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Vermicompost on the production and nutraceutical quality of jalapeño pepper fruits (*Capsicum annuum* L.)

Vermicompost en la producción y calidad nutracéutica de frutos de chile jalapeño (*Capsicum annuum* L.)

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SUMMARY

The vermicompost is used as a source of nutrients and substrate in protected horticulture because it promotes crop production more sustainable. The objective was to evaluate different proportions of vermicompost: sand (VC:S, v:v) on quality and yield of jalapeño pepper produced in greenhouse environments. Five proportions were compared VC:S, 1:1, 1:2, 1:3, 1:4, 1:5 and a control: (Steiner nutrient solution). The experiment was established in a randomized blocks design with ten replications. On average ratio, VC:S (1:1) produce highest fruit weight, fruit length, total phenolic compounds, flavonoids, and antioxidant capacity against to control treatment (0:1 VC:S). Those results indicate that VC is a fertilization alternative to increase nutraceutical fruit quality, without decrease the jalapeño pepper yield.

Index words: organic fertilizers, protected agriculture, Steiner nutrient solution.

RESUMEN

El vermicompost es una fuente de nutrientes y sustrato en la horticultura protegida, porque promueve la producción del cultivo más sostenible. El objetivo fue evaluar diferentes proporciones de vermicompost: arena (VC: S, v:v) sobre la calidad y el rendimiento de chile jalapeño producido en condiciones de invernadero. Se compararon cinco proporciones VC:S, 1: 1, 1: 2, 1: 3, 1: 4, 1: 5 y un control: (solución Steiner). El trabajo se estableció bajo un diseño de bloques al azar con diez repeticiones. En promedio, la proporción VC:S (1: 1) produce el mayor peso de fruto, longitud de fruto, fenoles totales, flavonoides y capacidad antioxidante en comparación al tratamiento control (0:1 VC:S). Esos resultados indican que el VC es una alternativa de fertilización para aumentar la calidad nutracéutica de los frutos, sin reducir la producción del chile jalapeño.

Palabras clave: fertilización orgánica, agricultura protegida, solución nutritiva Steiner

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INTRODUCTION

Chili is the oldest and most common vegetable in the world as a food condiment and nutraceutical value, and it also has an important economic value. China is the main producer with more than 17.5 million Mg, and Mexico is second with approximately 2.7 million Mg (FAOSTAT, 2016). Chili fruit is a source of vitamins (A, E, and C), carotenoids, capsaicinoids, and phenolic compounds with antioxidant properties for the human diet (Korkutata and Kavaz, 2015). Most of these compounds protect the human body against free radicals (Hallmann and Rembalkowska, 2012). Epidemiological studies have shown beneficial effects of antioxidant compounds in cancer prevention, cardiovascular diseases, and neurodegenerative disorders (Hamid *et al.*, 2010).

Beneficial effects of intake antioxidant compounds in human health play also an important role in the shelf life of fruits (Molina-Quijada *et al.*, 2010). In recent years the concern in the study and quantify antioxidant compounds of fruits has increased because of their nutraceutical properties (Paz *et al.*, 2015). There is also a growing tendency of consumers to prefer healthy foods, additives free, safe, and nutritious (Hasperué *et al.*, 2015). A current option to produce high-quality food with a higher content of vitamins, phenolic compounds, sugars, and antioxidant compounds is the organic production, which avoids the use of chemical synthetic products (Pradeepkumar *et al.*, 2017; Salas-Pérez *et al.*, 2017).

In Mexico, the jalapeño chili is one of the greatest crops regarding the economic value, due to its wide consumption and to its high profitability and high labor demand (Macías *et al.*, 2012). However, for obtaining high fruit yields is necessary to use fertilizers and pesticides in large amounts, thus increasing production costs, creating risk in human health, and causing a negative impact on the environment (Castellanos *et al.*, 2017). To mitigate negative effects of fertilizers and reduce the problem of organic solid waste generated by agricultural production systems in a sustainable manner, one option is to use organic fertilizers such as vermicompost (VC) which is a potential source of i) soluble nutrients (Reyes-Pérez *et al.*, 2017a), ii) enzymes (Álvarez-Solís *et al.*, 2016), iii) bacterial activity (Maji *et al.*, 2017) and iv) production of humic and fulvic acids and phytohormones capable of

stimulating growth and crop yield in organic farming systems (Mendes *et al.*, 2012).

