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Trichoderma erinaceum AND *Trichoderma virens* IN THE CONTROL OF *Meloidogyne incognita* IN *Solanum lycopersicum*

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ABSTRACT

In this study, the antagonistic potential of *Trichoderma erinaceum* 10-15 and *T. virens* 32-09 against the nematode *Meloidogyne incognita* was evaluated in tomato (*Solanum lycopersicum* L.) plants. A solution of 10^6 conidia mL^{-1} of each strain was inoculated on tomato plants, and the variables of nematode control, galling index, eggs per gram of root, and females per gram of root were determined. The *in vitro* antagonism of *Trichoderma* filtrates on the hatching of eggs and J2 juveniles of *M. incognita* was evaluated. The results were used for analysis of variance and comparison of means using the Tukey method ($p \leq 0.05$). Control variables of the phytopathogen on *S. lycopersicum* were determined by measuring the area under the disease progress curve (AUDPC), the Weibull parameter, the coefficient of determination, and the final severity of root damage. *T. erinaceum* 10-15 showed a greater inhibitory effect on *M. incognita*, relative to *T. virens* 32-09. Both strains evaluated showed significant differences in comparison to the uninoculated control, resulting in a 60 % reduction in juvenile stage mobility and egg hatching, as well as greater control of the phytonematode in the AUDPC variables, Weibull parameter, and final severity under controlled conditions. The strain *T. erinaceum* 10-15 showed a better antagonistic effect on egg formation at 68 days, at 60.3 %, and on reducing the number of *M. incognita* females with at 60 days, at 80.6 %. Both *T. erinaceum* 10-15 and *T. virens* 32-09 were found to be potential biocontrol agents of *M. incognita* in *S. lycopersicum*.

Key words: galling, filtering, nematode, severity, tomato.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the vegetables with the highest demand worldwide, where Mexico is the main supplier of exports. However, in recent years, the total area of the crop has decreased (SIAP, 2020) due to production losses from diseases caused by fungi, viruses, bacteria, and nematodes, the latter with a wide geographical distribution and host range (Mukhtar *et al*., 2018).

Parasitism caused by nematodes is a devastating and difficult-to-manage problem, as in the case of root-knot nematodes of the genus *Meloidogyne*, which are the most destructive and cause significant crop yield losses (Khan *et al*., 2020). *Meloidogyne incognita* is a polyphagous, obligate endoparasitic, gill-forming nematode on plant roots and is considered one of the most damaging agents for crops worldwide (Fan *et al*., 2020) because it reduces plant growth, quality, and yield, and has reduced host resistance to biotic and abiotic stresses. In its juvenile stage, this organism penetrates the root through the cortex, near the elongation zone, and migrates towards the root tips, where it establishes its feeding site, which generates hypertrophy and hyperplasia of the surrounding cells (Temitope *et al.*, 2020), which causes weakening of the tips, inhibition or excessive root stimulation, and also induces the formation of knots or galls in the root system (Martínez-Medina *et al*., 2017).

Several strategies have been developed to control *M. incognita*, the most common of which is the use of chemical nematicides, which are sometimes ineffective (Cristóbal-Alejo *et al*., 2018), as they affect human health and generate resistance. Because of this, it is necessary to implement safe and sustainable alternatives, such as the use of biological controllers through microorganisms, which offer a safe and economically feasible alternative for the control of nematodes (Pocurull *et al*., 2020). Herrera-Parra *et al*. (2017) demonstrated a greater nematicidal effect of *T. atroviride* compared to the chemical Oxamyl 24 % at a dose of 1 mL L^{-1}. *Trichoderma* spp. can be an alternative biocontrol against *M. incognita* by reducing the number of galls, eggs, females, and galling index in *S. lycopersicum* (Candelero *et al*., 2015). In *Capsicum chinense,* it showed similar effects from the nematicide Oxamyl at the same dose. (Herrera-Parra *et al.*, 2018). Moo-Koh *et al.* (2018) evaluated incompatible combinations of *T. citrinoviride* 33-58 and *T. harzianum* 33-59 that, when interacted, showed promising results in reducing *M. incognita*, in addition to improving the growth of *S. lycopersicum*.

