum* L.). Rev. Fitotec. Mex. 43(3):291-298. https://doi.org/10.35196/rfm.2020.3.291.