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Influence of *Trichoderma harzianum* inoculation and pruning on the growth and yield of *Capsicum chinense* Jacq.

Influencia de la inoculación de *Trichoderma harzianum* y la poda sobre el crecimiento y rendimiento de *Capsicum chinense* Jacq.

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ABSTRACT

The production of *Capsicum chinense* Jacq. is an economically important activity in Mexico. *Trichoderma harzianum* inoculation and pruning to three and four stems on plant growth, fruit quality, and yield of *C. chinense* was evaluated. A factorial experimental design A (inoculation and non-inoculation of *T. harzianum*) × B (pruning to three and four stems) was employed, establishing four treatments. The plant height, stem diameter, fruit quality (fruit- weight, length, and width), and yield (fruits plant^{-1}, g plant^{-1}, and t ha^{-1}) were measured. Inoculation of *T. harzianum* increased plant height (from 4.3 to 7.9%), without favoring yield. Pruning to three stems increased the plant height (from 7.7 to 14.5%), fruit weight (7.7%), and yield [fruits plant^{-1} (25.8%), g plant^{-1} (26.3%), and t ha^{-1} (26.3%)]. Inoculated plants with *T. harzianum* and pruned to three stems showed the best yield (15.38 t ha^{-1}) compared to plants inoculated with *T. harzianum* and pruned to four stems (10.71 t ha^{-1}). *T. harzianum* favored the vegetative growth, while pruning improved fruit weight and the yield of *C. chinense*.

Keywords: Biofertilizer; biological agriculture; habanero pepper; fruit quality; stems.

RESUMEN

La producción de *Capsicum chinense* Jacq. es una actividad económicamente importante en México. Se evaluó la inoculación de *Trichoderma harzianum* y poda a tres y cuatro tallos sobre el crecimiento vegetativo, calidad de frutos y rendimiento de *C. chinense*. Se empleó un diseño experimental factorial A (inoculación y no inoculación de *T. harzianum*) × B (poda a tres y cuatro tallos), estableciendo cuatro tratamientos. Se midieron la altura de planta, diámetro del tallo, calidad del fruto (peso, largo y ancho de fruto) y rendimiento (frutos planta^{-1}, g planta^{-1} y t ha^{-1}). La inoculación de *T. harzianum* incrementó la altura de planta (de 4,3 a 7,9%), sin favorecer el rendimiento. La poda a tres tallos aumentó la altura de planta (de 7,7 a 14,5%), peso del fruto (7,7%) y rendimiento [frutos planta^{-1} (25,8%), g planta^{-1} (26,3%) y t ha^{-1} (26.3%)]. Las plantas inoculadas con *T. harzianum* y podadas a tres tallos mostraron el mejor rendimiento (15.38 t ha^{-1}) en comparación con las plantas inoculadas con *T. harzianum* y podadas a cuatro tallos (10.71 t ha^{-1}). *T. harzianum* favoreció el crecimiento vegetativo, mientras que la poda mejoró el peso del fruto y el rendimiento de *C. chinense*.

Palabras clave: Biofertilizante; agricultura biológica; chile habanero; calidad de fruta; tallos.

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1. Introduction

The habanero chili pepper (*Capsicum chinense* Jacq.) is a specie within the Solanaceae family, under a proper agronomic management, this plant can thrive for a period of 12 months, reaching heights ranging from 0.75 to 2.5 m. It possesses a robust and erect stem, accompanied by a taproot that typically extends from 0.4 m to 1.2 m in deep (Devi et al., 2022). In the southeastern region of Mexico, the habanero chili pepper holds cultural significance as an integral component of Mexican cuisine. This is attributed to its pungency value and rich content of minerals and vitamins A, C, and E. *Capsicum chinense* fruits, also its importance as a vegetable, has pharmacological properties in countering certain irritant and anti-inflammatory effects. Consumption patterns encompass 65 % fresh and 35 % processed forms, including sauces, teargas, cosmetics, varnishes, ointments, and paints (Meneses-Lazo & Garruña, 2020).