The objective of the present study was to evaluate the *in vitro* antagonistic effect of two native species, *T. erinaceum* 10-15 and *T. virens* 32-09 against *M. incognita*, under controlled conditions on *S. lycopersicum* L. plants.

MATERIALS AND METHODS

Trichoderma strains used

The strains *T. erinaceum* 10-15 and *T. virens* 32-09, previously identified (Martinez-Canto *et al*., 2021; Moo-Koh *et al*., 2018), were seeded on potato dextrose agar medium PDA (BD BIOXON, Mexico) (4 g potato infusion, 20 g dextrose, and 15 g agar per L, pH 5.6) for 8 days (d). Then, 5 mm diameter mycelial discs were extracted and deposited in 250 mL Bosch bottles (PYREX®, Czech Republic) with the potato-dextrose broth culture medium CPD (SIGMA-ALDRICH, Saint Louis, MO, USA) (300 g potato and 20 g dextrose per L, pH 6.8). Cultures were maintained at 30 °C without shaking for 27 d. The culture supernatant was filtered with sterile gauze and centrifuged (SOLBAT C600, Mexico) at 3000 rpm for 10 min, subsequently filtered with Whatman No. 1 paper and finished with a 0.45 μm millipore filter (Fisherbrand, Ireland); filtrates were deposited in sterile 50 mL Falcon tubes and stored at 4 °C until use (Candelero *et al*., 2015).

Obtaining of *Meloidogyne incognita*

Egg masses were obtained from galled roots of *S. lycopersicum* that were disinfected with 1 % sodium hypochlorite (NaClO) for 2 min before being washed with potable water in sieves with 300 and 400 mesh numbers (FIIC S. A. de C. V., Mexico) to remove excess NaClO and incubated at 30 °C until J2 hatching (Cristóbal-Alejo *et al*., 2018). The *M. incognita* species was confirmed through perineal patterns of females and morphotaxonomic characterization (Jepson, 1987), for which a compound microscope (LABOMED Lx500, USA) was used.

Antagonistic effects of *Trichoderma* on the immobility of J2 of *Meloidogyne incognita*

The assay was carried out using a siracusae, 2.5 cm wide by 3 cm high, with 100 μL of the filtrate of the cultures of *T. erinaceum* 10-15 and *T. virens* 32-09, and 900 μL of esteril distilled water, to which 20 viable J2 nematodes of *M. incognita* were added. The nematostatic effect was determined at 72 h under laboratory conditions with an environmental temperature of 30 °C. Sterile distilled water was used as a negative control, and the commercial product Oxamyl 24 % (Vydate®, Dupont, Mexico) was used as a positive control at a concentration of 1 mL L^{-1}. Using a stereoscopic microscope (Leica ZOOM 2000, Buffalo, NY, USA) and with the help of a brush, the immobility of the nematode was corroborated when stimulated in the cephalic region, and, when no response to the stimulus was presented, it was considered immobile (Cristóbal-Alejo *et al*., 2018), the percentage of immobility was calculated according to the formula proposed by Abbott (1925).

In vitro effect of *Trichoderma* on hatching inhibition of *M. incognita* eggs

In this assay, 100 μL of the filtrates of *T. erinaceum* 10-15 and *T. virens* 32-09 were added to the siracusae. Five egg masses of *M. incognita* were placed in each egg mass, and the ability to inhibit egg hatching was evaluated with the aid of a stereoscopic microscope. Hatched juveniles were counted at 7, 14, and 21 days after hatching (dah) to fungal filtrates. Sterile distilled water was used as a negative control and the commercial product Oxamyl 24 % at a concentration of 1 mL L^{-1} was used as a positive control (Moo-Koh *et al*., 2018), the percentage of hatching inhibition was calculated according to the formula of Abbott (1925).

