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Chemical and organic fertilization on the yield of serrano pepper (*Capsicum annuum* L.) in Veracruz, Mexico

Fertilización química y orgánica y su efecto sobre el rendimiento de chile serrano (*Capsicum annuum* L.)

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RESUMEN ABSTRACT

The use of organic fertilizers generates multiple benefits for agricultural productivity and constitutes an alternative to the problems generated by the intensive use of chemical fertilizers. This work aimed to compare the effect of chemical and organic fertilization on the growth, development, and yield of fresh fruit of Serrano pepper (*Capsicum annum* L.). A completely randomized block experimental design was used with six treatments (control, chemical fertilization, bokashi, vermicompost, bokashi + chemical fertilization, and vermicompost + chemical fertilization) and four replications. Plant height, stem diameter, leaf length and width, SPAD units, flowering, leaf area, fruit number, fruit length, fruit diameter, average fruit weight, and yield were evaluated. An ANOVA and all pairwise comparisons were applied using Tukey ($p \leq 0.05$). Significant differences ($p \leq 0.05$) were observed for all variables except plant height, mainly attributed to the environmental conditions. The results indicated that the bokashi treatment promoted the best plant and fresh fruit characteristics. Using organic fertilizers represents a sustainable option with higher profitability for Serrano pepper production.

KEY WORDS: *Capsicum*, organic nutrition, chemical fertilization, sustainability.

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RESUMEN

El uso de abonos orgánicos genera múltiples beneficios para la productividad agrícola, y constituye una alternativa a los problemas que ha generado el uso intensivo de fertilizantes químicos. El objetivo de este trabajo fue comparar el efecto de la fertilización química y orgánica sobre el crecimiento, desarrollo y rendimiento del fruto fresco de chile serrano (*Capsicum annum* L.). Se utilizó un diseño experimental de bloques completamente al azar con seis tratamientos (Testigo, fertilización química, bocashi, lombricomposta, bocashi + fertilización química y lombricomposta + fertilización química) y cuatro repeticiones. Se evaluó altura de planta, diámetro de tallo, largo y ancho de hoja, unidades SPAD, floración, área foliar, número de frutos, largo de fruto, diámetro de fruto, peso promedio de fruto y rendimiento. Se aplicó un análisis de varianza y prueba de comparación de medias mediante Tukey ($p \leq 0.05$). Se observaron diferencias significativas ($p \leq 0.05$) para todas las variables, excepto altura de la planta, principalmente atribuido al ambiente de evaluación. Los resultados indicaron que el tratamiento con bocashi promovió las mejores características de planta y fruto fresco. El uso de abonos orgánicos representa una opción sustentable con una mayor rentabilidad para la producción de chile serrano.

PALABRAS CLAVE: Capsicum, nutrición orgánica, fertilización química, sustentabilidad, rendimiento.

Introduction

One of the most important crops in Mexico and the world is the chili pepper (*Capsicum* spp.), whose use and cultivation are essential from an economic, medicinal, cultural, nutraceutical, and food value point of view (Momo *et al.,* 2022). Mexico is a center of origin and diversification of chili pepper (Carrizo-García, 2019); several wild and cultivated species of chili peppers have been reported (Bosland & Votava, 2000; Aguilar-Rincón *et al.,* 2010; Halikowsky, 2015; Pérez-Castañeda *et al.,* 2015), of which only *C. annum, C. baccatum, C. chinense, C. frutescens and C. pubescens* are widely cultivated (Kraft *et al.,* 2014).

Chili pepper production in Mexico is subdivided into two systems oriented by the destination of the harvest: fresh chili and dried chili peppers. Both types of production have different social, economic, agronomic, cultural, environmental, and technological characteristics. Thus, during the year 2021, approximately 3.7 million ha were harvested worldwide; of which, a production volume of 40.3 million t was obtained, in which fresh and dried chili yields of 17,457.6 and 2,573.9 kg ha^{-1}, respectively, were obtained (FAOSTAT, 2022). Specifically, Mexico contributed to the world total with 3.3 million t, standing out as the second largest producer of this vegetable; of which, it obtained a fresh and dried chili yield of 17,848.3 and 1,932.5 kg ha^{-1}, respectively (SIAP, 2022). During the

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2021-2022 agricultural cycle, the states of Chihuahua, Sinaloa, and Zacatecas contributed 55% of the total national production of fresh chili peppers (SIAP, 2022).