The use of biofertilizers and bioinoculants based on asexual microscopic fungi in the production of habanero peppers has been the object of study in recent years. Among the species that have been evaluated to improve the growth and yield of *C. chinense* stand out *Beauveria brongniartii*, *Purpureocillium lilacinum* (Luna-Fletes et al., 2023), and *Trichoderma* spp. (Larios-Larios et al., 2019). The latter is a genus of a filamentous fungus often found in soil, roots, and leaf environments of plants in diverse ecosystems. This species confers biotechnological benefits to plants through the production of antibiotic substances that parasitize various phytopathogenic microorganisms by degrading chitin and other cell wall polysaccharides. In addition, as a beneficial fungus, *Trichoderma* spp. enhances nutrient absorption and improves plant growth (Yao et al., 2023).

On the other hand, the yield of *C. chinense* not only depends on biological or mineral fertilization, crop management in relation to pruning influences yield and fruit quality (Murillo-Cuevas et al., 2021). Furthermore, the objective of pruning is to modify the growth of trees, plants, or shrubs by removing certain parts. Different pruning methods exist, with the Spanish and Dutch pruning techniques being commonly used in vegetables, including *C. chinense*. The latter involves directing the plant's growth along guides while removing one of the two branching points where a bud will divide. In Spanish pruning, the plant is allowed to grow freely (Monge-Pérez et al., 2016). In this sense, Vasquez-Velázquez et al. (2022) assessed the effects of pruning on agronomic variables and fruit quality of *C. chinense*, plants pruned to have two branches yielded 42.0 % first-grade fruits (large) and 48.0 % second-grade fruits (medium). With three branches, the first-grade yield increased to 48.0 %, and the second-grade yield decreased to 42.0 %. In plants left unpruned (four branches), only 6.0 % of first-grade fruits were obtained.

Both biofertilization and pruning in *C. chinense* cultivation can improve plant growth and yield. However, these factors have generally been studied separately; therefore, the objective of this research was to evaluate plant growth, yield, and fruit quality of *C. chinense* "Megalodon" hybrid in screenhouse with pruning management at three and four stems and inoculation of *T. harzianum*.

2. Material y methods

2.1. Experimental area

The research was carried out in a screenhouse with anti-aphid mesh (20 × 10 threads·cm^2), in Tecoman, Colima, Mexico. The predominant climate in the region is warm subhumid A(w0) with an average annual temperature of 26.30 °C, 750 mm of precipitation per year and 33 m.a.s.l. The experiment was carried out from November 2020 to April 2021.

2.2. Habanero chili pepper plantlets

Capsicum chinense plantlets were cultivated in polyethylene trays (200 cavities) with a peat moss and vermiculite substrate (Compaqpeat QTA, Canada) maintained at 80% water holding capacity. Seeds of *C. chinense* Megalodon hybrid (Lark Seeds, USA) were sown individually in each tray cavity. Germination was encouraged covering the trays with black bags for five days, followed by a seven-week period in a nursery. Plantlets were fertilized twice weekly Triple 17 (1.0 g L^{-1}), Root Factor (1.0 g L^{-1}), and Maxirad (0.5 mL L^{-1}). Upon reaching 20 cm in height, the plantlets were transplanted into a screenhouse after irrigation the furrows to field capacity. During the transplant plantlets roots were immersed in a solution containing Ridomil Gold (0.5 mL L^{-1}), Radigrow (1 mL L^{-1}), and Decis Forte (1 mL L^{-1}).