Effect of *Trichoderma* spp. on *M. incognita* in *S. lycopersicum*

To evaluate the level of antagonism of *Trichoderma* strains on *M. incognita* on *S. lycopersicum*, a suspension of 10^6 conidia mL^{-1} of *T. erinaceum* 10-15 and *T. virens* 32-09, obtained from mycelium grown in Petri dishes on potato dextrose agar medium PDA (BD BIOXON, Mexico) for 8 d, was prepared. At the time of transplanting *S. lycopersicum* plants from the seedbed to plastic pots (capacity 8 kg) with previously homogenized soil, inoculations of 10^6 conidia mL^{-1} of each strain were made directly at the base of the stem, which was maintained with daily irrigation. The commercial product Oxamyl 24 % was used as a positive control, dosed at 1 mL L^{-1} at the time of transplanting, and sterile distilled water was used as a negative control, without the application of conidia. Two more applications of the same concentration (10^6 conidia mL^{-1}) of *Trichoderma* were made at 15 and 30 days after transplanting (dat). Each treatment included 10 replicates, homogeneously distributed in a completely randomized design under protected conditions (Moo-Koh *et al*., 2018).

Estimation variables in the control of nematodes

Galling index

The galling index was determined at 68 dat, estimated using the severity scale proposed by Taylor and Sasser (1978), where root damage was evaluated: 0 = healthy root system, 1 = 1 to 10 % small galls present in the root system, 2 = 11 to 25 % severely galled root system, 3 = 26 to 50 % severely galled root system, 4 = 51 to 75 % severely galled root system, and 5 = 76 to 100 % severely galled root system with sparse healthy roots (Moo-Koh *et al*., 2018). The galling index test was defined by an analysis of variance that determined the area under the disease progress curve (AUDPC), the distribution parameter of the Weibull model, the coefficient of determination (r^2) and the final disease severity (Y_f).

Eggs per gram of root

To determine the number of eggs per g of root, 2 g of fragmented galled roots were cut, homogenized, and one gram of the sample was taken and liquefied in 30 mL of 2 % NaClO for 10 s. In order to recover the eggs, the mix was sieved successively in sieves of 50, 100, 200, 325, and 500, respectively. They were rinsed in running water and counted using compound microscopy with the aid of a nematode counting chamber (Cristóbal-Alejo *et al*., 2018).

Females per gram of root

To determine the variable of the number of adult females per root, 1 g of root was stained with 4 mL of acid fuchsin (Analytyka, Mexico) in 50 mL of distilled water until boiling point for 10 min. The mix was left to cool at room temperature. A series of washes with running water were made, and these were deposited in flasks with 78 % glycerin (Golden Bell, Mexico). Using stereoscopic microscopy, roots were dissected and adult females were counted (Moo-Koh *et al*., 2018).

Statistical analysis

For the analysis of the effect of *Trichoderma* spp. on J2 immobility and inhibition of *M. incognita* egg hatching, each treatment consisted of five replicates (five siracuses). With the data obtained, analysis of variance and comparison of means were performed using Tukey's test ($p \leq 0.05$) with the help of the InfoStat 2019 program.

To determine the estimation variables in nematode control, each treatment (*T. erinaceum* 10-15, *T. virens* 32-09, Oxamyl, and distilled water) consisted of 10 replicates, distributed in a completely randomized design. The data obtained were analyzed in SAS version 9.0 software for analysis of variance (ANOVA) and the separation of means was performed using Tukey's test ($p \leq 0.05$). The measurements of the variables recorded were determined in triplicate and calculated separately. Using SAS software, the galling index test was defined using an analysis of variance ($p \leq 0.05$) that determined the area under the disease progress curve (AUDPC), the distribution parameter of the Weibull model, the coefficient of determination (r^2), and the final disease severity (Y_f).

RESULTS AND DISCUSSION

Antagonistic effect of *Trichoderma* on the immobility of J2 of *M. incognita*

Differences were observed in the mobility of J2 at 72 h of exposure to the filtrates of the *Trichoderma* strains compared to the control; however, they were lower than those shown by the commercial product Oxamyl. Between the two *Trichoderma* strains, no significant differences were found, since *T. erinaceum* 10-15 showed an efficiency of 76 % of immobility and *T. virens* 32-09 had 64 %, while the chemical product (Oxamyl) showed a total capacity in the percentage of immobility of the J2 of *M. incognita*, while the control indicated a value of 1.6 % (Table 1).

