Colegio de Postgraduados

Agronomic response of two experimental varieties of habanero chili in the application of band vermicomposting

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ABSTRACT
The habanero chili pepper has great productive potential in Mexico, with an annual growth of 12.5% in the planted area in the last five years.
Objective: was to evaluate the agronomic response of two experimental varieties of habanero chili called HNC-6 orange color and HCC-8 chocolate color, belonging to the Center for Training and Development in Seed Technology.
Methodology: the study was established under five doses of vermicompost, 0, 0.3, 0.6, 0.9 and 1.2 kg plant^{-1} using a completely random design with a 2×5 factorial arrangement.
Results: the HNC-6 variety had a better agronomic response than HCC-8, its yield was 95% higher, the number of fruits per plant 84%, fruit length (FL) 25%, pericarp thickness 28%, fruit firmness 11%, and average fruit weight 4.7%. The HCC-8 variety exceeded the height of HNC-6 by 38% and the fruit diameter (FD) by 14%. The vermicompost doses exerted a similar effect on both varieties. In conclusion, the experimental variety HNC-6 showed a better agronomic response under the conditions tested. The vermicompost doses exerted a response effect and similar trend in the two experimental varieties of habanero pepper tested, the significant interactions found in FL, FD, and total soluble solids indicate that the application of vermicompost influenced the quality of the fruits in some aspects.
Conclusions: the main factors that determined the response of the crop are its genetic component in response to the environment and the degree of maturity of the vermicompost.

Keywords: *Capsicum chinense* Jacq. genotype, earthworm humus, quality, yield.

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INTRODUCTION

Habanero chili pepper (*Capsicum chinense* Jacq.) is a vegetable with high commercial potential in Mexico. It is considered as one of the spiciest chili peppers in the world since it presents the highest levels of burning aftertaste or pungency in Scoville units [1]. In the year 2021, Mexico reached a production value of $441,205.73 million pesos, with

Image by PublicDomainPictures at Pixabay a surface of 1517 hectares planted, whose average yield was 17.99 t ha^{-1}, the main producing states are Sinaloa (305 hectares), Yucatán (264.72 hectares), Tabasco (274 hectares), Campeche (173 hectares), and Veracruz (116 hectares), where the main form of production is open-air and corresponds to 90.2% of the total production [2]. Producing habanero chili requires a high investment cost, although its value is generated due to its preference in domestic and exports markets; however, despite the profitability potential that it represents, there is a low technological level for its production process, which is reflected in the low harvest volumes [3].

On the other hand, the generation of new varieties will always be a priority objective for agriculture, and one of the tools to achieve it is genetic improvement, whose objectives is to select the best genotypes within the populations and to create new genotypes with previously defined characteristics. In Mexico, these activities are directed at increasing the productivity, the quality and the adaptability of cultivated species to current and future changes that are foreseen. In the case of habanero chili peppers, cultivars are sought with high levels of capsaicin and ascorbic acid, and it is considered that Yucatán is the center of genetic diversity of habanero chili pepper, so the potential for improvement is high [4].

Habanero chili pepper is one of the products that is demanded in large volumes globally, due to its high levels of capsaicin, which confer an exclusive added value to the fruits; therefore, producers aim at exports markets as their target business, although they are particularly strict with the management of inputs that are required in the production process [4]. Under this context, organic production is a development strategy that attempts to change the limitations in conventional production; it is founded not only on improving the soil and a promotion of the use of local inputs, but also in giving a higher added value to the final products, in addition to being perceived and promoted as healthy and safe for the environment [5]. It has been documented that organic fertilizers improve the soil quality and as consequence the environment, and consequently foster sustainable agriculture [6]. An example of this is vermicomposting, which is the process by which organic waste is decomposed through the synergic actions of earthworms and microbial communities [7], in addition to containing nutrients that are important in the growth and productivity of plants [8], and also substantially improve the chemical, biological and physical properties of the soil [9]. Therefore, the application of vermicompost can represent an alternative to help modify the management of agricultural inputs, promoting growth, productivity and profitability of the crops in a sustainable manner [10]. Because of the aforementioned, this study sets out to understand the agronomic response of two experimental varieties of habanero chili peppers identified as HNC-6 and HCC-8 to the application of band vermicomposting.

MATERIALS AND METHODS

Location of the experiment

The experiment was carried out in a macro-tunnel of the Department of Horticulture of the Universidad Autónoma Agraria Antonio Narro (25° 21' 23.126" N and 101° 2' 6.801" W), where the climate is dry with few rains and the temperatures range between 5 °C and 24 °C; the field work was conducted in the period of May to December in 2021.