Among the most commonly cultivated varieties for the production of fresh chili peppers is the Serrano pepper (*C. annuum L.*), its use as a condiment makes it of utmost importance in the Mexican diet; in this sense, its annual per capita consumption amounts to more than 17.2 kg (SIAP, 2022). On the other hand, to reach large production volumes, agriculture depends mainly on the use of chemical fertilizers; however, the price of fertilizers has recently registered a significant increase, as a consequence of the economic effects caused by the war in Ukraine, as well as other aspects related with the supply chains (Granados & González, 2022), additionally, the irrational use of chemical fertilizers has caused severe environmental affectations such as soil degradation, water contamination and environmental degradation (Hirzel *et al.,* 2004; Mendoza-Elos *et al.,* 2020). This has forced the search for and evaluation of alternatives to satisfy the nutritional demand for crops at lower costs.

An alternative offered to producers is the partial substitution of mineral fertilizers with organic preparations or fertilizers (Maeda *et al.,* 2011). The latter is obtained through the degradation and mineralization of organic materials such as manure, household waste, and green grasses incorporated into the soil, among others (Mosquera, 2010); in addition, its production is low cost, they offer multiple benefits for agricultural production, among which are soil structure improvement, increased water holding capacity and fertility, as well as microbial activity (Huamaní, 2014; Restrepo, 2007). Therefore, this research aimed to compare the effect of chemical and organic fertilization and the combination of both on the growth, development, and yield of fresh fruit of Serrano pepper, using regional-generated agricultural by-products.

Material and Mhetods

Description of the study area

The experiment was established under rainfed conditions during the spring-summer 2022 cycle, in the community of Venta Parada, municipality of Amatlán de los Reyes, Veracruz. The site is geographically located at 18°51’15.2’’ N; 96º51’10.0.0’’ W, at an altitude of 619 masl. It is characterized by a warm humid climate with summer rains, an average annual temperature of 26.2 ºC, and annual precipitation of 843.6 mm (García, 2004). The prevailing soil in the site has a sandy loam texture, pH of 7.2, electrical conductivity of 637 µS cm^{-1}, organic matter of 1.88 %, cation exchange capacity 2.16 cmol (+) kg^{-1}, bulk density 1.75 g cm^{-3}, total nitrogen of 0.012 %, phosphorus of 96.88 mg kg^{-1}, potassium 136.5 mg kg^{-1}, calcium 817.6 mg kg^{-1}, magnesium 729.1 mg kg^{-1}. All analyses were performed at the Soil Laboratory of the Facultad de Ciencias Biológicas y Agropecuarias de la Universidad Veracruzana.

Plant material

Serrano pepper (*Capsicum annuum cv*. Serranito) seeds were used. The seeds were sown on February 27, 2022, in 200-cavity polystyrene trays under greenhouse conditions; later, on April 12, they were transplanted in field when they reached 12 cm in height and showed 8 to 9 true leaves.

Treatment design

Treatments were established under a completely randomized block design with four replications. Five treatments and a control were evaluated: Control (T_1), chemical fertilization (254 N; 102 P; 294 K) (T2), bokashi (4 t ha^{-1}) (T3), vermicompost (4 t ha^{-1}) (T4), bokashi with chemical fertilization (4 t ha^{-1}; 254 N; 02 P; 294 K) (T5), and vermicompost with chemical fertilization (4 t ha^{-1}; 254 N; 102 P; 294 K) (T6). The experimental plots consisted of five plants, planted every 0.5 m between plants and 0.5 m between rows, to obtain a population density of 40,000 plants ha^{-1}.

