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Article

Morphometry and yield of Capsicum chinense Jacq. in Arteaga, Michoacán

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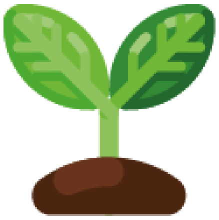
Abstract

In Mexico, the production of Capsicum chinense is limited due to the technological level used, the incidence of pests and diseases, and poor nutrition and irrigation control. The objective was to evaluate the morphometric and production response of C. chinense subjected to six fertilization treatments under shade mesh in Arteaga, Michoacán, Mexico. A Pearson analysis (r) was performed to identify correlations between the morphometric variables of the plants, in which five nitrogen-phosphorus-potassium (NPK) treatments and a control treatment were evaluated under a randomized complete block design with 10 replications and a linear mixed model (LMM). The value of r reports a correlation between yield (g) and the dimensions of leaf diameter (r= 0.622) and base (r= 0.497). The Anova and Tukey's mean separation test (a= 0.05) indicate a differentiation in plant dimensions in height and basal and leaf diameters, as well as a diverse slenderness index 45 days after transplanting. Both in the yield ratified through the LMM and the morphometry, the N240-K240-P240 treatment was the one with the highest production per plant. The fruits obtained in this work were of first quality since the weight was greater than 6.5 g, and the average yield was 584 g plant^{-1} in 10 cuts made. Due to the yield obtained, the cultivation of this vegetable is an attractive economic alternative for this region of the country.

Keywords:

habanero chili, protected agriculture, vegetable production.



Introduction

In Mexico, the production of Capsicum chinense Jacq. (habanero chili) has been limited due to the low level of technology in production, the incidence of pests and diseases, and poor nutrition and irrigation control (Rincones, 2009; Huez, 2013). The nutritional requirements for C. chinense indicate that the use of fertilization doses as a measure to increase productivity is an activity that should be analyzed and implemented according to the growing conditions.

The habanero chili crop demands high quantities of nitrogen (N), phosphorus (P), and potassium (K), which have been documented to lead to an increase in the yield and quality of the fruit (Borges et al., 2010). The phytosanitary problems of C. chinense make this agricultural activity unprofitable, so looking for production alternatives such as the system of crops protected with shade mesh provides protection against excessive exposure to solar radiation, torrential rains, intense winds and controls access to pests and organic agents that are factors that have a negative impact on the development of plants, yield, and quality of the fruit (Santoyo and Martínez, 2012).

C. chinense is grown in southeastern Mexico, mainly in Yucatán, which has the highest production and is reported to have an area of ≈708 ha, followed by Tabasco, Campeche, and Quintana Roo, where yields in these regions of the country vary from 10 to 30 t ha^{-1}, which depend on the level of technification used (Tucuch et al., 2012; Latournerie et al., 2015).

Fifty percent of the area destined for this vegetable is sown with landrace materials, the rest with free-pollinated varieties, and a minimum area of recently formed hybrids (Ramírez et al., 2018). In Michoacán, C. chinense is usually produced in the temperate to tropical climate transition zone in the municipality of Tacámbaro, where small areas are sown because its productivity is limited by environmental conditions and poor crop management.

In Michoacán, this crop is not controlled at the variety level; in addition, production is still far from covering the demand, which leads to a high price due to its organoleptic properties and high degree of pungency (Tapia et al., 2016). Due to the restricted area of production in Michoacán and market demand, it is considered essential to expand the production area, promote profitable cultivation in rural areas of tropical climates, and implement viable agronomic alternatives for these regions.

The objective was to evaluate the morphometric response and yield of C. chinense plants subjected to fertilization treatments under shade mesh in Arteaga, Michoacán, Mexico, under the hypothesis that the different nutrition plans used for C. chinense influence the development and characteristics of the plant, the shape of the harvested fruit, and commercial yield.

Materials and methods

The study was conducted in Espinoza, municipality. of Arteaga, Michoacán, located at coordinates 18° 28’ 33.9” north latitude and 102° 15’ 28.5” west longitude, at an altitude of 952 m. The fieldwork spanned from June to December 2020, the protected agriculture technique was used, where the crop was covered with a shade mesh of 50% light interception, which maintained an average temperature between 19 °C and 30 °C, evaluated with an HTC-2 digital thermometer - hygrometer.