Plant material

Seeds from two experimental varieties of habanero chili pepper were used, of names HNC-6 and HCC-8, from the germplasm that is held in the Training and Center for Training and Development in Seed Technology of the Universidad Autónoma Agraria Antonio Narro.

Sowing

The experimental varieties HNC-6 and HCC-8 were sown in polystyrene trays with 200 cavities, each cavity with a mixture of peat moss and perlite substrate in a proportion of 70/30%. Application of low-volume irrigation was carried out using triple 17 (17-17-17+Me) dissolution added with microelements for the seedling nutrition, in doses of 0.5, 0.75 and 1 g L^{-1} at the second, fourth, and sixth week after emergence, respectively, until before the transplant.

Soil preparation

In the preparation of the experimental area, first, the weeds were removed, the soil was de-compacted, and cultivation beds were formed; a canal of approximately 15 cm of depth and 20 cm of width was opened, where band vermicomposting was applied, which was integrated to the furrow; finally, the beds were reformed. The composition of the vermicompost used in this research study (applied in bands), is shown in Table 1.

Table 1. Nutritional composition of the vermicompost used in the execution of the experiment.

Element	Unit	Quantity
Total nitrogen	%	1.51
Phosphorus (P)	%	0.54
Potassium (K)	%	1.28
Calcium (Ca)	%	10.4
Magnesium (Mg)	%	0.85
Sodium (Na)	%	0.21
Sulfur(S)	%	0.37
Iron (Fe)	mg kg^{-1}	5950
Copper (Cu)	mg kg^{-1}	16.8
Manganese (Mn)	mg kg^{-1}	249
Zinc (Zn)	mg kg^{-1}	237
Boron(B)	mg kg^{-1}	61
Humidity	%	14.4
Organic material	%	31.8
Ashes	%	68.2
Organic carbon	%	18.5
C/N ratio		12.2

Trasplanting

After the furrows were created, ribbon irrigation and padding were applied, and irrigation at field capacity; transplanting was done at double line (in herringbone pattern), with 25 cm of distance between lines and 30 cm between plants; the distance between cultivation beds was 1.5 m, and the approximate plantation density was 44,000 plants ha^{-1}.

Description of the treatments

Two experimental varieties of habanero chili peppers were evaluated, called HNC-6 and HCC-8, treated with five doses of vermicompost: 0, 0.3, 0.6, 0.9 and 1.2 kg $plant^{-1}$. The distribution of treatments was with a completely random design with factorial arrangement of 2×5, with a total of ten treatments with four repetitions each, and each repetition with six plants, of which only four were used placed right at the center of the experimental unit to carry out the corresponding evaluations and quantifications; the data obtained were analyzed in the Infostat® statistical software.

Variables evaluated

Agronomic variables

Plant height (cm): the measurements were recorded starting at 15 days after transplanting and a measuring tape graded in centimeters was used for their quantification, while the stem diameter (mm) was also quantified at 15 days after transplant with the help of a digital Steren® Vernier, HER-411; both response variables were evaluated every 15 days.

Yield variables

Number of fruits per plant: the total number of fruits harvested in each plant were counted and the yield of fruit in grams per plant (g) was determined with the help of a digital Steren® balance, MED-080; the average weight of the fruit resulted from dividing the total weight of the fruits by the number of fruits per plant (g). The calculated yield (t ha^{-1}) resulted from multiplying the yield of each plant by the total number of plants according to the plantation density established in the experiment (44,000 plants).

Variables quantified in fruit

For the measurement of fruit length and fruit diameter (mm), fruits were collected randomly on which the length and the diameter were measured in each harvest with the help of a digital Steren® Vernier HER-411. To determine the percentage of total soluble solids or (°Brix), the fruits were macerated, and this way cell extract was obtained which was taken to a digital Soonda® refractometer 0-85%. And finally, to determine the firmness of the fruit (Kg cm^{-2}), data were taken with the help of a digital Force Gauge GY-4 penetrometer.

RESULTS AND DISCUSSION

According to the analysis of variance (ANOVA $p \leq 0.05$), significant statistical differences were found between varieties (Table 2). The variety HCC-8 presented plants of larger size

Table 2. Analysis of variance and means test of growth variables, yield and components, of two experimental varieties of habanero chili pepper treated with five doses of band vermicomposting.