2.3. *Trichoderma harzianum* formulation

Whole rice grains were used for *T. harzianum* conidiospore production, the strain was obtained from the collection of entomopathogenic and antagonistic fungi collection of the Colima University. The rice was washed three times using potable water, with and addition of chloramphenicol (100 ppm) during the third wash, followed by a 45 min resting period. Subsequently, the washed rice was spread out on plastic trays and air-dried over 30 min. After ensuring the rice was thoroughly dry and cleaned, it underwent sterilization. Precisely, 200 g of rice were enclosed in high density polyethylene bags (2 kg) and subjected to autoclaving at 121 ºC for 20 min. Upon completion of sterilization each bag was inoculated with 5 mL of *T. harzianum* at a concentration of 1×10^{7} conidiospores mL^{-1}.

Incubation occurred over 16 days under conditions of 25 ± 3.0 ºC, artificial white light (10: 14 h light: darkness) and 75 ± 5% relative humidity. Spores were harvested by shaking through a sieve (150 µm), micronized diatom (5 g per bag of colonized and dry rice) was used as carrier. With the harvested conidiospores, a wettable powder product was formulated using micronized diatom (40%), soluble carbohydrate (55%), humic and fulvic acids (2.5%) and *T. harzianum* conidiospores as active agent (2.5%). The dose was formulated to weigh 400 g at a concentration of 1×10^{11} conidiospores dose^{-1}.

2.4. Soil preparation and fertilization plan

The experimental soil was a sandy loam (17% clay, 77% sand and 6% silt) with an electrical conductivity, pH and organic matter content of 8.53 mS·cm^{-1}, 6.88 and 0.60%, respectively. With agricultural machinery (plow and harrow) furrows were made every 1.5 meters with 50 cm width and 25 cm height. The furrows were covered with silver-black plastic mulch with holes every 30 cm. An irrigation tape with drippers every 30 cm was installed under the plastic mulch. The irrigation water came from a water tank fed with a 0.5 HP pump and a manual timer. Considering the physical-chemical characteristics of the soil, the fertilization plan described in Table 1 was used. Nutrient sources (N-P-K) were phosphonitrate (30-3-0), potassium sulfate (0-0-51+18 S) and monopotassium phosphate (0-52-34). Turgent-Ca was used for Ca contribution. Micronutrients were supplied by FullMix B® (B, Cu, Fe, Mn, Mo, and Zn).

2.5. Treatments

Trichoderma harzianum applications were made every seven days, for one month (four applications). A quantity of 50 mL plant^{-1} was applied at a dose of (2.5 g L^{-1} of formulated product at a concentration of 1×10^{11} conidiospores mL^{-1}). Pruning was carried out with garden shears that were disinfected with 70.0 % alcohol after each use. The plants without pruning kept their four stems after the second bifurcation. While the pruned plants, one of the four stems was removed after the second bifurcation, leaving only three stems. Figure 1 shows the appearance of the plants pruned to three and four stems. Therefore, the study factors were A) inoculation of *T. harzianum* (inoculation and non-inoculation) and B) pruning (to three and four stems), resulting in four treatments: 1) with *T. harzianum* + 3 stems (+ Th + 3 St), 2) without *T. harzianum* + 3 stems (- Th + 3 St), with *T. harzianum* + 4 stems (+ Th + 4 St) and without *T. harzianum* + 4 stems (- Th + 4 St).

Figure 1. Plants of *Capsicum chinense* Megalodon hybrid pruned at three (A) and four (B) stems.

2.6. Response variables

2.6.1. Plant height and stem diameter. With a flexometer, the plant height was measured from the base of the soil to the apical meristem. With a digital Vernier, the stem diameter was measured at 10 cm above the soil (Luna-Fletes et al., 2023).

Table 1
Fertilization plan

Phenological stage		Ratio			No. of fertigations	Nutrient units per ha (kg·ha^{-1})		
		N	P	K		N	P	K
I.	Adaptation + 20 days	2	1	1	6	32.6	19.8	19.3
II.	Development 20 + 30 days (50)	2.5	1	2	2	8.4	3.5	7.0
III.	Fruiting 50 + 35 days (85)	1	1.5	1	9	35.7	58.2	38.0
IV.	Production 85 + 75 days (160)	2	1	4	63	99.8	48.5	189.7
	Total	7.5	4.5	8	80	176.5	130	254

2.6.2. Fruit quality. The quality of the fruit implied the measurement of the weight, length, and width of the fruit. The weight of the fruit was determined with a portable scale, the length and width of the fruit was measured with a digital Vernier (Luna-Fletes et al., 2023).