Table 1. *In vitro* antagonistic effect of *Trichoderma* spp. filtrates on *M. incognita.*

Treatment	J2 immobility at 72 h (%)	Inhibition of egg hatching at day 7 (%)
Oxamyl	100.0 a	100.0 a
T. erinaceum 10-15	76.0 ab	84.2 a
T. virens 32-09	64.0 b	63.3 a
Control	1.6 c	0.0 b

a,b,c Means with different letters are statistically different (Tukey, $p \leq 0.05$).

In similar assays against second instar larvae of *Meloidogyne* sp., Xalxo *et al*. (2013) reported that *T. viride* filtrates, isolated from agriculturally active soil, had an immobilization capacity on juveniles of 65 % at 48 h, and 93.7 % at 72 h. Similarly, *T. harzianum* has been reported to possess nematicidal activity from the first 24 h of exposure as it showed significant antagonistic effects on *M. incognita* juveniles (Pinzón-Espinoza *et al*., 2015); these results match with those reported by Sellami *et al*. (2017), who showed that *T. harzianum* Th.6 and *T. atroviride* Ta.13 possess significant mortality rates of juveniles at three different concentrations evaluated, where the most effective was *T. harzianum* (71.9 %) with 100 % filtrate, while *T. atroviridae* had an effectiveness of 56.94 %. Zhang *et al*. (2015) determined the antagonistic capacity of different concentrations of *T. longibrachiatum* on J2 of *M. incognita*, demonstrating a linear relationship between the lethal effects of this antagonist and the juvenile stage of the phytoparasite, as higher concentrations of *T. longibrachiatum* increased the mortality rate of J2 of *M. incognita.*

It is known that the antagonistic capacity of filtrates, more than the species itself evaluated, is associated with the type of strain, the element composition of the substrate used for its growth, and the exposure time of the J2 of *M. incognita* to the volatile and non-volatile secondary metabolites contained in *Trichoderma* filtrates, such as peptaibols, siderophores, policetides, and terpenoids (Fan *et al*., 2020). In the working group, previous trials have been conducted with the strain *T. virens* 32-09, where the antagonistic effect against *M. incognita* in tomato was determined (Pinzón-Espinoza *et al*., 2015; Moo-Koh *et al*., 2018). It has also been shown that residual filtrate fractions of *T. virens* 32-09, at a concentration of 100 %, presented a mortality of 83 % on *M. incognita* juveniles at 72 h, while the antagonistic effect of ethyl acetate fractions from this same strain registered a mortality of 100 % against *M. javanica* juveniles, also at 72 h (Moo-Koh *et al*., 2022). These differences in sensitivity in the behavior of different nematode species, or even between different populations of the same species, are attributed to various exposure conditions, both in their habitat and the environment in which they develop (Nourani *et al*., 2015). No studies were found evaluating the antagonism of *T. erinaceum*, so the use of this species as a potential biological controller of *M. incognita* was considered.

***In vitro* inhibitory effect of *Trichoderma* on hatching of *M. incognita* eggs.**

The egg hatch inhibition parameter indicates the ability to reproduce and could be interpreted as a decrease of the phytonematode in the field (Cristóbal-Alejo *et al*., 2018). At 7 d, a significant difference between treatments was observed because the filtrate of strain *T. erinaceum* 10-15 had a percentage inhibition of egg hatching of 84.1 %, followed by strain *T. virens* 32-09 with 63.3 %. The commercial nematicide Oxamyl showed 100 % hatch suppression (Table 1). Sellami *et al.* (2017) determined that *T. harzianum* Th.6 filtrate was the most effective in suppressing *M. incognita* egg hatching after 8 d of exposure, comparable to those used in the present study. Hernández-Ochandía *et al.* (2015) demonstrated the parasitic capacity of *T. asperellum Ta*. 90 on eggs of *M. incognita* race 2 using microscopy, indicating that the fungus is capable of penetrating and damaging the egg contents, generating dark spots characteristic of parasitism, as well as emerging hyphae, which caused the embryos to die.

