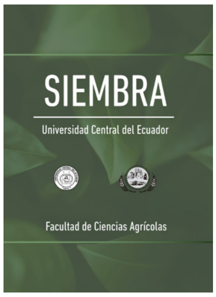
Use of organic amendment and efficient microorganisms in Habanero peppers (Capsicum chinense Jacq.)



Uso de enmienda orgánica y microorganismos eficientes en chile habanero (Capsicum chinense Jacq.)

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Abstract

The Habanero chilli peppers are one of the most important vegetables in Mexico's culinary culture due to its unique aromatic characteristics. Its cultivation is concentrated in the south and southeast of Mexico, typically using the principles of conventional agriculture. According to this model, large quantities of fertilizers and pesticides are used, affecting production safety. In order to evaluate two proportions of compost as substrate (100 and 50 %) in addition to a control, with and without the application of efficient microorganisms (EM), under a completely randomized design, a trial was conducted in Villaflores, Chiapas, Mexico (N 16º 32' and W 93º 45'). The six treatments had five replicates, each with five plants. Seedlings were transplanted 21 days after sowing (DAS) in polyethylene bags with the indicated proportions. Organic management was based on the application of biofertilizer every eight days until 64 days after sowing. The parameters evaluated were plant height, stem diameter, fruit number and weight, as well as polar and equatorial diameter. Analysis of variance, mean tests (Tukey $p \leq 0.05$) and simple correlations (Pearson) were performed. Statistical superiority was determined for the parameters evaluated in the treatments using organic amendment in its two proportions, improving phenological and yield variables with the application of EM, in symmetries of 5 to 20 %. Correlations showed correspondence of phenological variables and yield components of Habanero chili peppers.

Keywords: compost, mountain, organic, production.

Resumen

El chile habanero constituye una de las hortalizas más importantes en la cultura culinaria de México debido a sus características aromáticas singulares. Su cultivo se concentra en el sur y sureste de México, usándose típicamente los principios de la agricultura convencional. Bajo este modelo se utilizan grandes cantidades de fertilizantes y plaguicidas, lo que afecta la producción con inocuidad. Con el objetivo de evaluar dos proporciones de composta como sustrato (100 y 50 %), además de un testigo, con y sin la aplicación de microorganismos eficientes (EM), bajo un diseño completamente al azar, se realizó un ensayo en Villaflores, Chiapas, México (N 16º 32' y W 93º 45'). Los seis tratamientos tuvieron cinco repeticiones, cada una con cinco plantas. Las plántulas se trasplantaron a los 21 días después de la siembra (DDS) en bolsas de polietileno con las proporciones señaladas. El manejo orgánico se fundamentó en la aplicación del biofertilizante cada ocho días, hasta los 64 DDS. Los parámetros evaluados fueron altura de planta, diámetro de tallo, número y peso de frutos, así como diámetro polar y ecuatorial. Se realizó análisis de varianza, pruebas de medias (Tukey $p \leq 0{,}05$) y correlaciones simples (Pearson). Se determinó superioridad estadística de los parámetros evaluados en los tratamientos de uso de la enmienda orgánica en sus dos proporciones, mejorándose las variables fenológicas y de rendimiento con la aplicación de los EM, en simetrías del 5 al 20 %. Las correlaciones señalaron correspondencia de las variables fenológicas y de los componentes de rendimiento del chile habanero.

Palabras clave: composta, montaña, orgánico, producción.