Variety	PH (cm)	SD (mm)	GPP (g)	NFP	AFW (g)	CY ($t\ ha^{-1}$)
HNC-6	65.00*	14.72 a	718.74 a	129.93 a	5.52 a	31.63 a
HCC-8	90.47 a	14.60 a	363.80 b	69.55 b	5.27 a	16.01 b
ANOVA p≤	<.0001	0.945	<.0001	<.0001	0.2980	<.0001
MSD	8.66	3.69	84.06	10.26	0.39	3.69
Vermicompost (kg plant^{-1})						
0	83.63 a	17.50 a	594.38 a	108.66 a	5.43 a	26.16 a
0.3	82.24 a	13.79 a	519 .09 a	90.16 a	5.65 a	22.84 a
0.6	79.97 a	12.81 a	565.63 a	103.66 a	5.43 a	24.89 a
0.9	73.88 a	15.00 a	532.78 a	94.97 a	5.52 a	23.44 a
1.2	68.96 a	14.21 a	494.47 a	101.25 a	4.95 a	21.76 a
ANOVA p≤	0.1785	0.5516	0.5762	0.1808	0.2158	0.5657
MSD	19.50	8.32	189.19	23.10	0.88	8.32
CV(%)	17.18	38.89	23.94	15.86	11.22	23.93
Interaction						
ANOVA p≤	0.6431	0.7679	0.996	0.200	0.4041	0.9964
MSD	32.48	13.86	305.19	38.47	1.47	13.86

Different letters in the same column differ statistically (Tukey $p \leq 0.005$). MSD=minimum significant difference, CV=coefficient of variation. PH=plant height, SD=stem diameter, GPP=grams harvested per plant, NFP=number of fruits per plant, AFW=average fruit weight, CY=calculated yield ($t\ ha^{-1}$).

in their final height (90.47 cm) compared to HNC-6 (65 cm); this is below the results found by Tapia [11] who reported an average height of 137 cm, although above those reported by Camposeco [12] in chocolate habanero peppers, both studies with exclusive mineral fertilization; therefore, it is inferred that the environmental conditions of the crop and the type of fertilization influence the agronomic behavior of the varieties. In the varieties yield in grams harvested per plant (GPP), number of fruits per plant (NFP) and yield calculated in tons per hectare ($t\ ha^{-1}$), significant differences were found between varieties, with the variety HNC-6 being superior to HCC-8 in average fruit weight, while there was no significance in stem diameter. On the other hand, the doses of vermicompost applied do not exert a significant effect in any of these response variables, and statistical differences were also not observed in the interactions. In relation to this, it has been documented that the different ways of vermicomposting determine the different physical and chemical properties, which can influence the growth and the morphology of the plants in various ways, thus impacting the final yield of a crop [15].

The differential statistical response between varieties (ANOVA $p \leq 0.05$) indicates that the variety HNC-6 presented fruits with greater length, pericarp thickness, number of locules, and fruit firmness, while the variety HCC-8 only presented fruits with greater diameter. Statistical significance was not observed in total soluble solids (Table 3). This was probably due to the genetics of the variety [21], in addition to the possible influence of the environment [22], and its high interaction with the genotype [23]. Meanwhile, no significant statistical differences were found in the treatments with vermicompost, except for the variable fruit diameter (Table 3 and 2), which was higher in the treatment control or without vermicompost. In relation to this, a very important factor to consider with the use of vermicompost or compost is the C/N rate, which influences the balance of nutrients in the environment; a C/N rate <20 indicates a high degree of stabilization of the organic matter and a satisfactory degree of maturity [13], and this condition is necessary although not sufficient, since vermicompost has a low C/N rate, lower than 18-19; vermicomposting is faster but the excess in nitrogen is released quickly as ammonia, and this process induces loss of nitrogen rapidly from volatilization, which is a fundamental element for the growth and development of plants [18]. In addition, Márquez [18] mentions that for the process of vermicomposting to be conducted correctly, the C/P rate should be between 70 and 150, while the N/P rate should be between 5 and 20. The analyses performed on the vermicompost used in this research report a C/N rate of 12.25, the C/P rate is 34.25, and the N/P rate is 2.79, values that are far below the optimal values suggested, which probably led to the loss of nitrogen [18]. This would explain the response observed in the genotypes and with the vermicompost doses tested; this condition also modifies the microbial activity, since the lack of nitrogen alters the metabolism of carbon, decreases the levels of malate and organic acids in general, and increases the levels of starch, which affects the growth, development and yield of the crop and also the quality of fruits and

Table 3. Analysis of variance and means test of fruit quality variables, from two experimental varieties of habanero chili peppers treated with five doses of band vermicompost.