Processing of organic fertilizers

For the bokashi type organic fertilizer elaboration, 60 kg of black soil, 60 kg of cattle manure, 60 kg of coffee husks, 6 kg of wheat bran, 6 kg of rock flour, 6 kg of charcoal, 6 L of molasses, 0.006 kg of yeast and constant water were combined. The materials were mixed uniformly and kept under a shade covered with black plastic, the temperature was daily monitored with a digital thermometer for the substrates model Thermco ACC310SUP SUPRA®. To avoid high temperatures during the fermentation process, the temperature control was turned over, maintaining a temperature between 20 and 25 °C. Humidity was maintained at values around 70 to 80 %. Chemical analysis of the bokashi showed the following composition: pH (8.5), EC (5500 μS cm^{-1}), OM (23.5 %), CEC (36 cmol (+) kg^{-1}), total N (0.2 %), Ca (561.1 mg kg^{-1}) and Mg (255.3 mg kg^{-1}).

To obtain vermicompost, the first step is pre-composting organic waste such as cattle manure, and household waste of vegetable origin, husks, and stems, respectively. Subsequently, 7 kg of red Californian earthworm (*Eisenia foetida*) were used as breeding stock to obtain approximately one ton of vermicompost. The chemical characteristics of the vermicompost are as follows: pH (7.48), EC (11300 μS cm^{-1}), OM (36.9 %), CEC (42 cmol (+) kg^{-1}), total N (0.12 %), P (302.07 mg kg^{-1}), Ca (148.2 mg kg^{-1}) and Mg (629.8 mg kg^{-1}).

Evaluated variables

The following dependent variables were recorded: plant height (cm) was measured with a TRUPER flexometer® from the base of the stem to the apex, stem diameter (mm) was measured with a Caliper Neiko® Digital Vernier in the middle part of the stem before the first bifurcation, leaf length (cm) was measured with a metal ruler from the petiole to the apex, leaf width (cm) was

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measured with a metal ruler at the broadest part of the leaf, leaf chlorophyll index was obtained measured as SPAD units, the measurement was made in the middle third of the newest developed leaf at three points of the plant (low, medium, and high), days to flowering was measured as the number of days from sowing until 50% of the plants had at least one open flower, leaf area index (cm^2) was measured as the length and width of three true leaves at random, length was multiplied by the width of each leaf, the result was multiplied by the factor 0.75. Thereafter, the soil area occupied per plant was determined and finally, the leaf area index was obtained by dividing the leaf area of the plant by the area of occupied soil, the total number of fruits per plant was counted, fruit length (cm) was measured with a metal ruler from the base to the apex of the fruit, fruit diameter (mm) was measured with a digital Vernier in the middle third of the fruit, average fruit weight (g) each fruit was weighed individually with a RHINO digital scale® and fruit yield (kg ha^{-1}) estimated over six harvests.

Benefit-cost ration analysis

To determine the benefit/cost ratio, the total net benefits ($/ha) were considered and related to the total costs per treatment incurred in the production of the crop cycle.

Statistical analysis

Before performing the analysis of variance, the assumptions of normality, homoscedasticity of variances, and independence of errors were validated. Subsequently, all variables were subjected to an ANOVA and a Tukey mean comparison test ($p \leq 0.05$). All analyses were performed with SPSS software® version 25.0 (IBM Corp. Released 2017).

Results and Discussion

Analysis of variance in agronomic variables

Statistically significant differences ($p \leq 0.05$) were found for all variables except plant height (Table 1). The effects derived from chemical fertilizers alone or combined with organic fertilizers can promote faster and more vigorous plant growth, stimulate lateral shoot development, strengthen roots, and increase flower and fruit production (Abreu-Cruz *et al.*, 2018). Similar results were obtained by López *et al.* (2012) who found significant differences for all the variables evaluated in the habanero pepper crop. It was observed that the coefficients of variation ranged from 9.39 to 48.9 %; those variables that presented high coefficients of variation (leaf area index, number of fruits, and fresh fruit yield), were probably caused by the genetic constitution of the variety and its interaction with the environment (Balzarini *et al.*, 2008; Tlelo-Cuautle *et al.*, 2020).

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Agronomic and physiological variables

For the analysis of means, the treatments evaluated did not cause a significant effect ($p \geq 0.05$) on the plant height variable (Table 2). Nevertheless, numerically the vermicompost + chemical fertilization treatment (T6) caused the greatest height with 49.05 cm, surpassing the rest of the other treatments. Similar results were reported by Nieto-Garibay *et al.* (2002) when they presented an increase in plant height of Habanero bell pepper (*C. chinense* L. Jacq.) with the application of 50 t ha^{-1} of vermicompost.