1. Introduction

Agriculture based on the application of technological packages has negatively impacted productive systems' ecological, economic, and social elements. Therefore, significant efforts are required to increase and maintain agricultural productivity and safeguard the ecological viability of agricultural and wild ecosystems (Martínez-Centeno & Huerta-Sobalvarro, 2018). This agriculture has caused soil degradation and contaminated the water table due to the excessive use of inorganic fertilizers that tend to leach quickly (González-Reyes et al., 2015). Intensive agriculture and livestock farming, the application of agrochemicals, and the overexploitation of natural resources put the biodiversity of agroecosystems at risk and contribute to climate change (Reyes-Palomino & Cano-Ccoa, 2022). This vulnerable ecological state in which industrial agriculture finds itself constitutes a significant threat to humanity's food security (Altieri & Nicholls, 2018). The adverse effects of modern agriculture on natural resources in tropical agroecosystems tend to be more expeditious due to the dynamics of warm environments (Ojeda Bustamante & Íñiguez Covarrubias, 2011). This information has led to the search for production alternatives that focus on potentiating the use of local natural resources through building bridges for developing natural cycles, as well as seeking production with food safety and climate-smart.

Organic agriculture prohibits synthetic fertilizers and allows only natural fertilizers in production systems (Rizo-Mustelier et al., 2017). This agriculture mainly uses various production techniques to maintain balance and harmony with nature (Gil & Vivar, 2018). Currently, organic agriculture is the emerging model to follow because it eliminates synthetic agrochemicals that adversely impact the environment. Biological fertilization with natural products is privileged (Díaz Franco et al., 2016). De Luna-Vega et al. (2018) mention that the negative effects of agricultural activities on the environment have generated the implementation of sustainable fertilization practices in all production systems, constituting a central element of organic agriculture. In many spheres, agroecology and organic agriculture are synonymous, a vision they try to promote. However, the paradigm remains the same: producing food in accordance with nature, not against it (Soto, 2020). The practice of organic agriculture is based on the use of agroecological alternatives that replace inputs of industrial origin and that are locally relevant. In tropical agriculture, organic amendments and efficient microorganisms that have demonstrated positive effects in the short term to support production processes in horticultural crops stand out.

Organic fertilizers constitute one of the fundamental alternatives in organic agriculture, especially those obtained from recyclable organic sources such as compost and vermicompost (Luna Murillo et al., 2015). Using organic fertilizers improves the soil's physical, chemical, and biological properties by incorporating nutrients and regulating the water balance (Cotrina-Cabello et al., 2020). Furthermore, the use of organic fertilizers such as compost is an alternative to reduce production costs, which is essential when talking about inorganic fertilization in horticultural crops (González-Betancourt et al., 2020). The beneficial effects of using organic amendments in horticultural crops are recognized because they provide organic matter in quantity and quality and essential nutrients, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, P, K, Ca, Mg, Na, Fe, Mn, Cu, Zn andf B,, to agricultural soils, which contributes to increasing the fertility and productivity of crops (Hirzel Campos & Salazar Sperberg, 2016). The habanero chili has been shown to benefit production systems. Mendoza-Elos et al. (2020) obtained satisfactory results in combining synthetic fertilizers and 50 % organic fertilizers for fruit quality (weight, locules, and pericarp thickness) and the number of seeds and their germination. Hence, they suggest exploring doses and allowing them to apply organic fertilizers that improve the fruit and seeds production and quality. Javier-López et al. (2022) report that using 100 % vermicompost benefited the growth and yield of habanero chili by more than 50 % compared to chemical fertilization and its combination with organic amendment.

Efficient microorganisms [EM] or activated mountain microorganisms [AMM] are a liquid concentrate that contains a variety of microorganisms and is mainly composed of photosynthetic or phototrophic bacteria *(Rhodopseudomonas spp*.), lactic acid bacteria (*Lactobacillus* spp.) and yeasts (*Saccharomycetes spp*.), which are used in agriculture as liquid biofertilizer, to help to replace synthetic fertilizers (Callisaya Quispe & Fernández Chávez, 2017). EM, as a microbial inoculant, restores the microbiological balance of the soil, improves its physical-chemical conditions, and increases crop production and protection (Luna Feijoo & Mesa Reinaldo, 2016). EM can induce crops systemic resistance to diseases and suppress undesirable pathogenic microorganisms by "competitive exclusion or absolute dominance" in addition to promoting flowering, growth, and fruits development and allowing more successful plant reproduction (Table -Reinaldo, 2020). Organic amendments and efficient microorganisms are viable alternatives for the nutrition of organically produced crops, and their use benefits the crops (Peralta-Antonio et al., 2019).