Before establishing the experiment, 120 seedlings were propagated in a polystyrene tray of 25 cm^3 capacity with a substrate mixture based on peat moss-perlite (70-30%). Seeding was carried out at a depth of 1 mm, and the cavities were covered with black plastic to maintain temperature and humidity until the development of the embryo (Ramírez et al., 2016). Twelve days after sowing (das) and germination, the plastic cover was removed to encourage the development of the root and aerial system; at 20 and 30 das, a soaked lentil-based rooting agent was applied at a rate of 5 ml plant^{-1}.

The 30 x 30 cm black polyethylene bags were filled with substrate available in the region, sifted forest soil to remove large elements and impurities (regosol) and decomposing organic matter from the soil at 50-50%. A total of 60 seedlings without the presence of pests or diseases and with the greatest development were selected for transplanting, which was done at 60 das when the individuals had eight true leaves, a height of 5 cm and an average basal diameter of 2 mm (López et al., 2018).

The spacing was 35 cm between plants and 70 cm between rows (Ramírez et al., 2016) (Villa et al., 2010). Irrigation was carried out according to the needs of the plant: 20 ml plant^{-1} day^{-1} in the germination stage, 0.5 L plant^{-1} day^{-1} in transplantation, and subsequently 1 L plant^{-1} day^{-1} (Medina, 2016). Irrigation was applied twice a day (9:00 and 18:00 h), and it was suspended on cloudy or rainy days to reduce the likelihood of fungal diseases or management problems.

The nutritional program was established in accordance with INIFAP (1997); Tun (2001); Soria et al. (2002) for the production of C. chinense, which is in a dosage range from 95 to 250 kg ha^{-1} of NPK. A control (T6) consisting of seedlings without fertilization and five levels of NPK were evaluated. The nutrient doses (treatments) were: 240-240-240 (T1), 120-120-120 (T2), 100-100-100 (T3), 160-160-160 (T4), and 200-200-200 (T5), the plants were placed under shade mesh in a randomized complete block design (RCBD) with 10 replications.

Nutrition began eight days after transplantation (Borges et al., 2010) by dissolving the fertilizer in 2.5 L of water corresponding to each treatment and applying it manually (250 ml of solution plant^{-1}). This activity was performed every seven days and was suspended when the first physiologically ripe fruit appeared (Tun, 2001).

When the plants reached a height of ≈22 cm, lateral shoots below the first bifurcation were removed to prevent them from damaging the epicotyl, competing for nutrients, and negatively influencing flower emission, pollination effectiveness, and fruit set; the leaves located below the first bifurcation were also removed (Medina, 2016; Villegas, 2016). One month after transplanting, in order to avoid the breakage of stems and branches, 70 cm wooden stakes were placed to keep the plants upright (Macías et al., 2013).

In the evaluation of the morphometric characteristics of each plant by block and treatment, the following variables were measured: plant height (Hei, cm), basal diameter (Bd, mm), leaf diameter (Ld, cm), and slenderness (Si: Hei/Bd) and protrusion indices (Pi: Hei/Ld). The shape of the fruit and the commercial yield by treatment were carried out in 10 harvests every four days, where the number of fruits per plant (Num), equatorial diameter (ed, mm), length (leng, cm), and weight of each chili (Yield, g) were quantified (Borges et al., 2010; López et al., 2020).

The leng and ed data were averaged per plant and treatment, while the weight of each fruit was added to obtain the yield in kg plant^{-1}. The plants' measurement of Hei, Bd, and Ld began when the individuals presented eight true leaves, Hei> 5 cm, and Bd of 2 mm. Hei and Ld were measured with a Cadena MGA 3619 tape measure; the first was determined from the base of the stem to the apex, and the second was obtained by measuring the crown of the plant crosswise and averaging the value; the Bd was obtained at 2 cm above the substrate with a digital plastic analog King's foot vernier.