Regarding leaf chlorophyll content, the treatment with vermicompost (T4) reached average values of up to 65.94 SPAD units; however, the plants with bokashi (T3) presented the lowest values with an average of 61.66 SPAD units (Table 2). These results are congruent since vermicompost presents the highest values in the aforementioned chemical characteristics; in addition, like bokashi, it provides essential nutrients and improves soil structure, which promotes greater chlorophyll synthesis in the leaves. According to Novoa & Villagrán (2002), the values obtained in the present research work are not considered low, since SPAD values lower than 35.3 would indicate an N deficiency. These results could be attributed to the content of nutrients provided by the organic materials.

On the other hand, in the multiple testing of means, a significant group was found in the thickness of plant stems in the treatments with vermicompost (T4), bokashi + chemical fertilization (T5), and vermicompost + chemical fertilization (T6), respectively, with values from 5.61 to 6.76 mm (Table 2). These results agree with Jayanthi *et al.* (2014) who mention that the application of vermicompost reduces by 50% the application of chemical fertilizer in addition to improving soil quality, yield, and quality characteristics of chili pepper. López-Arcos *et al.* (2012) obtained 115 % greater stem thickness when using vermicompost on Habanero pepper plants in Tabasco state. However, contrasting results were obtained by Palma-López *et al.* (2020) who, with the application of vermicompost, did not observe a stimulus for the variable stem thickness. On the other hand, as in the present research, Gómez *et al.* (2008) suggest the importance of using organic fertilizers to improve yield in vegetables such as chili pepper, radish (*Raphanus sativus* L.), and beans (*Phaseolus vulgaris* L.).

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Table 1. Mean squares and statistical significance were evaluated in 12 agronomic and physiological variables in Serrano pepper (*Capsicum annum* L.). Venta Parada, Veracruz. Winter-spring cycle 2022.

Source of Variation		Treatments	Repetition	Error	Total	C.V (%)
D.F.		5	3	107	119	
Dependent variables	Ph (cm)	365.74NS	612.85*	171.01		29.64
	Sd (mm)	12.17*	11.92*	4.1		37.25
	LeafL (cm)	10.02**	21.12**	2.8		20.04
	LeafW (cm)	2.19*	1.53NS	0.97		25.4
	SPADU	42.36*	101.97*	35.66		9.39
	IAf (cm^2)	4911.86*	7241.83**	1688.12		40.45
	Nfruit	2395.23**	470.9*	124.24		45.76
	FruitL (cm)	11.25**	7.64**	0.86		12.29
	FruitD (mm)	9.38**	0.81NS	1.08		13.9
	AFW (g)	8.72**	0.88NS	0.45		20.12
	RfrutY (kg ha^{-1})	648176829.1**	57483734.4ns	24920270.92		48.9

* $p \leq 0.05$; ** $p \leq 0.01$; *NS*= non-significant differences at $p > 0.05$; D.F = degrees of freedom; C.V (%) = coefficient of variation; Ph = plant height; Sd = stem diameter; LeafL = leaf lenght; LeafW = leaf width; SPADU = SPAD units; IAf = leaf area index; Nfruit = number of fruits; FruitL = fruit lenght; FruitD = fruit diameter; AFW = average fruit weight; FruitY = fruit yield.

The treatments with vermicompost (T4) and vermicompost + chemical fertilization (T6) produced the best values for leaf length and leaf width at 9.2 and 4.2 cm, respectively (Table 2). These same treatments generated the best values for leaf area index with 117 and 118 cm^2, respectively. Similar results are reported by Ríos (2015) who obtained higher leaf area in Jalapeño pepper (*C. annuum* L.) plants where 1 t ha^{-1} of vermicompost was applied compared to chemical fertilization of 30 and 60 kg N ha^{-1}; and finally, Mendoza-Pérez *et al.* (2017) who obtained values 0.30-0.80 m^2 in Poblano pepper plants. Leaf area is the measure of the photosynthetic tissue of a plant, plants with greater leaf area and under favorable conditions become able to better utilize solar energy with more efficient photosynthesis (Deaquiz *et al.*, 2008). In this sense, the determination of leaf area index (LAI) is a fundamental parameter in the evaluation of crop growth and development (Manjarrez-Martínez *et al.*, 1999).