The habanero chili (*Capsicum chinense* Jacq.*)* is a vegetable of socioeconomic importance in Mexico, with a high consumption culture in the diet of the human population (Meneses-Lazo et al., 2018). Its planting at the national level is concentrated in the south-southeast of Mexico, mainly in the Yucatán Peninsula (80 %) (Ramírez Meraz et al., 2018). In 2020, Mexico produced 21,973 tons of habanero chili, of which 72 % was obtained from Sinaloa, Yucatán, Campeche, Tabasco, and Quintana Roo. For Chiapas, production of 1,523 tons was recorded, representing 6 % of national production (Servicio de Información Agroalimentaria y Pesquera [SIAP], 202). This research aimed to evaluate two proportions of compost-type organic fertilizer plus the application of efficient microorganisms sprayed to the habanero pepper crop managed under the principles of organic agriculture.

2. Materials and Methods

2.1. Study area

The experiment was carried out at the facilities of the University Center for Technology Transfer, [CUTT, by its acronym in Spanish] San Ramón, of the Faculty of Agricultural Sciences Campus V, of the Autonomous University of Chiapas, located in the municipality of Villaflores, Chiapas, Mexico, on the 16th parallel. 15' 13.9'' north latitude and 93º meridian 15' 14.2'' west longitude. The altitude is 610 m a.s.l. According to García (1987), the predominant climate is warm-subhumid AW1 (W'') (i) g with an average annual temperature of 22 ºC and an average annual rainfall of 1,200 mm.

2.2. Experimental design

The experimental design was based on a quantitative and descriptive approach; six treatments were defined related to using compost as a substrate and activated mountain microorganisms sprayed as liquid biofertilizer in cultivating habanero chili (Table 1) under a completely randomized design. Each treatment was represented by five replicates, with five plants per replicate, 25 plants per treatment, and 150 plants in the entire experiment. The agricultural soil was collected in the lower part of the experimental field (alluvial soil), sieving through a 1.5 x 1.5 cm metal sieve mesh. Once the substrates were prepared, the polyethylene bags (30 x 30 x 40 cm) were filled. The bags were placed between 40 cm and 80 cm between rows. The seedlings were transplanted 21 days after sowing [DAS] to bags filled with the indicated experimental substrates.

2.3. Capture, reproduction, and activation of efficient microorganisms

The efficient microorganisms were captured in parts of no or low anthropogenic disturbance within the San Ramón CUTT. For this purpose, organic waste in an advanced state of decomposition and with evidence of white and/or rosacea mycelia was collected in the understory parts. Once the efficient microorganisms were collected, they were removed with 25 kg of wheat bran and 20 L of molasses dissolved in water, and it was moistened until reaching a percentage of approximately 70 %. The prepared material was placed inside a container with a capacity of 200 L, compacting well between layers to eliminate air and promote anaerobic fermentation of the EM. Subsequently, it was sealed hermetically and allowed to rest in the shade at room temperature for 30 days. After this time, the efficient microorganisms were activated; for this, approximately 10 kg of reproduced microorganisms were removed. They were placed in a blanket bag inside a 200 L container, where 180 L of water was also added. 20 L of molasses were dissolved, then covered tightly and let rest for 30 days. After this time, the biofertilizer was ready for the experiment. This process was carried out according to what Suchini Ramírez (2012) suggested.

Table 1. Experimental treatments.