These data were used to calculate the indices of slenderness (Si: Hei/Bd) and protrusion (Pi: Hei/Ld). The variables of Num, ed, leng, and Yield were evaluated 75 days after transplantation (dat) when the plants presented their maximum development and mostly ripe fruits. For the first variable, the harvested fruits were counted and recorded; the ed was determined by measuring the width of each fruit in mm, and the length was considered from the base of the calyx to the apex of the chili, using a graduated ruler of 30 cm and a digital vernier; the weight of each fruit and yield in kg plant^{-1} was obtained with an Escali digital scale.

The analysis of variance (Anova) for the variables of Hei, Bd, Ld, Si, Pi, Num, ed, leng, and Yield was processed in the Rstudio® program using the aov function (Chambers et al., 1992), where the hypotheses of equality of means between the treatments (Ho) were contrasted against the alternative hypothesis, which considers that at least one of the treatments is different from the rest (Ha), both with a significant level of 0.05.

The mathematical model proposed for this design was: Yij= u+Ti+Bj+eij, i = 1, ..., 6; j=, ..., 10. Where: yij= dependent variable by treatment i, of block j; u= overall mean effect; Ti= effect by treatment; Bj= block effect; and eij= error (Martínez-González et al., 2006) (Infante and Zárate, 2012).

The coefficients of variation (CV) and the least significant difference (LSD) were calculated, and compliance with the regression assumptions of normality and homoscedasticity of the residuals

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was evaluated using the Shapiro-Wilk (SW) and Bartlett tests, respectively (Martínez-González et al., 2006). The decision rule in the value of W (Shapiro-Wilk) and K^2 (Bartlett) at a 99% confidence level ($p > 0.01$) (Infante and Zárate, 2012) was used for both tests.

The means were grouped through Tukey's t-test, considering an a= 0.05 (RStudio Team, 2020). Due to the availability of multiple morphometric variables that could affect the yield of C. chinense, a correlation matrix was constructed to identify trends and degree of association of the variables through the value of Pearson's coefficient (r): $r = 0$ indicates a null correlation between the variables, values of $r < 0.3$ correspond to a weak association; when $0.3 \leq |r| \geq 0.7$ the association is moderate, and values of $r > 0.7$ denote a strong correlation (Martínez-González et al., 2006).

With the variable with the highest association, a linear model without intercept was fitted to predict yield per plant with the inclusion of the random effect by treatment as follows: $y = b + b\,i * x + e$ (Pinheiro et al., 2019), where y is the yield or production of chilis per plant (g), b is the parameter related to variable x, and b_i the parameter related to the treatment and e the error term.

Results

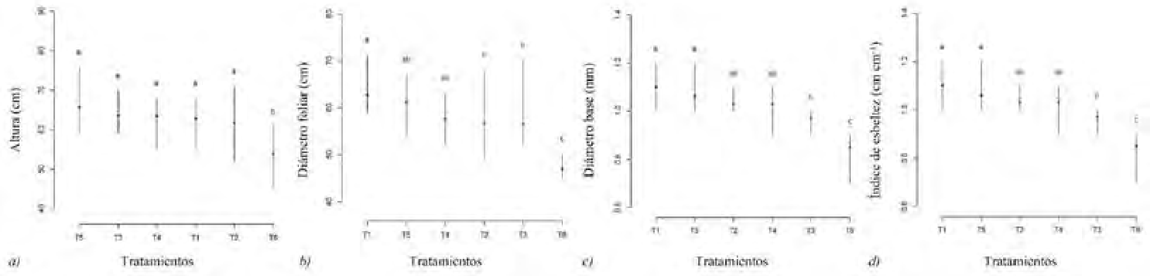
The Anova by measurement for the morphometric variables of Hei, Bd, Ld, and Si showed that, until the sixth record (45 dat), there were significant differences; after that, the plants began to differ by treatment until measurement 9, where the morphometric record was completed. The Anova for the variables of Hei, Bd, Ld, and Si indicated significant differences since the F-values for the treatments were 10.61 (residual: 15.706), 19.07 (residual: 15.813), 17.52 (residual: 0.004), and 4.13 (residual: 0.002), respectively, with a probability value $p < 0.05$ in all cases.