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Tabla 2. Efecto promedio de los tratamientos con abonos orgánicos y fertilización química sobre 12 variables agronómicas y fisiológicas en chile serrano (*Capsicum annuun* L.). Venta Parada, Veracruz. Ciclo invierno-primavera 2022.

Trat.	Ph (cm)	Sd (mm)	LeafL (cm)	LeafW (cm)	SPADU	IAf (cm^2)	Nfruit	FruitL (cm)	FruitD (mm)	AFW (g)	FruitY (kg ha^{-1})
1	39.75a¶	4.51b	7.15b	3.4b	63.73ab	75.77b	7.65c	6.33d	6.22c	2.20 d	1927.80e
2	38.40a	5.04b	8.39a	3.87ab	62.99ab	100.82ab	14.60c	6.94c	7.38b	3.03c	5407.80d
3	43.80a	5.01b	8.23a	3.70ab	61.66b	96.02ab	34.40 a	8.30a	7.86ab	4.12a	17270.40a
4	47.00a	5.61ab	8.80a	4.24a	65.94a	117.17a	25.10b	7.93ab	7.46b	3.47bc	10177.20c
5	46.75a	6.76a	8.67a	3.79ab	64.40ab	101.09ab	32.35ab	8.02ab	8.24a	3.73ab	14288.40ab
6	49.05a	5.71ab	9.23a	4.28a	63.03ab	118.52a	32.05ab	7.66b	7.63ab	3.37bc	12186.00bc
Media	44.13	5.44	8.41	3.88	63.63	0.25	24.36	7.53	7.47	3.32	10209.53

¶ Different letters in the same column indicate significant differences, according to Tukey = 0.05; Trat.= treatments; 1= control; 2= chemical fertilization; 3= bokashi; 4) vermicompost; 5) bokashi + chemical fertilization; 6) vermicompost + chemical fertilization; Ph = plant height; Sd = stem diameter; LeafL = leaf lenght; LeafW = leaf width; SPADU = SPAD units; IAf = leaf area index; Nfruit = number of fruits; FruitL = fruit lenght; FruitD = fruit diameter; AFW = average fruit weight; FruitY = fruit yield.

Regarding days to flowering, the treatment with chemical fertilization (T2) accelerated the onset of flowering, which occurred at 78 dds, this could be attributed to the fact that chemical fertilizers accelerate the physiological processes of the plants (López-Arcos *et al*., 2012). On the other hand, the treatments with bokashi (T3) and bokashi + chemical fertilization (T5) initiated flowering at 91 dds (Table 2). Contrasting results were reported by Amador *et al.* (2014) who found no responses in flowering, fruiting, phenology, and yield of Mirasol pepper concerning the type of tillage and incorporation of oat residues into the soil.

Fruit yield components

The highest number of fruits was obtained with bokashi (T3) with more than 34 fruits per plant^{-1} surpassing all treatments (Figure 1c); it also promoted the best values for fruit length and fruit weight with 8.3 cm and 4.12 g^{-1}, respectively. According to Hang *et al.* (2015), it has been demonstrated that the application of compost increases the production of larger fruits, which directly influences commercialization.

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Regarding fruit diameter, the bokashi treatment + chemical fertilization (T5) (Figure 1e) promoted the best values with 8.2 mm (Table 2). In this sense, organic fertilizers exert a positive effect on some variables cataloged as components of fruit yield, resulting in an ecological, economic, and sustainable alternative for the small producer. Reyes-Pérez *et al.* (2016) point out that the benefit found could be explained by a series of physiological and biochemical processes interrelated among themselves and activated when organic fertilizers are applied; gibberellins, phytohormones found in their composition, can stimulate high flowering and fruiting of plants. On the other hand, this effect could be related to the contribution of humic substances with different metabolites, including potassium and other minerals involved in plant nutrition, which, when absorbed by the roots or leaves, guarantee adequate development. These elements, when found in appropriate concentrations, promote an adequate gain in both fruit mass and diameter. Gómez *et al.* (2000) refer to the influence of potassium as a fundamental element for good fruit development, which may have caused the fruit to behave better than the control under the action of organic fertilizers.