Treatment	Description
1	100 % compost + 20 % de EM
2	100 % compost
3	50 % compost + 50 % agricultural soil + 20 % de EM
4	50 % compost + 50 % agricultural soil
5	100 % agricultural soil + 20 % de EM
6	100 % agricultural soil (control)

2.4. Compost production

To prepare the compost, sheep manure, and ground dry straw of *Cynodon plectostachyus* (K. Schum.) Pilg. were used, in a proportion of 3:1. It was made in piles, first placing a layer of ground dry straw and then manure, successively until the required amount was reached. Water was stirred and added until 70 % humidity was reached. The management consisted of removing the organic amendment every eight days and adding water, if necessary, until reaching the cooling stage. The organic amendment used has been characterized by Aguilar Jiménez et al. (2023).

2.5. Crop management

The transplant of the habanero pepper was carried out manually in the rainy season, corresponding to June 2022, in the indicated bags, which were adequately moistened. One seedling was placed per bag. The Chichén Itzá F1® hybrid seedlings were acquired by suppliers in the study area. The EM liquid biofertilizer was applied manually with a backpack sprayer (20 L) one week after transplantation. The sprays were carried out every eight days on the foliage of the plants, with seven applications being made during the experimental phase. No other fertilization strategy was used since the experiment addressed the response of habanero pepper to solid and liquid biofertilizers (organic amendment and mountain microorganisms). Control of weeds emerging between the rows of the bags was carried out manually with the help of agricultural tools (hoes), while those germinated inside the bags were pulled out manually. Pest control was carried out using organic repellents based on neem, garlic, and pepper extracts to repose and reduce the presence of pest insects. The repellent was applied based on the presence of pest insects that were observed during the vegetative cycle of the habanero pepper crop. To control diseases, it was only carried out preventively on two occasions with the application of Bordeaux broth, combining lime water ($Ca(OH)_2$) plus copper sulfate ($CuSO_4$) in a proportion of 1 kg + 1 kg + 100 L of water, which was applied to the foliage of the plants.

2.6. Variables evaluated and statistical analysis

The collection of variables, plant height, and stem diameter was carried out at 15 DAS, carrying out a total of four samplings with intervals of 15 days. In the productive phase, the parameters were evaluated: number and total weight of fruits per plant and equatorial and polar diameter of fruits per plant. These quantifications were carried out when the fruits presented a characteristic ripening for the harvest, making four cuts, with a separation of Approximately 10 to 12 days between each sampling, the first at 45 DAS. The variables collected in the field were subjected to an analysis of variance and Tukey's multiple range test of means ($p \leq 0.05$), as well as simple correlation analysis (Pearson), using the SPSS Version 19 statistical package.

3. Results and Discussion

3.1. Plant height

At the four sampling times, the greatest plant height was quantified in the treatments using compost alone and combined with agricultural soil plus the application of EM (Table 2). This indicates a beneficial effect of combining both agroecological technologies favored greater habanero chili plant growth compared to the absolute control and with the application of liquid biofertilizer. The organic amendment favored the crop substrate, and the microorganisms enhanced the plants' functions. Taller habanero pepper plants produce more fruit (Reyes-Ramírez et al., 2014). Muñoz et al. (2015) point out that the application of organic fertilizers favors the soil's chemical properties, improving the pH and promoting better availability of nutrients for plants; in addition, the use of compost favors plant health. Umaña et al. (2017) mention that EM are highly beneficial for productive edaphic systems because the mobility of chemical elements and the soil's structure and characteristics are improved, positively affecting the physiological response of plants even in short productive cycles.

Table 2. Test of averages for plant height (cm).†

Treatment	15 DAS	30 DAS	45 DAS	60 DAS
100 % compost + EM	26,48 ± 3,79 a	29,54 ± 4,72 a	30,30 ± 4,99 ab	31,40 ± 5,71 a
100 % compost	25,78 ± 2,71 ab	28,58 ± 2,85 ab	30,96 ± 3,52 ab	32,40 ± 3,76 a
50 % soil + 50 % compost + EM	27,28 ± 1.98 a	29,59 ± 2,50 a	31,46 ± 2,66 a	32,40 ± 3,50 a
50 % soil + 50 % compost	24,90 ± 3,64 ab	27,42 ± 3,49 ab	28,04 ± 3,92 ab	28,06 ± 3,94 ab
100 % soil + EM	20,36 ± 2,88 b	25,00 ± 2,12 ab	26,50 ± 1,00 ab	26,90 ± 1,24 b
100 % s soil	20,30 ± 2,33 b	22,72 ± 2,11 b	24,80 ± 2,41 b	25,30 ± 2,63 b
p-Value	0,002**	0,010**	0,023*	0,019*
C.V. (%)	16,27	14,02	13,66	15,03