Similar percentages to those obtained in this study were reported by Fan *et al.* (2020) when evaluating the ovicidal capacity of *T. citrinoviride* Snef1910, indicating that it had an inhibition in the hatching of *M. incognita* eggs higher than 90.2 % at 48 h, since it maintained its ovicidal potential on *M. incognita* eggs for approximately 96 h. An increase in enzymes (chitinases and proteases) prevented hatching by parasitizing the different layers that protect the embryo inside the egg, such as vitellin and chitin, which, together with primary, secondary metabolites and various active compounds, give *Trichoderma* its antimicrobial and biocontrol properties (Zhang *et al*., 2015; Benttoumi *et al*., 2020).

Variables in nematode control

Galling index

To evaluate the galling index, a comparison was made between the roots of the different treatments by analysis of variance ($p \leq 0.05$). Differences between treatments were observed, as well as a correlation between the different parameters of epidemic intensity. The AUDPC values fluctuated between 817.1 of the negative control and 310.4 of the positive control (Oxamyl). The two *Trichoderma* strains did not show significant differences in this value; however, *T. erinaceum* 10-15 showed the greatest effect with a value of 539.0 (Table 2). As for the Weibull parameter, Oxamyl recorded the lowest value (0.0100), followed by *T. erinaceum* strain 10-15, with 0.0109. A relationship

Table 2. Variables in the control of the severity of *M. incognita* in tomato plants inoculated with *Trichoderma* spp.

Treatment	AUDPC (% unit day^{-1})	Weibull	r^2	Y_f (%)
Oxamyl	310.4 a	0.0100 a	0.9983	16.6 a
T. erinaceum 10-15	539.1 b	0.0109 a	0.9675	27.7 ab
T. virens 32-09	581.4 b	0.0123 ab	0.9960	35.8 b
Control	817.1 c	0.0145 b	0.8363	60.2 c

a,b,c Means with different letters are statistically different (Tukey, $p \leq 0.05$). r^2: coefficient of determination; Y_f: final disease severity.

between r^2 and Y_f was also observed in the *Trichoderma* treatments, where *T. erinaceum* 10-15 was the strain that achieved a decrease in the galling index with a coefficient of determination of 0.9675 and a final severity of 27.7 (Table 2).

The variability of the results obtained in this work could be due to the interaction of the different *Trichoderma* strains with the pathogenic capacity of the nematodes, the origin of the isolates, genetic variability, or efficiency of the antagonists to parasitize the nematodes. These results are in agreement with those reported by Al-Hazmi and TariqJaveed (2015), who indicated that higher concentrations of *T. harzianum* and *T. viride* persistently and significantly suppressed the gilling index of *M. javanica* in tomato, in addition to the number of eggs and juveniles, where it was found that *T. harzianum* was able to suppress the reproductive characteristics of the nematode.

Some *Trichoderma* species have been shown to have the ability to induce systemic resistance in plants through an early increase in transcript levels of jasmonic acid marker genes (Babu and Kamra, 2021). Martínez-Medina *et al*. (2017) pointed out that *T. harzianum* T78 could limit the infection cycle of *M. incognita*, as it affected galling, fecundity, and invasion in tomato roots. Temitope *et al.* (2020) reported that the higher the application rate of *T. asperellum*, the lower the population of *M. incognita* on *Celosia argentea*. This was due to the fact that *Trichoderma* conidia can adhere to and parasitize the eggs and prevent the mobilization of the juveniles. As they are not present, galling does not occur; therefore, the number of nematodes is directly proportional to the galling index. The antagonism exerted by *Trichoderma* varies according to species and isolate, as different strains show variable controlling activity on *M. incognita* (Moo-Koh *et al*., 2018).

Number of *M. incognita* eggs

At 60 d, strain *T. virens* 32-09 showed a mean egg number of 1756, which represented 67.55 % relative to the control, which had a mean of 5412, while strain *T. erinaceum* 10-15 recorded a mean of 4065, equivalent to 24.88 % (Figure 1). However, at 68 d, the strain *T. erinaceum* 10-15, with a mean of 5808.67, showed a greater suppressive effect on the hatching of *M. incognita* eggs per gram of root with 60.27 %, while the strain *T. virens* 32-09 recorded a suppression of hatching of 20.62 % compared to the control, which had a mean average number of eggs of 14621.33 (Figure 1). On both days, Oxamyl recorded higher hatch suppression. Zhang *et al.* (2015) reported that *T. harzianum* has the ability to decrease both the number of eggs and the galling rate per gram of root of *M. incognita* in a short time; however, such effects tend to decrease in the long term, a result that matches what was observed in the present work with strain *T. virens* 32-09, which up to day 60 showed an ascending effect, but at the conclusion of day 68, a decrease in its ability to suppress egg production was observed.