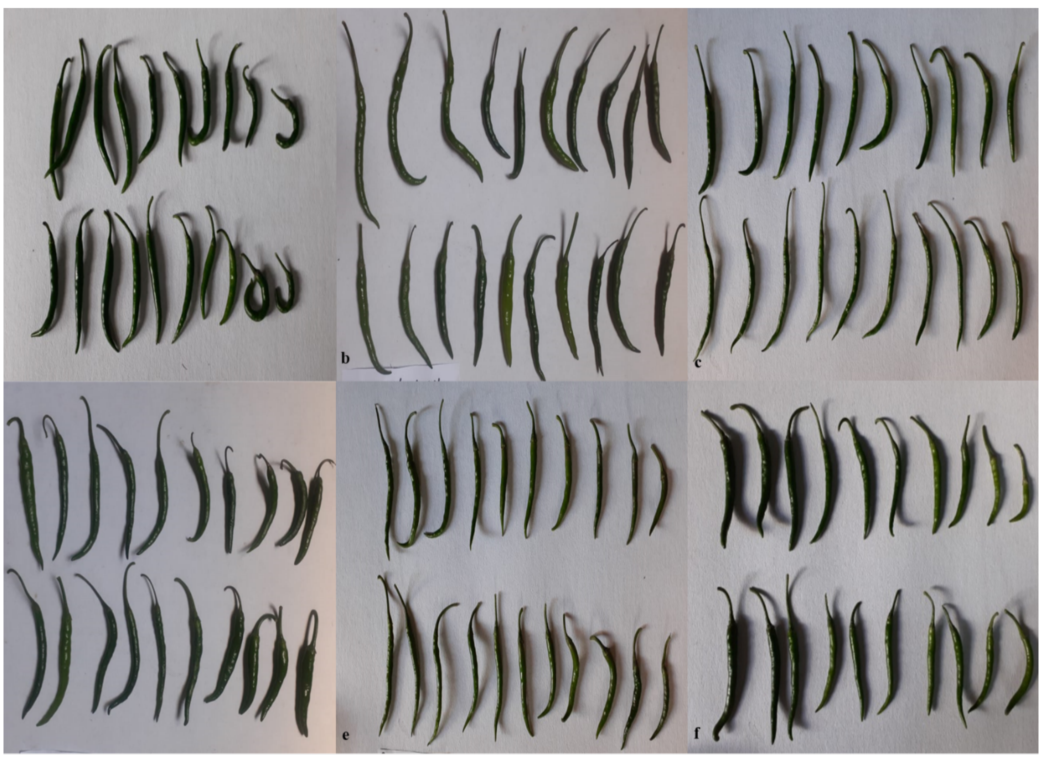

Figure 1. Morphological characteristics and dimensions of the Serrano pepper fruit (*Capsicum annum* L.); a) control; b) chemical fertilization; c) bokashi; d) vermicompost; e) bokashi + chemical fertilization; f) vermicompost + Chemical fertilization.

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Fresh fruit yield

The highest fresh fruit yield was obtained with bokashi (T3) with an average value of 17,270.4 kg ha^{-1} (Figure 1c), followed by the treatment bokashi + chemical fertilization (T5) with a value of 14,288.40 kg ha^{-1} (Figure 1e), while for the treatments vermicompost, vermicompost + chemical fertilization and chemical fertilization, values of 12,186; 10,177 and 5,407 kg ha^{-1}, respectively, were obtained (Table 2). Bokashi is produced by fermentation of organic residues with the help of microorganisms, is rich in nutrients, and improves soil quality. The application of 400 g of bokashi (T3), may have provided an adequate source of nutrients for the plants, promoting better growth and fruit development. On the contrary, although chemical fertilization can provide nutrients quickly and specifically, it is possible that the combination of bokashi + chemical fertilization (T5) caused competition for nutrients between both types of fertilizers. This affected the availability and uptake of nutrients by plants, which in turn influenced fresh fruit yield.