† *Different letters in the same column indicate significant difference between treatments. * significant difference ($p < 0.05$), ** highly significant difference ($p < 0.01$).*

3.2. Stem diameter

The use of compost and EM favored the stem diameter. In the last three samplings (30, 45, and 60 DAS), organic amendment and EM treatments were statistically superior to the control treatment and agricultural soil plus liquid biofertilizer (Table 3). It provides grounds to point out that the use of compost mainly as a growing substrate and the complementary application of EM as biofertilizers favor the increase in the stem thickness of habanero peppers managed under the principles of organic agriculture and cultivated in polyethylene bags as an alternative to direct sowing on agricultural soil. Torres et al. (2018) report that compost promotes greater vegetative development, plant height, number of leaves, and stem diameter, justifying that this is due to the contribution of organic matter and the greater availability of nutrients that promote the use of the organic amendment. Parra-Cota et al. (2018) mention that the application of biofertilizers based on efficient microorganisms has beneficial effects on the plants' growth and health, promoting their development and increasing the diameter of the stem in crops. In this sense, Torres Pérez et al. (2022) mention that EM improves plants' physiological development variables regardless of application frequency, alluding to the fact that there is a better response to higher concentrations.

3.3. Fruit number

The number of fruits at 45 DAS, in the treatments of 50 % agricultural soil + 50 % compost with and without liquid biofertilizer, was statistically higher, which indicates that fruit production is benefited mainly by the combined use of agricultural soil plus compost in the growing substrate. At 60, 75, and 90 DAS, the treatments that had only compost as a substrate in the culture bags were statistically thebest without showing an effect of using EM (Table 4). The greater fruits production in the last cuts for the treatments using the solid organic amendment results from the humification process that the organic matter used as a growing substrate undergoes. Bulgari et al. (2019) mention that biostimulants (EM and compost) increase crop productivity through metabolic activities and promote nutrient absorption through nitrogen fixation and nutrient solubilization. They modify the hormonal state by inducing the biosynthesis of plant hormones such as auxins, cytokinins, etc., and help to have better resilience in the face of biotic or abiotic stress.

Table 3. Test of means for stem diameter (mm). †

Treatment	15 DAS	30 DAS	45 DAS	60 DAS
100 % % compost + EM	4,12 ± 0,70 b	5,42 ± 0,84 a	6,12 ± 0,54 a	6,72 ± 0,62 a
100 % compost	3,54 ± 0,21 bc	5,06 ± 0,31 a	5,74 ± 0,38 a	6,40 ± 0,31 a
50 % soil + 50 % compost + EM	3,52 ± 0,24 bc	4,88 ± 0,42 a	6,28 ± 0,32 a	6,72 ± 0,17 a
50 % soil + 50 % compost	4,96 ± 0,49 a	5,86 ± 0,36 a	6,20 ± 0,29 a	6,40 ± 0,25 a
100 % soil + EM	3,36 ± 0,27 bc	3,86 ± 0,58 b	4,70 ± 0,50 b	5,02 ± 0,67 b
100 % s soil	2,92 ± 0,20 c	3,68 ± 0,29 b	4,24 ± 0,56 b	4,58 ± 0,39 b
p-Value	0,00**	0,00**	0,00**	0,00**
C.V. (%)	20,20	19,29	16,26	15,97

† *Different letters in the same column indicate significant difference between treatments. ** highly significant difference (p < 0.01).*