2.6.3. Fruit yield. For the fruit yield, the numbers of fruits harvested per plant, the total weight of the fruits and the yield per ha were recorded. For this last variable, the yield per plant (kg plant^{-1}) was multiplied by the planting density ha^{-1} (21, 778.0 plants ha^{-1}) (Luna-Fletes et al., 2023).

2.6.4. Experimental design and data analyses. The experiment was established under a randomized design with factorial arrangement A x B. Factor A consisted of inoculation (with and without) of *T. harzianum* and factor B consisted of pruning (three and four stems). In total there were four treatments, in each one, twelve repetitions were established, and one repetition consisted of one *C. chinense* plant.

3. Results and discussion

3.1. Plant height

The inoculation of *T. harzianum* increased the plant height in *C. chinense* from 60 days after transplant (dat) (P = 0.0067) up to 90 dat (P = 0.0283). The increases in height were 7.4, 7.9 and 4.3 %, at 60, 75 and 90 dat, respectively (Table 2). Pruning also influenced the growth of the plants, between 45 (P = 0.0005) and 75 dat (P = 0.0010), the plants with three stems presented greater height compared to the plants with four stems. The increases were 11.7, 14.5 and 7.5 %, at 45, 60 and 75 dat. Regarding to the treatments, it was found that the inoculation of *T. harzianum* in plants with three stems (+ Th + three st) achieved greater height from 45 dat (P = 0.0018), until the last evaluation at 90 dat (P = 0.0008), if they are compared with the other treatments (Table 2).

Several *Trichoderma* spp. have been reported as plant growth promoters in *C. chinense*. In the nursery stage, Candelero et al. (2015) reported that *Trichoderma* sp. Th05-02 (13.8 cm) increased the height of *C. chinense* plants by 125.0 % compared to the control (6.4 cm) under nursery conditions. In a similar study, Larios-Larios et al. (2019) reported that the inoculation of native strains of *Trichoderma* sp. (Clombta) and *Trichoderma* sp. (SP6) increased in 44.7 and 28.9 % the plant height of *C. chinense* seedlings in nursery environment.

In habanero pepper production systems, Cristóbal-Alejo et al. (2021) reported that the inoculation of *T. harzianum* Th02-01, *T. virens* Th05-02 and *T. virens* Th27-08 in *C. chinense* plants with fertilization limited to 50%, allowed greater plant height compared to the control without inoculation, the increases in plant height were 6.1, 4.3 and 6.5 % for *T. harzianum* Th02-01, *T. virens* Th05-02 and *T. virens* Th27-08, respectively. Recently, Ajiboye & Sobowale (2022) co-inoculated *Trichoderma koningii* and the phythopathogenic fungi *Fusarium oxisporum* and *Pythium ultimatum* in *C. chinense* plants to evaluate de plant growth. The results indicated that the inoculation of *T. koningii* at concentrations of 1×10^5 to 1×10^7 conidiospores mL^{-1} improved the plant height, despite the inoculation of the phytopathogenic fungi, suggesting that *T. koningii* counteracted the severity of the pathogens, at the same time it promoted the increase in plant height of *C. chinense.*

Trichoderma harzianum has been one of the most studied microscopic fungi for improving the production and development of several crop species by its capability to stablish symbiotic association with the root plant and its ability to abate soil borne plant diseases (Bononi et al., 2020). Likewise, *T. harzianum* could solubilize insoluble phosphates such as phosphoric rock and superphosphate, produce siderophores, auxins (indole acetic acid) and various secondary metabolites that promote a microenvironment in plant roots that favors the suppression of phytopathogenic fungi (Joo & Hussein, 2022). All these abilities of *T. harzianum* could be involved in improving the growth of *C. chinense*, including plant height.