The use of organic fertilizers in the cultivation of chili pepper has a positive and significant effect since nutrients are available for plants in the soil, given that their release is slow and gradual, while synthetic fertilizers are required in increasing quantities for production, which causes environmental degradation. Likewise, these responses can be attributed to the microbial load, mainly bacteria that promote growth and development through different mechanisms such as phosphate solubilization, phytohormones production, and nitrogen fixation, among others (Corrales-Ramírez *et al.*, 2014).

Cost-benefit analysis

The profitability was obtained for the different nutrition treatments for Serrano pepper (Table 3). Higher profitability was found when bokashi (T3) was applied as a source of fertilization, with which a cost-benefit of $3.35 was achieved, which indicates that, for each peso invested in producing serrano chili, $2.35 is recovered. The treatments with chemical fertilization and the control did not generate benefits because the benefit-cost ratio was below the accepted minimum of 1 or greater than 1 (Mancilla *et al.*, 2020).

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Table 3. Benefit/cost ratio of a production cycle in the cultivation of serrano pepper (*Capsicum annum* L.). Venta Parada, Veracruz. Winter-spring cycle 2022.

Treatment	Performance (kg ha^{-1})	Value ($/$kg^{-1}$)	IB ($/$ha^{-1}$)	Cost. Prod. cost ($/$ha^{-1}$)	Profit ($/$ha^{-1}$)	Ratio (C/B)
Control	1927.8	46	-25125.2	1113804	88679	-0.22
Chemical fertilization	5407.8	45	2358	240993	243351	0.01
Bokashi	17270.4	45	598340.15	178827.85	777168	3.35
Vermicompost	10177.2	45	273872	184102	457974	1.49
Bokashi + chemical fertilization	14288.4	45	418555	224423	642978	1.87
Vermicomposting + chemical fertilization	12186	45	318668	229702	548370	1.39

Value ($/ha) = price per kilogram of fresh fruit; IB ($/$ha^{-1}$) = total net profit; Cost. Prod. ($/$ha^{-1}$) = cost of production per treatment; Profit ($/$ha^{-1}$)= net profit; Ratio (B/C) = benefit-cost ratio.

Even though the yields obtained are low (10209.53 kg ha^{-1} on average), the treatments with organic nutrition are profitable, this is because the investment is lower in raw materials, labor, and indirect expenses; in addition, most of the organic fertilizers were made at home and with materials that are easily found in the region. The benefits of using organic manures are very broad, since in addition to providing humified organic matter and nutrients to the soil, it has been shown that they can prevent, control, and influence the severity of soil pathogen attacks (Mancilla *et al.*, 2020). Zayed *et al.* (2013) reported that organic fertilization, soil solarization, and inoculation with mycorrhizae, together or combined, resulted in significant increases in chili fruit yield, total number of fruits per plot, fruit length, and fruit diameter. The results reflect the relevance of producing Serrano pepper in an alternative way in the central zone of the state of Veracruz, since in addition to applying sustainable management, it helps to improve the soil, water, and environment, contributing to food sovereignty and human health.

Conclusions

The production of organic fertilizers based on local agro-industrial waste provides the producer with an ecological, economic, and sustainable alternative. The simple application combined with chemical fertilization has a positive influence on the phenological development and agronomic behavior of the Serrano pepper crop. There is greater profitability when producing

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Serrano pepper with organic fertilizers, being a good option for the producers of the region and offering the possibility of competing in the commercialization of the product. This work shows that it is a good business option since the profitability that could be obtained is greater than the opportunity cost. At larger scales, it will be necessary to consider the labor costs required to produce large quantities of bokashi, which requires a more extensive analysis of these parameters.

Author contribution

Original idea for the paper, author 1, author 2, author 3; methodology development, author 2, author 3, author 5; software management, author 2; experimental validation, author 3; analysis of results, author 1, author 4, author 5; Data management, author 2, author 3; manuscript writing and preparation, author 1, author 2; writing, revising, and editing, author 1, author 2, author 5; project manager, author 1; fund acquisition, author 2, author 3.

"All authors of this manuscript have read and accepted the published version of this manuscript."

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Conflict of interest

"The authors declare that they have no conflict of interest."

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