Besides, there is evidence that supplying VC to soils or growth substrates promotes fruit growth and production of various vegetable crops as tomato (*Solanum lycopersicum* L.) (Márquez-Quiroz *et al.*, 2014), lettuce (*Lactuca sativa* L.) (Kapoulas *et al.*, 2017), melon (*Cucumis melo* L.) (Sánchez *et al.*, 2016), and cucumber (*Cucumis sativus* L.) (Díaz-Méndez *et al.*, 2014), among other species from commercial interest. The VC helps to increase fruit yields as well as the antioxidant activity of chili fruits (Castellanos *et al.*, 2017). However, the incorporation of substrates derived from the decomposition of organic waste, including VC, can cause high salinity and pH in the root zone. To reduce the negative effects of VC it is necessary to mix it with inert media such as river sand that is used in crop production without soil, to improve their physical and chemical characteristics avoiding hypoxia and damage salinity, so it can be used as a substrate or component in greenhouse conditions (Díaz-Méndez *et al.*, 2014). In this context, the objective was to evaluate different proportions of vermicompost: sand (VC:S) on yield and nutraceutical quality of chili in plants grown in greenhouse environments.

MATERIALS AND METHODS

Plant Material and Growth Conditions

The research was conducted in a greenhouse provided with automatic cooling of the Antonio Narro University located at Torreón, Coahuila, México (25° 33' 26" N, 103° 22' 31" W, at an altitude of 1230 m). The study crop was jalapeño chili cv. Hijo de Mitla germinated in polystyrene trays with 200 holes filled with, peat moss (Premier®, México) as substrate. These plant trays were covered with black plastic for 72 h and irrigated every 24 h. The transplant was made 45 days after seed sowing when plants presented average tallness of 150 mm, each plant per pot. The pots were black bags of polyethylene of 500 thickness and 18 L capacity, filled with different proportions of VC:S. Sand from the river was washed and disinfected using 5% sodium hypochlorite solution. The bags were located in a double row at 30 cm from center to center between bags and 1.60 m between rows, to get plant density of 4.2 plants m². Crop water requirements

were provided by manual irrigation, as detailed next. For treatments T1 to T5 the average water supply at four days after planting (DAP) was 0.5 L day⁻¹ pot⁻¹, then increased to 1 L day⁻¹ at 40 DAP, until it reached 2 L day⁻¹ after 60 DAP. In the control treatment, pots were watered with the Steiner nutrient solution at an average rate of 0.5 L day⁻¹ to the four DAP, and the increased to 1 and 2 L day⁻¹ at 40 and 60 DAP, respectively. Tap water showed small salinity and small sodium content (Ayers and Westcot, 1994). The crop season lasted 120 DAP. The weather conditions inside the greenhouse were: maximum and minimum temperature of 32.3 and 17.4 °C, respectively, and relative humidity oscillating between 30 and 70%.

Design of Experiment and Treatments

The randomized complete block design was used, with ten repetitions, five treatments (T1 to T5) evaluated were proportions of vermicompost:sand (VC:S, v:v) 1:1, 1:2, 1:3, 1:4, 1:5 plus a control (T6) that consisted of 100% sand with Steiner nutrient solution (Steiner, 1961) with pH adjusted to 5.5 and electric conductivity to 2.0 dS m⁻¹. The VC was obtained by biotransformation a mixture of manures (goats, horses, and rabbits, 1:1:1; v:v:v) with *Eisenia fetida* earthworms during 90 days (Bhat *et al.*, 2015). The chemical analysis of VC is displayed in the next Table 1.