By other side, the pruning at three stems has been demonstrated that increase the plant height in *C. chinense* in 31.6 %, according to López-Gómez et al. (2020). The studies in relation to pruning *in C. chinense* are not extensive, mostly the studies with this factor have been carried out in *Capsicum annuum*; in this regard, Aydin et al. (2022) reported that *C. annuum* plants pruned to three and four stems increased their height by 25.5 and 23.9 %, respectively. Pruning stimulates growth if it is done correctly. There are small nodes or regions along each plant structure that contain growth hormones (auxins), and if you prune directly above them with a clean, sharp tool, these hormones are triggered to repair or regrow plant tissue (Lee et al., 2019). Pruning carried out at the correct age of the plant can benefit growth and therefore the size of the fruit and yield. In *C. chinense*, pruning is recommended after three weeks after transplanting (López-Gómez et al., 2020).

3.2. Stem diameter

Only at two sampling dates (7 and 45 dat) significant differences were found by the effect of *T. harzianum* inoculation. The stem diameter of *C. chinense* plants increased by 31.8 (P = 0.00001) and 6.8 % (P = 0.0303) due to the *T. harzianum* inoculation at 7 and 45 dat (Table 3). Meanwhile, the pruning did not increase the stem diameter of *C. chinense* plants in the stage of development and fructification (15 to 90 dat). Therefore, the treatments did not achieve significant effect in the stem diameter of *C. chinense* plants (Table 3).

In previous studies, it has been shown that *Trichoderma* spp. can increase the stem diameter of inoculated *C. chinense* plants, some increases reported are 2.0%, 11.2% and 30.7%, in studies of Candelero et al. (2015), Larios-Larios et al. (2019) and Ajiboye & Sobowale (2022), respectively. The increases in the thickness of the stem diameter of *C. chinense* plants inoculated with *Trichoderma* spp., could be due to the symbiotic effect that this microorganism has with the roots of the plants, since it increases root biomass while minimizing the attack of phytopathogenic fungi and nematodes (Herrera-Parra et al., 2017).

Likewise, the pruning in *C. chinense* plants (three stems) has been demonstrated that did not increase the stem diameter (López-Gómez et al., 2020). However, in *C. annuum* plants contrary results have been reported, in this regard, Aydin et al. (2022) reported that pruning to three stems significantly increased stem diameter by 7.3%.

Table 2
Plant height (cm) of *Capsicum chinense* "Megalodon" hybrid inoculated with *Trichoderma harzianum* and pruned at three and four stems

Factors	Days after transplant						
	7	15	30	45	60	75	90
T. harzianum							
Inoculation	15.6	19.8	39.2a	65.2	111.8a	127.1a	192.5a
Non inoculation	14.8	19.7	36.7b	61.6	104.1b	117.8b	184.5b
Pruning							
Three stems	14.3b	19.1	38.3	66.9a	115.5a	126.9a	191.5
Four stems	16.1a	20.4	37.6	59.9b	100.9b	118.0b	185.4
Treatments							
+ Th + three St	14.4	18.6	39.3	68.7a	122.8a	135.8a	201.5a
- Th + three St	14.1	19.6	37.3	65.2ab	107.1b	118.1b	181.6b
+ Th + four St	16.7	21.1	39.1	61.7ab	100.8b	118.4b	183.4b
- Th + four St	15.4	19.8	36.1	58.02b	101.0b	117.6b	187.4b
P-values							
T. harzianum	0.2614	0.8760	0.0434	0.0632	0.0067	0.0007	0.0283
Pruning	0.0134	0.0839	0.5422	0.0005	0.00001	0.0010	0.0903
Treatments	0.0513	0.1582	0.1955	0.0018	0.00001	0.00001	0.0008

Means with different literals are significantly different from each other, according to Tukey's multiple range comparison (P = 0.05). Th = *Trichoderma harzianum* and St = stem.