Variety	FL (mm)	FD (mm)	PT (mm)	NL	TSS (°Brix)	FF (Kg cm^{-2})
HCN-6	51.27 a*	28.90 b	1.95 a	3.60 a	9.49 a	1.99 a
HCN-8	41.86 b	33.07 a	1.52 b	3.05 b	9.91 a	1.78 b
ANOVA≤	<.0001	<.0001	<.0001	0.0002	0.3515	0.005
MSD	1.8977	1.8063	0.0813	0.2611	0.9040	0.1425
Vermicompost (kg plant^{-1})						
0	46.37 a	32.89 a	1.74 a	3.25 a	8.75 a	1.72 a
0.3	48.52 a	31.10 ab	1.73 a	3.25 a	9.73 a	1.88 a
0.6	46.39 a	31.44 ab	1.77 a	3.50 a	9.79 a	1.99 a
0.9	46.32 a	29.85 b	1.77 a	3.25 a	9.56 a	1.89 a
1.2	45.23 a	29.67 b	1.65 a	3.38 a	10.68 a	1.96 a
ANOVA≤	0.2806	0.0040	0.3417	0.6541	0.1334	0.1479
MSD	4.27	2.43	0.18	0.58	2.03	0.32
CV (%)	6.28	5.37	7.24	12.11	14.36	11.63
Interaction						
ANOVA≤	0.033	0.0177	0.2050	0.9594	0.0117	0.94
MSD	7.11	4.05	0.30	0.97	3.38	0.53

Different letters in the same column differ statistically (Tukey $p \leq 0.005$). MSD=minimum significant difference, CV=coefficient of variation. FL=fruit length, FD=fruit diameter, PT=pericarp thickness, NL=number of locules, TSS=total soluble solids, FF=fruit firmness.

seeds; in addition, it alters the content of vitamins, sugar and soluble solids [19, 20], which also causes an inadequate proliferation of microbial fauna from the lack of phosphorus available. Therefore, it is inferred that what was described before, together with the lack of maturity of the vermicompost used, did not allow observing differences between the doses used in this experiment.

No significant statistical differences were found between the vermicompost doses applied for the variable plant height (ANOVA p≤0.05); however, a trend is seen in the growth of both varieties through time, where at the end of the cycle, the applications of 0.3 and 0.6 kilograms of vermicompost per plant resulted in slightly larger plants compared to the control (Figure 1). The main element present in organic matter is carbon, fundamental for the photosynthetic process [13], and it has nutritional functions in the plants due to its action in the generation of carbohydrates together with solar radiation and water,