Fruit Yield and Commercial Quality

In each experimental unit, the yield was estimated considering the number and the weight of the individual

fruit per plant. The quality of fruit was evaluated in 15 fruits randomly sampled per plant in every treatment and repetition, by recording individual fruit traits such as weight with a balance (Ohaus 3729®, México), length, equatorial diameter and pericarp thickness with a vernier (Truper®, México) and firmness with a penetrometer (FHT200, Exttech Instruments®; USA) provided with 3 mm plunger.

Nutraceutical Quality

Extract preparation. for nutraceutical quality determination (phenolic compounds, flavonoids, and antioxidant capacity), samples of 2 g fruit fresh were mixed with 10 mL ethanol in plastic tubes that were closed with a screw cap. A stirrer type "Stuart" was used to keep mixture stirring for 24 h. After that tubes were centrifuged at 3000 rpm for 5 minutes. The supernatants were extracted for their physical-chemical analysis.

Total phenolic content. was determined using a modified Folin-Ciocalteu method (Esparza *et al.*, 2006). The results were expressed in mg of gallic acid equivalents per 100 g⁻¹ fresh weight basis (mg GAE 100 g⁻¹ fresh weight).

Total flavonoid content. was determined using the colorimetric method proposed by Zhishen *et al.* (1999). The results were reported in mg of quercetin equivalents per 100 g⁻¹ fresh weight basis (mg QE 100 g⁻¹ fresh weight).

Antioxidant capacity. was determined based on the Brand-Williams *et al.* (1995) results were reported in µM Trolox per 100 g⁻¹ of fresh weight (µM Trolox 100 g⁻¹ fresh weight).

Table 1. Chemical characteristic of the vermicompost evaluated as a growth medium in the cultivation of jalapeño pepper under greenhouse conditions.

Substrate	N	P	K	Fe	Mn	Cu	Zn	Ca	Mg	MO	pH	EC
	mg kg ⁻¹						meq L ⁻¹			%		dS cm ⁻¹
VC	125.1	81.8	342	5.25	4.55	1.21	3.98	27.99	2.01	21.8	8.4	4.65
S	3.9	10.9	91	1.52	2.56	0.44	0.87	6.01	0.2	2.01	7.85	0.92
OR	>30	>30	>170	2.5-4.5	1-2.5	0.30-1	0.5-1	†	†	>3	6.5-7.5	2-8

MO = organic matter; EC = electrical conductivity; VC = vermicompost; S = sand; OR = optimum range; values recommended by the soil laboratory of the Cooperativa Agropecuaria de la Comarca Lagunera. † = value not indicated.

Statistical Analysis

All variables described above were analyzed through ANOVA. In cases where the statistical difference was found, mean comparisons were made applying the Tukey test ($P \leq 0.05$) (SAS, 2004).

RESULTS AND DISCUSSION

Fruit Yield and Commercial Quality

Proportions of VC:S showed significant differences in fruit weight, fruit length, and yield ($P < 0.05$), while the equatorial diameter, pericarp thickness, strength, and fruit number the differences were highly significant ($P < 0.01$) (Table 2). The average fruit weight of organic treatments was higher than the control. Also, plants fruits developed in treatment T1, exceed in 54.02% the fruits weight respect to the control plants. Organic treatments affected positively plant height, which increases photoassimilates, which allows increasing the fruit weight (Rodríguez *et al.*, 2009). Also is possible that treatments based on VC, assimilates demand, and other phytohormones in apical tissues are reduced, which helps the content of cytokinins and the accumulation of photoassimilates in fruits (Márquez-Quiroz *et al.*, 2014). The fruit weight gotten in treatments with VC (T1 to T5) corresponds

to medium size according to the standards of NMX-FF-025-SCFI-2014 (NMX, 2014). The results of this variable were similar to found by López-Gómez *et al.* (2012) and Moreno *et al.* (2014) who reported greater fruit weight in chilies grown with VC.