Table 3
Stem diameter (mm) of *Capsicum chinense* "Megalodon" hybrid inoculated with *Trichoderma harzianum* and pruned at three and four stems

Factors	Days after transplant						
	7	15	30	45	60	75	90
T. harzianum							
Inoculation	2.86 a	3.9	5.8	8.7 a	11.2	12.0	14.2
Non inoculation	2.17 b	3.9	5.5	8.1 b	11.0	11.7	14.1
Pruning							
Three stems	2.83 a	3.7 b	.7	8.4	11.1	11.7	14.0
Four stems	2.19 b	4.0 a	5.6	8.4	11.0	12.0	14.4
Treatments							
+ Th + three St	2.72 a	3.6	5.7	8.5	11.5	11.9	14.4
- Th + three St	2.94 a	3.8	5.7	8.2	10.8	11.6	13.7
+ Th + four St	2.99 a	4.1	5.9	8.9	11.0	12.1	14.4
- Th + four St	1.42 b	3.9	5.3	8.0	11.1	11.9	14.5
P-values							
T. harzianum	0.00001	0.8777	0.1120	0.0303	0.4110	0.4797	0.3049
Pruning	0.0001	0.0282	0.6013	0.8116	0.7684	0.4483	0.1638
Treatments	0.00001	0.0530	0.2109	0.1273	0.5808	0.7786	0.1793

Means with different literals are significantly different from each other, according to Tukey's multiple range comparison (P = 0.05). Th = *Trichoderma harzianum* and St = stem.

Even though in *C. chinense* the stem diameter does not increase, pruning the plants has favorable effects for it, the leaf area is reduced, which allows better management of pests and diseases, the wind circulates better, which allows better pollination and fruit formation, since *C. chinense* is an open-pollinated plant (Mussa & Shinichi, 2019).

3.3. Fruit quality

The inoculation of *T. harzianum* in the production of *C. chinense* did not increase the fruit quality parameters (length, width, and weight). On the contrary, the non-inoculated plants achieved greater length (P= 0.0330, 48.58 mm) and width (P = 0.0012, 33.37 mm) of the fruit compared to the inoculated plants (length = 45.47 mm and Width = 30.96 mm, Table 4). The fruit weight did not significantly achieved differences (P = 0.6435, inoculated plants = 12.97 g and non-inoculated plants = 13.19 g) by the effect of *T. harzianum* inoculation. The pruning did not affect the width (P = 0.7696) and length (P = 0.1128) of the fruits, the fruits presented an average of 32.16 mm and 47.0 mm in width and length, respectively (Table 4). However, the plants pruned at three stems registered a significant increase in fruit weight (P = 0.0348, 13.57 g) compared to the plants pruned at four stems (12.59 g). Therefore, with the effect of these factors, the treatments that achieved the best fruit quality in relation to length and width were the plants without *T. harzianum* inoculation and with pruning to three or four stems (Table 4).

In this study, the inoculation of *T. harzianum* did not favor the increase in fruit quality, this result contrasts with that reported by Cristóbal-Alejo et al. (2021), who reported that the inoculation of *T. harzianum* and *T. virens* in *C. chinense* plants increases the number and weight of fruits by 30.7 and 24.1 %, compared to the control. In another study, Murillo-Cuevas et al. (2021) inoculated a commercial strain of *T. harzianum* (PHC®, T22) in *C. chinense* Jaguar variety plants and reported that the length, width, and weight of the fruits increased from 3.53 to 4.13 cm, 2.82 to 3.12 cm, and 8.27 to 10.18 g, respectively, because of the inoculation. The variation of the results of this study to the previous ones, where fruit quality was improved, may be due to the specificity of the *Trichoderma* species and its host (plants), since it has been shown that *T. virens*, as well as other species, differentially express genes that encode different proteins depending on the host plant (Morán-Diez et al., 2015).