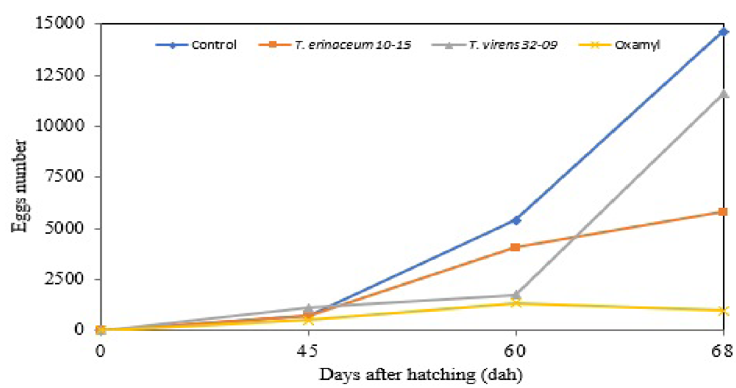

Figure 1. Temporal dynamics of the antagonistic effect of *Trichoderma* inoculum on the number of *M. incognita* eggs in *S. lycopersicum* roots.

On the other hand, strain *T. erinaceum* 10-15 decreased its suppressive capacity, but with a significant difference from the results obtained with strain *T. virens* 32-09. The literature indicates that many factors can contribute to the different levels of efficiency among *Trichoderma* species, such as contact time between antagonist and pathogen, pathogenicity of the fungus, species and origin of the nematodes, climatic adaptability, and crop type influence, among other unknown factors (Zhang *et al*., 2015). Kiriga *et al.* (2018) evaluated the efficacy of three *Trichoderma* species against *M. javanica* on commercial pineapple, *Ananas comosus*, and reported that *T. asperellum* M_2RT_4t reduced the number of galls by 81.8 %, number of egg masses by 78.5 %, and the number of eggs by 88.4 %.

These results suggest that the aggressiveness possessed by each *Trichoderma* species may be influenced by the origin and interaction of various biotic and abiotic factors during its development, as well as the dependent dose of the inoculum, since it has been shown that results obtained in biological control depend on the amount of inoculum applied and the time of exposure to it (Saikia *et al*., 2013). Similarly, when evaluating the antagonistic effectiveness of *T. viride* against *M. incognita* in tomato, it was reported that it is able to reduce the number of galls per plant, egg masses per gall, number of eggs per egg mass, and reproductive factors of the nematode when treating the crop soil with this fungus (Sonkar *et al*., 2018). Previous reports indicated that, although there is no reduction in the nematode galling index and number of galls, a decrease in the number of females and eggs per female is possible, suggesting a better behavior of plants still parasitized by nematodes (Hernández-Ochandía *et al*., 2015). There is evidence that *Trichoderma* is able to activate systemic defense in plants triggered by pests or pathogen attacks, which reduces the possibility of infections as well as the impact of a pest (Martínez-Canto *et al*., 2021; Poveda *et al*., 2021).

Number of *M. incognita* females

Regarding the number of females per gram of root, the analysis of variance showed significant reductions ($p \leq 0.05$) in this variable. At 45 d, no significant differences were observed between the treatments of the two *Trichoderma* strains, but significant differences were observed in relation to the negative control, which recorded an average of 471 females. *T. erinaceum* 10-15 recorded an average of 311.67 eggs, equivalent to 33.82 %, and *T. virens* 32-09 recorded a percentage of 48.05 %, with an average of 244.67 eggs per gram of root; Oxamyl obtained the best effect with 84 % inhibition in hatching (Figure 2). However, at 60 d, the treatment with the best results was strain *T. erinaceum* 10-15 with an average number of females of 43, which corresponds to 80.60 % with respect to the control, which had an average of 221.67 females per gram of root, while *T. virens* 32-09 and Oxamyl obtained percentages of 26.76 and 36.39 %, respectively (Figure 2).