The standardized critical value range for these analyses was 4.21, and the LSD was very similar in the different measurements performed; for its part, CV decreased as the plants in each treatment became longer lived and increased their dimensions. For the variables of Hei, Bd, Ld, and Si, the Anova of the last record (measurement 9) indicates CVs of 6.411, 6.981, 6.589, and 7.368, respectively, with LSD values of 5.274, 5.292, 0.088, and 0.061 for each variable.

Compliance with the regression assumptions of normality in the frequency of residuals was observed with values of SW between 0.978 and 0.98 and probability $p > 0.05$; on the other hand, the homoscedastic distribution of residuals in the variables of Hei (K^2: 2.46), Bd (K^2: 11.78), Ld (K^2: 5.72), and Si (K^2: 0.78) were not significant ($a > 0.05$) in all cases.

The grouping of the variables of interest (t-Tukey) indicated that treatment 1 (N240-K240-P240) stood out from the rest in the dimensions of Ld, Bd, and Si, and the control showed a lower response (Figure 1, T6). It can be inferred that the Hei of the plants was not a reliable indicator to differentiate the response of C. chinense to different treatments since the mean separation test did not show differences between the treatments, but it did with the control.

Figure 1. T-Tukey grouping of the ninth measurement for variables in *Capsicum chinense*.



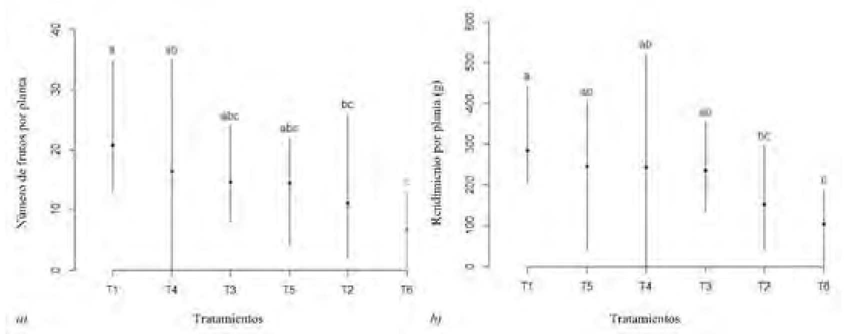
Nevertheless, the dimensions of the diameters and Si evaluated can be taken as a reference for plant selection and possible productivity, where the T1 and T5 treatments were consistently the best since they presented the highest values on average (Figure 1).

The Anova reported that, for the variables of number of fruits (F= 5.267, p= 0.0007, CV= 47.15) and yield plant^{-1} (F= 5.447, p= 0.0005, CV= 43.74), there are significant differences between the treatments and the assumptions of normality (SW= 0.97, p= 0.1494 and SW= 0.99, p= 0.6869) and homoscedasticity (K^2= 12.2, p= 0.03213 and K^2= 10.94, p= 0.05212) are met. For fruit diameter and length, the regression assumptions of normality (SW= 0.85, p< 0.0001 and SW= 0.83, p< 0.0001) and homoscedasticity (K^2= 29.24, p< 0.0001 and K^2= 16.8, p= 0.005) were not met, for this reason, it was decided to process the data under the Kruskal-Wallis non-parametric analysis.

To solve the non-compliance with normality and homoscedasticity in fruit diameter and length, the variables were transformed into x^2, root(x), 1/x, and log(x) (Zar, 2010). Levene's test was run for both variables (Fox and Weisberg, 2019), in which a homogeneity of variance between treatments was identified (F-value= 0.4516, Pr> F= 0.8103; F-value= 0.4883, Pr>F= 0.7835) and it provides the guideline for using the Kruskal-Wallis non-parametric analysis (Fox, 2016).

In the Kruskal-Wallis test, it was identified that there were no significant differences between the dimensions of the diameter and length of the fruit in response to the application of the different treatments (Chi^2= 7.9532, p- value= 0.1588; Chi^2= 2.2205, p-value= 0.8179); therefore, the Ho of equal means between treatments was accepted. For the variables of number of fruits and yield plant^{-1} (g), a significant difference was observed between the treatments, where treatment 1 (240-240-240) is the one that stood out from the others and is the one with the highest response; on the other hand, the control and treatment 2 (120-120-120) were different from each other but had the lowest response in the number of fruits and yield plant^{-1} (Figure 2).