Table 4. Test of means for fruit number.†

Treatment	45 DAS	60 DAS	75 DAS	90 DAS
100 % compost + EM	13,20 ± 1,48 abc	32,40 ± 1,14 a	32,60 ± 2,40 a	21,60 ± 1,14 a
100 % compost	13,40 ± 2,30 ab	34,20 ± 0,83 a	31,60 ± 3,36 a	21,80 ± 1,30 a
50 % soil + 50 % compost + EM	14,80 ± 1,48 ab	33,40 ± 1,14 a	29,80 ± 1,92 ab	19,60 ± 0,89 ab
50 % soil + 50 % compost	16,60 ± 2,70 a	29,80 ± 0,83 b	27,00 ± 1,00 b	18,20 ± 0,83 bc
100 % soil + EM	11,80 ± 0,83 bc	23,60 ± 1,51 c	21,20 ± 1,30 c	16,00 ± 1,58 c
100 % soil	9,80 ± 0,83 c	18,60 ± 1,14 d	19,40 ± 1,14 c	12,00 ± 1,58 d
p-Value	0,00**	0,00**	0,00**	0,00**
C.V. (%)	20,37	20,55	20,19	20,06

† *Different letters in the same column indicate significant difference between treatments. ** highly significant difference (p < 0.01).*

3.4. Fruit weight

Fruit weight at 45 and 60 DAS significantly favored the use of compost alone or combined with agricultural soil without showing a defined pattern of foliar application of EM. During the last cut (90 DAS), using the organic amendment alone and combined with agricultural soil as a substrate, plus the liquid biofertilizer, were the treatments with the highest quantified weight (Table 5). This indicates that when habanero chili is produced under the approach of organic agriculture in polyethylene bags, the combined use of experienced agroecological practices guarantees greater fruit weight per plant. Montoya-Jasso et al. (2021) mention that, in substrates with compost, the C/N ratio is < 19 due to the decomposition and release of N, concluding that compost favors the retention of nutrients in the substrate and increases the content of N, P, K, Ca, and CEC, benefiting the plant nutrition process. Alarcón Camacho et al. (2020) report that EM contributes significantly to having better physiological development and enhancing performance in the productive phase of horticultural plants. In this sense, Hernández-Valladares et al. (2021) mention that this type of biofertilizer positively affects the fresh weight and number of seeds in solanaceous ecotypes. Calero-Hurtado et al. (2018) report benefits when foliar applying EM in bean cultivars.

Table 5. Mean test for fruit weight (g).

Treatment	45 DAS	60 DAS	75 DAS	90 DAS
100 % compost + EM	77,00 ± 4,18 a	138,60 ± 3,04 a	139,80 ± 8,07 a	47,00 ± 1,58 a
100 % compost	73,40 ± 2,70 a	140,80 ± 5,35 a	116,60 ± 8,35 b	50,40 ± 2,50 a
50 % soil + 50 % compost + EM	77,80 ± 3,03 a	142,60 ± 4,72 a	105,40 ± 7,50 bc	47,00 ± 1,58 a
50 % soil + 50 % compost	76,80 ± 2,48 a	120,20 ± 5,63 b	97,60 ± 1,67 cd	38,60 ± 1,14 b
100 % soil +EM	53,20 ± 4,32 b	91,40 ± 5,36 c	88,00 ± 1,00 d	35,20 ± 2,38 b
100 % soil	45,20 ± 3,89 c	84,60 ± 3,50 c	75,60 ± 2,40 e	27,80 ± 2,94 c
p-Value	0,00**	0,00**	0,00**	0,00**
C.V. (%)	20,28	20,42	20,80	20,14

† *Different letters in the same column indicate significant difference between treatments. ** highly significant difference (p < 0.01).*