These results agree with Herrera-Parra *et al*. (2017), who reported that *T. atroviride* and *T. harzianum* C1 and C2 performed better against *M. incognita* on *Capsicum annuun* with reductions of 21.90, 14.52, and 8.80 %, respectively, in relation to Oxamyl at 24 % in doses of 1 mL L^{-1} of water. Also, Herrera-Parra *et al*. (2018) demonstrated the ability to

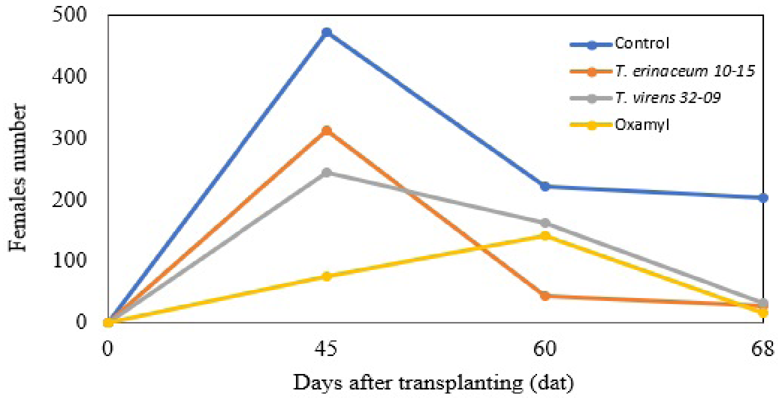

Figure 2. Antagonistic effect of *Trichoderma* on the number of *M. incognita* females at 45, 60 and 68 d on *S. lycopersicum* roots.

reduce the number of females per gram of *M. incognita* in *C. chinense*, indicating that *T. atroviride* and *T. harzianum* C1 and C2 were able to reduce the number of females above 50 % compared to the control, but without exceeding the product Oxamyl at 24 % in doses of 1 mL L^{-1} of water. At the end of 68 d, all treatments achieved a reduction of females greater than 80 % compared to the control, where the best result was Oxamyl with 92.47 %, although among the two strains evaluated, *T. erinaceum* was the best performer with 86.74 % (Figure 2).

Applications with *T. harzianum* and *T. virens* also achieved a decrease in the number of *M. incognita* females in tomato crops, with a percentage higher than 80 % (Pinzón-Espinoza *et al*., 2015; Cetz-Chi *et al*., 2018). Medeiros *et al.* (2017) reported that *T. atroviride* is able to activate a defense system in response to the attack of *M. javanica* on tomato plants, where the number of adults and galls was significantly reduced, even without establishing direct contact with the nematode. These results coincide with those obtained in this work, where a reduction of the nematode was observed before the inoculum of *Trichoderma* due to the effect exerted by this fungus against phytonematodes. This could be explained as the result of the production of diverse non-volatile metabolic compounds of enzymatic type, which are capable of exerting a defense response by hydrolyzing the main component of the nematode walls, besides increasing the production of phenolic compounds that intervene in the systemic resistance.

CONCLUSIONS

The *Trichoderma* species evaluated in this work, *T. erinaceum* 10-15 and *T. virens* 32-09, were able to reduce juvenile mobility at 72 h and egg hatching at day seven by more than 60 %. *T. erinaceum* 10-15 stood out in both variables, with values of 76 and 84.17 %, respectively. Regarding the results obtained in the galling index, both strains achieved similar performances in terms of ABCPE, Weibull parameter, and final severity; however, the antagonistic effect on egg formation at 68 d was better for *T. erinaceum* 10-15 (60.27 %) than *T. virens* 32-09 (20.62 %). *T. erinaceum* 10-15 had a similar performance, reducing the number of *M. incognita* females by 80.60 % at 60 d, surpassing the commercial control Oxamyl and which led to the conclusion that under optimal conditions, the *Trichoderma* strains used in this research could have better results than the commercial chemical products.

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