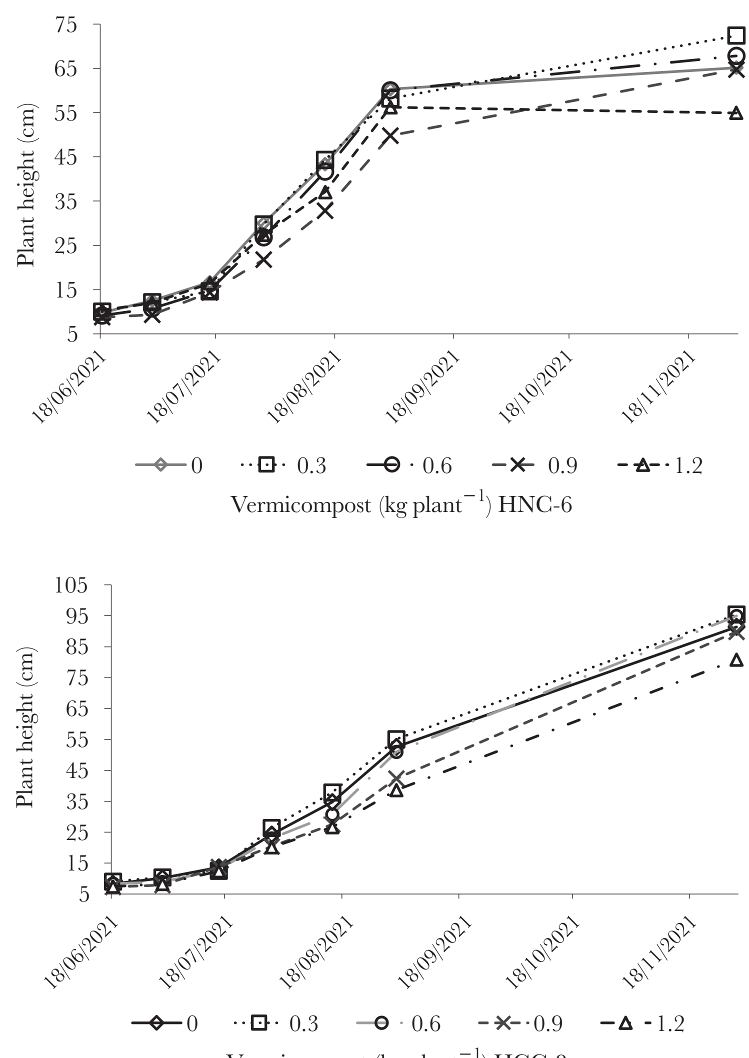

Figure 1. Growth curve of plant height in varieties HNC-6 and HCC-8 with the application of different doses of band vermicompost.

and in the catabolism of microorganisms that happens in organic compounds [14]. This is because with higher amounts of organic carbon, the soil pH improves, the apparent density decreases, the porosity and aeration capacity improve, the water retention capacity increases, and there is a higher microbial population in the soil, in addition to increasing the soil fertility, favoring nutrient absorption and consequently the growth, development and yield of crops [15,16].

In the case of stem diameter, no significant differences were found between varieties; however, when observing the growth of stem diameter in both varieties, the vermicompost dose of 0.9 kg results in thicker stems at the end of the cycle, followed by the control (Figure 2). With vermicompost applied as soil improver in some crops such as pepper, tomato and strawberry, it has been discovered that it is a source of macro and micronutrients, biologically active metabolites as growth regulators, humates, vitamins, enzymes, antibiotics and the presence of microorganisms that mainly improve the biological fixation of nitrogen and the solubilization of phosphorus [13, 15, 17].

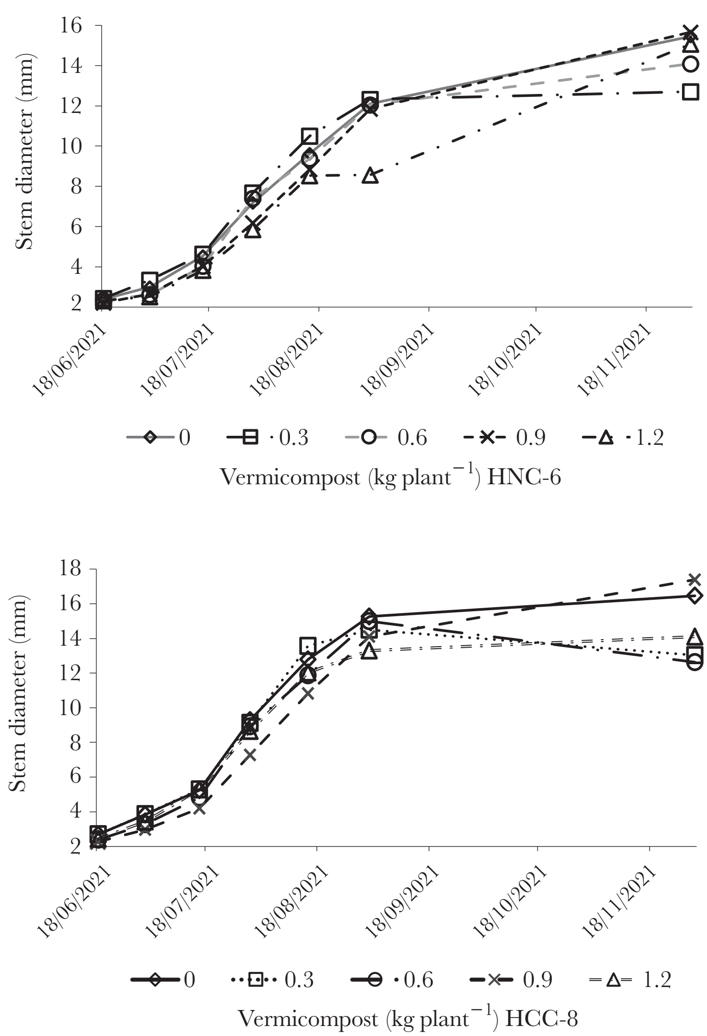

Figure 2. Growth curve of stem diameter of the varieties HNC-6 and HCC-8 with the application of different doses of band vermicompost.