3.5. Equatorial diameter

There were no significant differences between the treatments during the experimental phase for this variable. However, in general, the combined use of compost plus agricultural soil, as well as the application of EM, quantified the highest means (Table 6). Luna-Fletes et al. (2023) report benefits from using organic amendment as a substrate, which favors plant growth, the concentration of N and K, and the size and weight of fruits, which is why it is considered a viable alternative for producing this vegetable. Efficient microorganisms such as bacteria of the *Bacillus* genus can improve the development of seedlings, plants, and fruits in habanero peppers (Adame-García et al., 2021). These microorganisms have the capacity to produce organic compounds, carry out biological nitrogen fixation, and solubilize phosphates. These are activities that they carry out through enzymes such as nitrogenases and phytases, with a positive effect on promoting plant growth and increasing productive potential (Corrales-Ramírez et al., 2017).

Table 6. Mean test for equatorial diameter (mm).*

Treatment	45 DAS	60 DAS	75 DAS	90 DAS
100 % compost + EM	28,72 ± 2,86	26,64 ± 1,26	24,78 ± 1,35	21,30 ± 1,37
100 % compost	25,34 ± 2,47	25,08 ± 1,21	23,24 ± 1,07	21,06 ± 1,37
50 % soil + 50 % compost + EM	26,64 ± 1,06	27,00 ± 0,66	23,84 ± 1,93	21,96 ± 1,32
50 % soil + 50 % compost	27,62 ± 2,53	25,86 ± 0,56	23,06 ± 1,98	21,94 ± 0,60
100 % soil + EM	27,44 ± 4,01	27,34 ± 2,93	24,32 ± 0,96	24,16 ± 3,09
100 % soil	30,50 ± 5,33	26,10 ± 3,33	21,68 ± 2,58	21,58 ± 1,04
p-Value	0,255 ns	0,519 ns	0,121 ns	0,067 ns
C.V. (%)	12,43	7,44	8,04	8,33

* ns = not significant

3.6. Pole diameter

No significant differences were recorded between treatments for polar diameter at 45 and 60 DAS. At 75 DAS, the 100 % compost plus ME treatment was statistically superior. For the last cut (90 DAS), the 100 % soil + EM treatment was statistically superior, indicating that this parameter is favored by the liquid biofertilizer regardless of the growing substrate (Table 7). Murillo-Cuevas et al. (2021) obtained significantly larger fruits with the application of biostimulants based on efficient microorganisms (*Bacillus spp.,* and *Trichoderma spp.*) compared to the control treatment, highlighting that these microorganisms helped increase the fruit length and width. García-Aguilera et al. (2021) mention that EMs can suppress or generate plant resistance to the invasion of pathogenic organisms, translating into better productive characteristics. González and Fuentes (2017) suggest that EMs promote plant growth and productivity by suppressing phytopathogens and inducing the production of phytohormones, for example, indoleacetic acid (IAA) from the auxin group, gibberellic acid (GA3), cytokinins and abscisic acid (ABA).

Table 7. Test of means for polar diameter (mm).[†]

Treatment	45 DAS	60 DAS	75 DAS	90 DAS
100 % compost + EM	34,84 ± 3.98	30,72 ± 2,00	28,40 ± 0,90 a	20,10 ± 0,91 ab
100 % compost	32,16 ± 2,34	28,58 ± 1,98	26,48 ± 0,90 ab	20,42 ± 1,27 ab
50 % soil + 50 % compost + EM	28,66 ± 3,21	27,06 ± 1,63	22,74 ± 2,01 b	19,42 ± 1,36 b
50 % soil + 50 % compost	31,14 ± 4,55	26,32 ± 2,19	24,06 ± 2,26 b	19,86 ± 0,49 ab
100 % soil + EM	31,16 ± 2,28	29,74 ± 5,47	25,52 ± 2,44 ab	22,68 ± 2,71 a
100 % soil	34,38 ± 9,17	25,94 ± 1,25	22,86 ± 2,99 b	20,70 ± 2,10 ab
P-Value	0,380 ns	0,068 ns	0,01**	0,05*
C.V. (%)	15,32	11,10	11,16	8,96