Figure 2. Grouping by Tukey for the experimental design applied in *Capsicum chinense.*



By verifying these statistical differences graphically with the yield by cut (Figure 2), it can be seen how treatment 1 shows a higher production from the beginning of the harvest; in addition, the highest yields were reached in cuts 4, 5 and 6, to later decrease its production (Figure 3).

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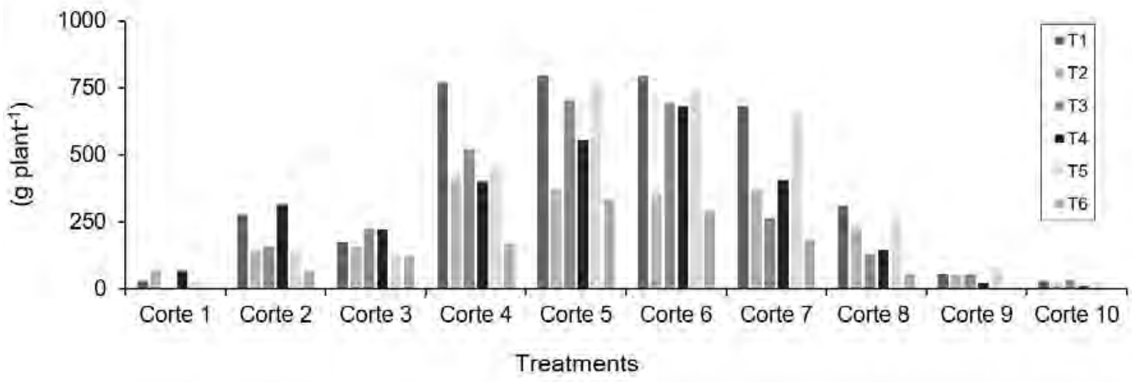
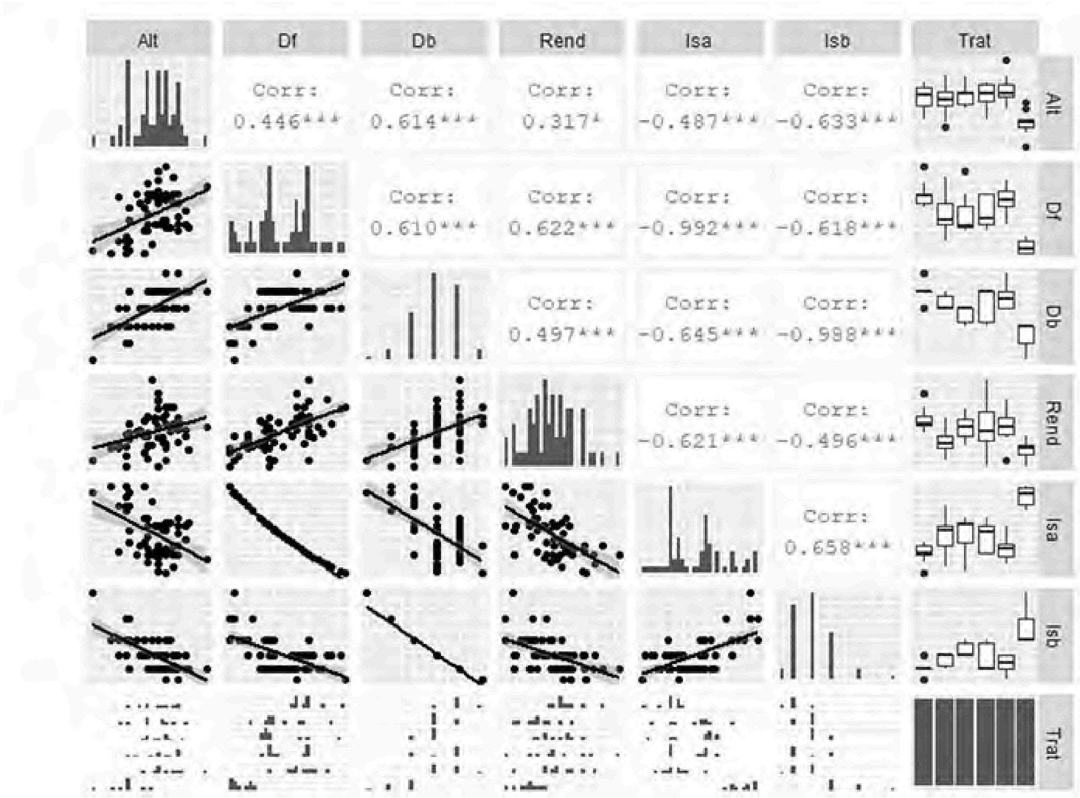
Figure 3. Yield distribution by cut and treatment applied to *C. chinense*.