Significant differences were present in the interactions of the variables fruit length, fruit diameter and TSS; in the variables length and diameter of fruit, the variety HNC-6 presented longer fruits when 0.3 kg of vermicompost was applied per plant, while the fruits with greater length and diameter in the variety HCC-8 were found with the control treatment and with 0.3 kg of vermicompost per plant. In relation to this, there are studies that indicate that the size of the orange habanero pepper grown in the greenhouse reaches on average 3.58 cm of length and 2.47 cm of diameter [24], the fruits of variety HNC-6 are larger with 5.12 and 2.89 cm, respectively. In the case of chocolate habanero peppers, fruits with 2.92 cm of length and 2.44 cm of diameter were reported [11], while the fruits of the variety HCC-8 are also chocolate color, with 4.18 and 3.3 cm, respectively, are above these values.

Authors such as De Avila [25] observed different behaviors in different cultivars of *C. chinense* in terms of lanyard and size of the fruits, and pointed to the lack of nitrogen decreasing the biomass and favoring the accumulation of starch in the leaves, which could be the reason why the variety HCC-8 produced fruits with smaller diameters in

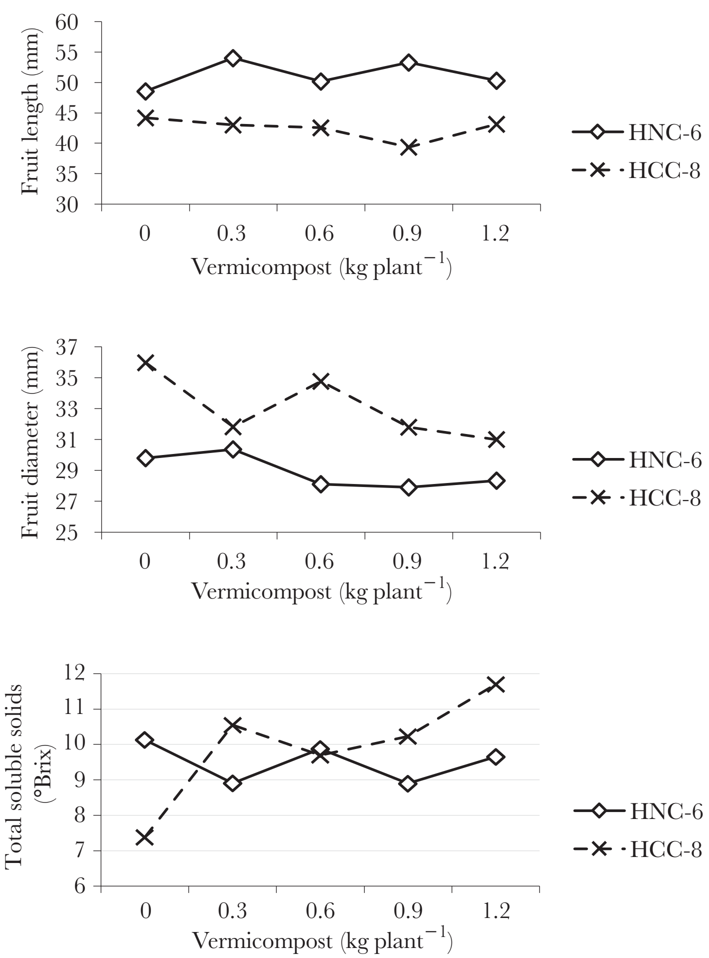

Figure 3. Significant interactions observed between variables HNC-6 and HCC-8, under the application of different doses of band vermicompost.

the vermicompost treatments, since the plants present lower fruit setting but of larger size when the levels of ammonium increase in the soil solution, as a tolerance mechanism [20].

For the case of total soluble solids (°Brix), a higher content was found in fruits of the variety HCC-8, and an increasing trend was seen in total soluble solids as the dose of vermicompost increased. In the case of the HNC-6 variety, it presented lower content of soluble solids than HCC-8, and in this sense, it has been reported that the content of total soluble solids is related to the taste of the fruits and the accumulation of sugars by the plant, and which are generally accumulated in the fruits [26]; these compounds increase when the fruit matures, because they are the main source of energy for respiration [27].

CONCLUSIONS

The experimental variety HNC-6 showed a better agronomic response under the conditions tested compared to HCC-8. The vermicompost doses exerted a similar response and trend effect in the two experimental varieties of habanero chili peppers tested.

In the interaction of the varieties and the vermicompost doses, significant differences were present for the variables FL, FD and TSS, and therefore, the application of vermicompost only influenced some aspects of the fruit quality.

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