[†] *Different letters in the same column indicate significant difference between treatments. ns = not significant, * significant difference (p < 0.05), ** highly significant difference (p < 0.01).*

Table 8. Correlation analysis between variables.*

Variables	PH 30 DAS	SD 30 DAS	PH 45 DAS	SD 45 DAS	PH 60 DAS	SD 60 DAS	NF 45 DAS	FW 45 DAS	NF 60 DAS	FW 60 DAS	NF 75 DAS	FW 75 DAS	NF 90 DAS	FW 90 DAS
PH 15 DAS	0,939**	0,614**	0,889**	0,681**	0,864**	0,746**		0,684**	0,686**	0,666**			0,665**	0,668**
SD 15 DAS		0,808**		0,675**		0,591**		0,616**						
PH 30 DAS		0,550**	0,954**	0,614**	0,931**	0,692**		0,619**	0,655**				0,687**	0,650**
SD 30 DAS				0,898**		0,866**	0,622**	0,809**	0,700**	0,669**	0,667**		0,662**	
PH 45 DDD					0,988**	0,602**			0,601**				0,637**	0,626**
SD 45 DAS						0,952**	0,676**	0,915**	0,823**	0,815**	0,776**	0,639**	0,786**	0,758**
PH 60 DAS						0,598**							0,651**	0,644**
SD 60 DAS							0,650**	0,924**	0,881**	0,875**	0,836**	0,719**	0,840**	0,829**
NF 45 DAS								0,762**						
FW 45 DAS									0,911**	0,902**	0,871**	0,735**	0,835**	0,820**
NF 60 DAS										0,971**	0,896**	0,773**	0,909**	0,934**
FW 60 DAS											0,931**	0,810**	0,881**	0,926**
NF 75 DAS												0,907**	0,865**	0,889**
FW 75 DAS													0,820**	0,798**
NF 90 DAS														0,960**

* PH: Plant height. SD: Stem diameter. NF: *Number of fruits*. FW: *Fruit weight.*

3.7. Correlation analysis

The correlation analysis between the growth and productivity variables indicated that the phenological development of habanero pepper was positively correlated with the yield components ($p < 0.05$) (Table 8). Plant height and stem diameter in the different samplings (DAS) were correlated with the fruit number and weight on the different cutting dates. Likewise, a reciprocity was shown within the vegetative and production parameters. The vegetative growth of *Capsicum chinense* Jacq. typically corresponds to larger harvest volumes and better fruit quality indicators (Torres et al., 2019), so adequate leaf area and stem development constitute a pertinent element when growing habanero peppers under organic agriculture. The use of organic amendments and EM are agroecological practices that contribute to the vegetative development of cultivated plants (Adame-García et al., 2021; Corrales-Ramírez et al., 2017; Luna-Fletes et al., 2023).

4. Conclusions

The combined use of compost and EM treatments was statistically superior to the 100 % soil treatment (control) in habanero pepper's phenological and yield parameters.

The use of the organic amendment as a growing substrate in polyethylene bags represented the agroecological practice that generated more significant benefits in the production process of *Capsicum chinense* Jacq.

Using 100 % compost or combined with soil (50 %) combined with EM favors the development of the variables plant height, stem diameter, fruits' number and weight, and fruits' equatorial and polar diameter.

Authors contributions

- Carlos Ernesto Aguilar Jiménez: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing - original draft, writing - review & editing.
- Ferman Alberto Nandayapa Solís: data curation, investigation, project administration, resources, writing - original draft.
- Isidro Zapata Hernández: conceptualization, methodology, supervision, validation, visualization, writing - review & editing.
- José Galdámez Galdámez: conceptualization, investigation, methodology, visualization, writing - review & editing.
- Franklin B. Martínez Aguilar: conceptualization, investigation, methodology, writing - review & editing.
- Héctor Vázquez Solís: conceptualization, investigation, methodology, supervision, writing - review & editing.

Ethical implications

Ethics approval not applicable.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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