Pearson's correlation analysis for the variables evaluated within the RCBD in C. chinense showed a direct linear relationship between plant yield (g) and the dimensions of Ld reached at 45 dat (r= 0.622) and in better association with Bd (r= 0.497) and Hei (r= 0.317) (Figure 4). In the indices constructed between the diameter dimensions and Hei, a correlation coefficient greater than 0.49 was identified (Figure 4). All results were significant at 95% reliability.

Figure 4. ***Pearson's correlation analysis for C. chinense variables.*** **Alt= height (Hei) (cm); Df= leaf diameter (Ld) (cm); Db= basal diameter (Bd) (mm); Rend= yield (g); Isa and Isb= Hei/Ld and Hei/Bd indices, respectively; Corr= Pearson's correlation coefficient. Significance code= '***' 0.001; '**' 0.01; '*' 0.05.**



With Ld, the variable most associated with Yield (Figure 4), the linear model without intercept was fitted to predict yield per plant with the inclusion of the random effect by treatment, which took the following form: y= b+ b i *Ld+e. Where: y was the yield per plant (g); b was the parameter related to Ld and b_i was the parameter related to the random factor (treatment); and e was the error term.

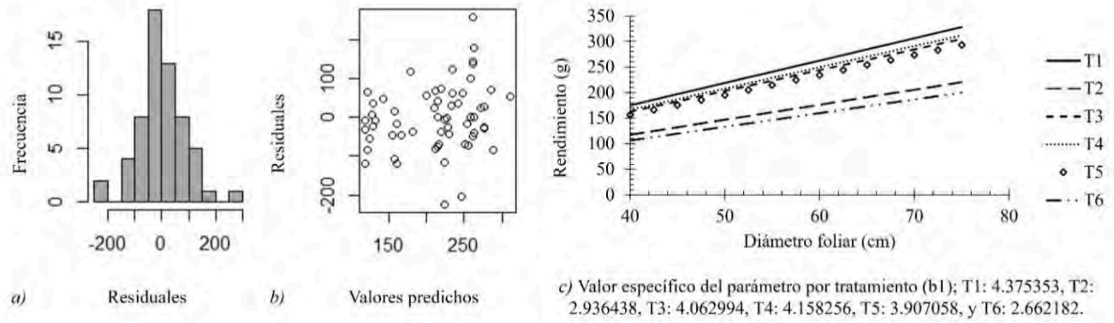
When fitting the model, it presented significant parameters ($p> 0.05$) and an average bias evaluated through the root mean square error (RMSE) of 1.8 g (Table 1); in addition, it met the assumptions of normality (Shapiro-Wilk: W= 0.99, p-value= 0.2835; Figure 5a) and homoscedasticity (Kolmogorov-Smirnov: D= 0.052364, p-value= 0.8972; Figure 5b); it also provided the possibility of comparing the response of Yield for each fertilization plan (Figure 5c), where it is confirmed that, by using the specific parameters, the fertilization rate 240-240-240 of NKP is the one with the highest overall yields.

Table 1. Value of the parameter and goodness of fit of the linear model without intercept under mixed effects by treatment in *C. chinense*.

Parameter	Value	Standard error	t-value	*p-value*	RMSE	AIC
b_1	3.683713	0.3421674	10.76582	<0.001	1.807832	719.7855

RMSE= root mean square error. AIC= Akaike information criterion.