Concerning fruit size (length and equatorial diameter) T1 and T5 had highest average 7.32 and 2.82 cm, which correspond to first commercial quality fruits (Vázquez-Vázquez *et al.*, 2011), and were highest in 22 and 24% in length and equatorial diameter to fruits of the control, respectively. The results can be explained due to the high content of potassium and the contribution of other nutrients by VC (Table 1), which ensure proper growth and plant development (Reyes-Pérez *et al.*, 2017b), also appropriate concentrations increase fruit size (Morón and Alayón, 2014). The length registered was higher than found by Macías *et al.* (2012) in chili fruits cv. Mitla, from plants fertilized with chicken and cattle manure under open field conditions, the results were slightly lower to fruit length interval, from 8.09 to 8.83 cm, determined by López-Espinosa *et al.* (2013). On the other hand, the equatorial diameter was 31.16 and 50% higher than average values reported by Macías *et al.* (2012), under management conditions already described and Álvarez-Solís *et al.* (2016) to assess the quality and yield of jalapeño pepper fertilized with Bokashi.

Table 2. Average values of agronomic variables evaluated in Chili jalapeño cv. Hijo de Mitla, after applying vermicompost mixtures with sand, in plants grown under greenhouse conditions.

Treatment	FW	FL	ED	PT	F	FN	Y
	g	----- cm -----			N		Mg ha ⁻¹
T1	22.02 a [†]	7.22 a	2.76 a	0.36 ab	12.72 ab	35.33 b	32.54 a
T2	21.00 a	6.76 ab	2.79 a	0.39 ab	13.64 a	32.67 bc	28.84 ab
T3	21.21 a	6.90 ab	2.69 ab	0.41 a	11.65 ab	27.33 de	24.48 ab
T4	19.58 ab	6.66 ab	2.77 a	0.35 b	13.06 a	29.17 cd	23.94 ab
T5	21.51 a	6.36 ab	2.82 a	0.37 ab	13.12 a	23.67 e	21.73 b
T6	14.29 b	6.00 b	2.26 b	0.27 c	10.89 b	47.00 a	28.26 ab
HSD (0.05)	6.309	1.132	0.439	0.052	2.072	4.445	8.865
CV (%)	17.78	9.56	9.19	8.17	9.30	7.68	18.70
Standard error	0.75	0.12	0.05	0.01	0.24	1.33	1.08

[†] Values with a different letter in each column indicate a significant difference at $P < 0.05$ according to the Tukey test. FW = fruit weight; FL = fruit length; ED = equatorial diameter; PT = pericarp thickness; F = firmness; FN = fruit number; Y = yield. HSD = honest significant difference; CV = coefficient of variation.

The highest value of pericarp thickness recorded in T3 treatment was 0.41 cm, exceeding 33.33% of the control treatment (Table 3). The fruits of organic treatments showed a greater pericarp thickness, which is desirable since this feature is directly related to fruit weight (Coelho *et al.*, 2003), also increases the shelf life due to increases firmness of fruits (Mena-Violante *et al.*, 2009). The pericarp thickness obtained in treatment T3 was higher than the average of 0.27 cm found by Berova *et al.* (2013) when supplied 100 cm³ of VC to the chili crop cv. Gorogled 6. Also, it was slightly lower than the average value of 0.58 cm reported by López-Espinosa *et al.* (2013), for pepper fruits using organic fertilizers. The firmness fruit increased 19.93, 20.48, and 25.25% in treatments T4, T5, and T2, respectively, in comparison to fruits of the control treatment. Fruit firmness increased because of the optimum level of potassium in organic fertilizers. Increased potassium in fruit firmness was related to greater tissue pressure potential. It indicates that potassium levels provided by VC (Table 1) increased fruit firmness (Kumar and Ponnuswami, 2013). This behavior coincides with reported by Aminifard and Bayat (2016) who indicate that firmness is significantly higher in chili fruits from plants fertilized with VC compared to fruits inorganically fertilized plants. Previous results were similar to Singh *et al.* (2008), who reported the application of VC at a rate of 2.5 to

10 Mg ha⁻¹ in the strawberry crop increased firmness fruit compared to inorganic fertilization. On the other hand, firmness value, 13.64 N obtained in fruits of T2 treatment was 116.5% higher than 6.3 N registered by Palma-Zavala *et al.* (2009), in chili fruits cv. Mitla conventionally produced. Cooper *et al.* (1998) indicate that fruits with greater firmness could be more resistant to decay caused by microorganisms, therefore plants fertilized with VC increase not only firmness but also could decrease fruit deterioration.