Table 4
Fruit quality of *Capsicum chinense* "Megalodon" hybrid inoculated with *Trichoderma harzianum* and pruned at three and four stems

Factors	Width (mm)	Length (mm)	Weight (g)
T. harzianum			
Inoculation	30.96 b	45.47 b	12.97
Non inoculation	33.37 a	48.58 a	13.19
Pruning			
Three stems	32.27	48.18	13.57 a
Four stems	32.05	45.87	12.59 b
Treatments			
+ Th + three St	30.60 b	47.79 ab	13.47
- Th + three St	33.94 a	48.56 a	13.67
+ Th + four St	31.31 ab	43.15 b	12.48
- Th + four St	32.80 ab	48.59 a	12.70
P-values			
T. harzianum	0.0012	0.0330	0.6435
Pruning	0.7696	0.1128	0.0348
Treatments	0.0068	0.0225	0.1970

Means with different literals are significantly different from each other, according to Tukey's multiple range comparison (P = 0.05). Th = *Trichoderma harzianum* and St = stem.

The results of this investigation, in relation to the increase in the weight of the fruits of *C. chinense* due to pruning at three stems, were like those reported by Bartz et al. (2017), who reported that the Duch V3 pruning (9.6 g) allows heavier fruits than the Spanish pruning (8.2 g). However, the Duch V3 pruning (201 fruits plant^{-1}) generates a smaller number of fruits compared to the Spanish pruning (381 fruits plant^{-1}). Recently, Vasquez-Velazquez et al. (2022) evaluated the effect of pruning at two, three and four stems on fruit quality and yield of *C. chinense*. However, the authors reported that they found no significant differences both in fruit quality and yield by the pruning effect, the fruits weighed 8.57 g and measured 3.11 and 3.06 cm of length and width, respectively. On the contrary, Lopes-Gómez et al. (2020) reported that pruning at three stems in *C. chinense* Jaguar variety increases the length and width of the fruit in 43.0% and 23.7%, respectively. Even though no significant differences were observed in fruit weight. The pruning of greenhouse-grown pepper plants reduces the number of stems so that light interception through the canopy would be increased thereby improving fruit set and fruit quality (Bartz et al., 2017). However, this is not a general rule, since only the weight of the fruit was increased and not the length and width.

3.4. *Capsicum chinense* yield

The inoculation of *T. harzianum* in *C. chinense* plants did not improve yield, in average the plants produced 563.09 g per plant and 12.56 t ha^{-1}, in the four harvests carried out during the experiment (Table 5). However, the pruning factor did increase yield, plants pruned at three stems produced 628.31 g plant^{-1} and 14.02 t ha^{-1}, 26.3% more compared to plants pruned at four stems (497.56 g plant^{-1} and 11.10 t ha^{-1}, Table 5).

Table 5
Yield of *Capsicum chinense* var. "Megalodon" plants inoculated with *Trichoderma harzianum* and pruned at three and four stems

Factors	Fruits plant^{-1}	g plant^{-1}	t ha^{-1}
T. harzianum			
Inoculation	47.75	585.05	13.05
Non inoculation	43.33	541.13	12.07
Pruning			
Three stems	50.75 a	628.61 a	14.02 a
Four stems	40.33 b	497.56 b	11.10 b
Treatments			
+ Th + three St	55.66 a	689.63 a	15.38 a
- Th + three St	45.83 ab	567.6 ab	12.66 ab
+ Th + four St	39.83 b	480.47 b	10.71 b
- Th + four St	40.83 ab	514.66 ab	11.48 ab
P-values			
T. harzianum	0.2838	0.3891	0.3891
Pruning	0.0140	0.0128	0.0128
Treatments	0.0336	0.0291	0.0291

Means with different literals are significantly different from each other, according to Tukey's multiple range comparison (P = 0.05). Th = *Trichoderma harzianum* and St = stem.