Figure 5. Normality (a) and homoscedasticity tests; (b) of the linear model without intercept under mixed effects by treatment for C. chinense; and specific parameters for each level (c).



c) Valor específico del parámetro por tratamiento (b1); T1: 4.375353, T2: 2.936438, T3: 4.062994, T4: 4.158256, T5: 3.907058, y T6: 2.662182.

Discussion

The size of the fruits obtained in this work corresponds mostly to a first quality production since the weight was greater than 6.5 g, as proposed and classified by (Borges et al., 2010): >6.5 g first, 5.5-6.4 g second, and <5.4 g third. In addition, it agrees with the average dimension of fruit diameter (25.96 mm) and yield (547.7 g plant^{-1}) reported by Huez (2013) on the coast of Hermosillo, Sonora for C. chinense when evaluating the effect of 5 doses of nitrogen fertilization.

The removal of lateral shoots below the bifurcation of the stem in the plant was considered as pruning; secondary stems or lateral branches were not removed, as done by López et al. (2020), because a decrease in yield is reported when performing this work; therefore, the activity carried out can be incorporated into the cultural tasks performed on C. chinense grown under shade mesh.

The maximum average yield reported for C. chinense (584 g plant^{-1}) was higher than the 302 g plant^{-1} obtained by Tucuch et al. (2012), with plants of 89.65 cm average Hei established in soils with different particle sizes. Similarly, the yield was higher than that mentioned by Tapia et al. (2016), who applied hormonal complexes and established the plants in a greenhouse (419 g plant^{-1}); however, the average yields plant^{-1} were lower than those reported by Borges et al. (2010) (1 253 g plant^{-1})

when producing C. chinense under different conditions of humidity and nutrition and harvesting weekly and not every four days as was done in this work.

The downward trend in yield in C. chinense as fertilization doses decreased is consistent with Wierenga and Hendrickx (1985), who grow Capsicum annuum with different fertilization doses and amounts of water. The results are consistent with those reported by Pire and Colmenarez (1996); Jaimez (2000), who both mentioned that the decrease in nitrogen available to the plant is closely related to the decrease in yield per plant in Capsicum sp. crops.

The yield trend decreases as the fertilization dose decreases, and the production decreases proportionally, a situation that agrees with Borges et al. (2010), who obtained the best results with the same NPK treatment (240-240-240) but with a different substrate and environment. The positive linear correlation between Ld at 45 data with yield (r= 0.622) and the linear model without intercept can be a reference to estimate the expected yield in Capsicum sp. under different treatments.

The leaf area index expressed through Ld is an indicator of photosynthetic maturity in the plant; it determines the assimilation rates of physiological processes and is correlated with the yield of each individual, as described by Jarma et al. (1999); Barraza et al. (2004) in other vegetables.

Similarly, and even when a model was not fitted with the variable of Bd, due to its correlation with yield (r= 0.497), this can be a morphometric variable to predict productivity, as mentioned by Stoffella and Bryan (1988) when evaluating growth and yield in C. annuum, who report high yields as a function of the state of morphological development, slenderness index and diameter characteristics in this crop.

Due to the yields shown in the work and the fact that the inputs used are accessible and available to producers in this region of Michoacán, which is not considered a growing area for C. chinense, this economic activity can be a viable economic alternative for rural areas in the region of Arteaga, Michoacán, Mexico.

Conclusions

The application of the different fertilization levels influenced the morphological dimensions and yield per plant of C. chinense Jacq. grown under shade mesh in Espinoza, Arteaga, Michoacán, Mexico. The production response obtained with respect to other studies can be improved through the inclusion of cultural tasks or hormones within the crop’s nutritional plan.

The correlation values between morphological variables and C. chinense yield can be considered in management, and they could provide the guideline for production when making predictions using the proposed linear model without intercept. Treatments with 240-240-240 (T1) and 200-200-200 (T5) nitrogen (N)-potassium (K)-phosphorus (P), respectively, showed higher yield productivity (g plant^{-1}).

In addition, due to the first-quality fruit obtained with these fertilization doses, the market price, and consumption demand in the region, this crop could be an alternative for economic and social development for this rural region of the state of Michoacán.

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