Yield variations were due to fruit number per plant and not weight thereof (Table 3). The highest yield was recorded in T1, with 32.54 Mg ha⁻¹, exceeding 11.37% to the rest of the treatments. The VC increases organic matter, nitrogen, phosphorus, and phytohormones in the growth medium, which promotes the development and activity of the root system. Well developed root system tends to register higher plant yield (Zuo *et al.*, 2018). The Yield of treatment T1 was superior to reported by Morón and Alayón (2014), who determined values of 17.3 Mg ha⁻¹ of jalapeño cv. Don Benito in an open field with inorganic fertilization. Likewise, the general average yield was 26.63 Mg ha⁻¹, which is 67.38% more than the yield obtained by Mexican producers whose value was 15.91 Mg ha⁻¹ (SIAP, 2016). Treatments T1 and T2, showed increases in yield of 15.14 and 2.05%, respectively, compared with control. The increased yields in T1 and T2, compared to T3, T4,

Table 3. Average values of nutraceutical fruit quality evaluated in Chili jalapeño cv. Hijo de Mitla obtained with different vermicompost: sand proportion under greenhouse conditions.

Treatment	Total phenols	Flavonoids	Antioxidant capacity
	mg de GAE 100 g ⁻¹ fresh weight	mg QE 100 g ⁻¹ fresh weight	μM Trolox 100 g ⁻¹ fresh weight
T1	68.60 a [†]	106.80 a	68.12 a
T2	56.60 ab	86.83 ab	46.84 b
T3	64.60 ab	93.95 ab	52.44 ab
T4	57.93 ab	70.15 b	56.08 ab
T5	56.80 ab	66.25 b	48.10 b
T6	49.33 b	68.43 b	41.90 b
HSD(0.05)	16.809	32.036	18.012
CV (%)	12.41	16.99	15.00
Standard error	1.83	4.02	2.24

[†] Values with a different letter in each column indicate a significant difference at $P < 0.05$ according to the Tukey test. HSD = honest significant difference; C.V. = coefficient of variation.

and T5 may be the result of better physical properties of the substrate by using greater proportions of VC (>30%) (Sánchez *et al.*, 2016). This effect is because the optimum ratio of VC stimulates the development and crop production (Pradeepkumar *et al.*, 2017), because of slow gradual nutrients liberation, improved physical and chemical properties of the substrate (Salas-Pérez *et al.*, 2017), microorganisms presence (Maji *et al.*, 2017), as well as the contributions of phytohormones and humic acids that accelerate cell division (Mendes *et al.*, 2012).

Nutraceutical Fruit Quality

Different proportions of VC:S applied to chili cultivation affected the contents of phenolic compounds ($P < 0.05$) and total fruit flavonoids ($P < 0.01$, Table 3). The highest phenolic content and total flavonoids were obtained for T1, with values of 68.60 mg of GAE 100 g⁻¹ fresh weight and 106.80 mg QE 100 g⁻¹ fresh weight, exceeding in 39.06 and 56.07% to the control treatment, respectively. This result coincides with established by Aminifard and Bayat (2016), who said that phenolic compounds in organic products are higher than conventional products. The synthesis and accumulation of phenolic compounds are a defense mechanism against biotic and abiotic stress (Kim *et al.*, 2010). Also, it is possible that the differences determined for phenolics and total flavonoids could be attributed to salinity caused by VC in the root medium (Grimaldo-Pantoja *et al.*, 2017). Salinity in the medium causes osmotic stress when the free energy of water decreases, reducing water and nutrients absorption. This restriction increases the biosynthesis of secondary metabolites, such as polyphenols, which promote a better nutraceutical fruit quality (Sánchez *et al.*, 2016). On the other hand, total phenolic compounds' values greatly exceeded the mean value of 40.3 mg of AG/100 fresh weight found by Aminifard *et al.* (2012) chili fruits cv. Red chili. Value of GAE 68.60 mg 100 g⁻¹ fresh weight recorded for T1, exceeded 119.94% of the total phenolic content of 31.19 mg of GAE 100 g⁻¹ fresh weight in fruits chili cv. Almuden, whose plants were developed with the application of inorganic fertilizers (Pérez-López *et al.*, 2007).