In the case of the treatments, the plants inoculated with *T. harzianum* and pruned at three stems achieved the highest yield (689.63 g plant^{-1} and 15.38 t ha^{-1}) compared to the treatment with plants inoculated with *T. harzianum* and pruned to four stems (480.47 g plant^{-1} and 10.71 t ha^{-1}, Table 5).
The results found in this study differ with those of Candelero et al. (2015), who reported that the co-inoculation of *Trichoderma* sp. (Th05-02) and *Trichoderma koningiopsis* (Th41-11) increased the number of fruits and yield (g per plant) of *C. chinense* plants by 49.5% and 60.8%, regarding to the un-inoculated plants. In the same way, Murillo-Cuevas et al. (2021) informed that the inoculation of *T. harzinaum* (T22, PHC®) (10.18 g fruit^{-1}) increased the fruit weight of *C. chinense* Jaguar variety (8.27 g plant-1) in 23.0 %. In *C. annuum* (Serrano chilli pepper) has been reporter too that the inoculation of *Trichoderma* sp. increased the yield from 5.98 to 15.67 and from 5.15 to 15.67 t ha^{-1} in HS-52 and Centauro hybrids (Espinoza-Ahumada et al., 2019).
In this study, *C. chinense* pruned plants at three stems increased its yield in fruit weight (25.8 %), g plant^{-1} (26.3 %) and t ha^{-1} (26.3 %), contrary to reported by Bartz et al. (2017), López-Gómez et al. (2020), and Vasquez-Velazquez et al. (2022) in *C. chinense*. In this sense, the non-pruned plants achieved the bets yield (190.0 fruits plant^{-1} and 1220.0 g plant^{-1}) in comparison to the pruned plants at three stems (35.0 fruits plant^{-1} and 313.0 g plan^{-1}, Bartz et al., 2017). In other study by López-Gómez et al. (2020) informed that the pruned plants at three stems achieved the lower (68.6 fruits plant^{-1}) yield in comparison to unpruned plants (278.6 fruits plant^{-1}). More recently, Vasquez-Velazquez et al. (2022) reported that there were not significant differences in the yield of *C. chinense* plants pruned at two (148.03 fruits plant^{-1} and 1279.7 g plant^{-1}), three (165.5 fruits plant^{-1} and 1357.0 g plant^{-1}) and four stems (152.6 fruits plant^{-1} and 1293.0 g plant^{-1}).
Probably, this discrepancy in the results is due to the varieties or hybrids, which have been genetically selected for certain characteristics such as resistance to pests (i. e. *Bemisia tabaci*) or tolerance to heavy soils. Some studies cited here are developed with varieties that adapt to specific regions such as the northeast (Jaguar variety, López-Gómez et al., 2020) and southeast (*C. chinense* landraces, Chiquini-Medina et al., 2019; Vasquez-Velazquez et al., 2022) of Mexico.
Likewise, we do not rule out the possibility that the plant trilling, which consists of guiding the branches (or stems) of the *C. chinense* plant upwards, is playing an important role in crop yield. The most common trilling in *C. chinense* is Dutch and Spanish. The Dutch trellis consists of vertical threads, one thread for each branch (or stem), which allows rapid growth of the stem and short or long bifurcations, depending on the amount of light that exists in the greenhouse. While the Spanish trellis consists of horizontal threads that support the stems (or branches) to support the weight of the fruit (Jovicich et al., 2003). Finally, factors such as the inoculation of microorganisms that promote plant growth, the types of pruning, tutoring and varieties must be considered through interactions to find the optimal systems that allow a higher yield for *C. chinense*.

4. Conclusions

The inoculation of *T. harzianum* increased the plant height and the stem diameter of *C. chinense*; however, it did not increase the variables of fruit quality and yield. The type of pruning at three stems increased plant height and improved fruit quality variables and yield (t ha^{-1}) of *C. chinense* plants. Finally, the best treatment was the inoculation of *T. harzianum* in plants with pruning at three stems, which allowed greater plant height and better results in fruit yield in fruits plant^{-1}, g plant^{-1} and t ha^{-1}.

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