Antioxidant capacity of chili fruits was significantly affected by proportions of VC:S ($P < 0.01$), values ranged between 41.90 and 68 µM Trolox 100 g⁻¹ fresh

weight. The highest antioxidant capacity was presented in T1 with a value of 68.12 µM Trolox 100 g⁻¹ fresh weight, exceeding at 29.90% all treatments, while the control showed lowest (41.90 µM) antioxidant activity (Table 3). Increases of antioxidant capacity in fruits with organic treatments, maybe due to the presence of phenylalanine in organic fertilizers which is the precursor of several phenolic substances that contribute to increasing total phenolic compounds (Kumar and Ponnuswami, 2013), these compounds present positive correlation with antioxidant activity (Sánchez *et al.*, 2016). Nevertheless, increase on antioxidant activity of chili fruits registered in T1 derived from the application of VC could be due, according to Preciado-Rangel *et al.* (2015) and Flores *et al.* (2009) to the high content of soluble salts and nitrogen present in organic fertilizer (Table 1), these chemical characteristics could cause nutritional stress, which promotes plant mechanisms defense and antioxidants production. In general, similar results were reported by other researchers who have found a significant increase in phenolic compounds content and antioxidant capacity of chili when applying organic fertilizers concerning the application of synthetic fertilizers (Aminifard *et al.*, 2012).

Following results presented in this research, VC in the substrate could be an alternative to obtain fruits with higher phenolic compounds content and better antioxidant activity which is important for public health because it can contribute to protecting from some diseases, besides, vermicompost is friendly with the environment.

CONCLUSIONS

The vermicompost used as a component substrate medium for plant growth produces favorable effects on the crop chili cv. Hijo de Mitla cultivated under greenhouse conditions in a hydroponic system because it stimulates the fruit quality. The VC:S ratio (1:1) registered highest, total phenolic compounds, and antioxidant capacity compared to the control; those are evidence of the possibility for producing jalapeño pepper in organic substrates. The VC could be a sustainable alternative to be used as a source of nutrients and growth medium to obtain a better nutraceutical quality of pepper fruits, besides contributing to preserve the environment without inorganic fertilizer supply.

ETHICS STATEMENT

During the development of the research, all the authors participated with important contributions according to their expertise and with an ethical basis in their proceedings.

CONSENT FOR PUBLICATION

Not applicable.

DATA AVAILABILITY

Data sets used or analyzed during the current study are available in their entirety, upon reasonable request to the author by correspondence.

COMPETING INTERESTS

The authors declare that they have no interests in competition.

FUNDING

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AUTHORS CONTRIBUTIONS

Conceptualization: Bernardo Espinosa Palomeque, Pedro Cano Ríos. Methodology: Pedro Cano Ríos, Pablo Preciado Rangel. Software: Bernardo Espinosa Palomeque. Validation: Lilia Salas Pérez, Pablo Preciado Rangel. Formal analysis: Pablo Preciado Rangel. Research: Bernardo Espinosa Palomeque. Resources: Lilia Salas Pérez. Data healing: Alma Velia Ayala Garay. Writing, preparation of the original draft: Bernardo Espinosa Palomeque, Pablo Preciado Rangel. Writing, review and editing: Arturo Reyes González. Visualization: Gabriela González Rodríguez. Monitoring: Pablo Preciado Rangel. Project management: Pedro Cano Ríos. Fund acquisition: Pedro Cano Ríos. All authors read and approved the final manuscript.

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