



## Spent substrate of *Pleurotus ostreatus* as a nematicide of *Nacobbus aberrans* in chili pepper (*Capsicum annuum*) plants

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### ABSTRACT

**Background/Objetivo.** The chili pepper (*Capsicum annuum*) is one of the most important agricultural crops in Mexico. Due to this, the aims were to determine the *in vitro* effect of the spent substrate by the edible fungus *P. ostreatus*, strain HEMIM-50, (SSPO) against *N. aberrans* and evaluate the *in situ* effectiveness of the SSPO against *N. aberrans* in chili pepper plants.

**Material and methods.** For the *in vitro* test, six serial concentrations of the hydroalcoholic extract (SSPO), ranging from 0.62 to 20 mg mL<sup>-1</sup> against *N. aberrans* juveniles. An ANOVA was carried out, followed by Tukey's means comparison test (p<0.05), adjusted with Schiller-Orelli. For the *in situ* assay with chili pepper plants, three treatments were evaluated: control (Peat moss), nematicide (Peat moss + Fluopiram) and SSPO (Peat moss 80% + SSPO 20%) and galls, egg masses and eggs per gram of root were measured after 45 days. The data were analyzed using the GLM and LSD tests to compare the means of each treatment. All statistical analyses were analyzed in the Statistical Analysis System program, SAS 9.0.

**Results.** The highest percentage of mortality was obtained with 20 mg mL<sup>-1</sup> of the SSPO with a mortality of 98% of mortality and had no significant difference with the positive control with Fluopiram (p<0.05), followed by a mortality of 88.3% with the treatment at 10 mg mL<sup>-1</sup>. In the *in situ* evaluation in a combination of Peat moss 80% + SSPO 20%, a reduction of 82% in the number of galls was observed, along with 99% in the mass of eggs and 98% in the number of *N. aberrans* in comparison with the control with Peat moss. There were no significant differences (0.0<sup>b</sup>) with the combination of Peat moss + Fluopiram commercial nematicide (Tukey, p<0.05).

**Conclusion.** The spent substrate by *P. ostreatus* (SSPO) had an *in vitro* nematocidal activity (98%) against juvenile *N. aberrans* nematodes; in addition, the input in which the fungus was planted presented a reduction in galls of 82% and 98% for *in situ* *N. aberrans* egg mass that infected the chili pepper crop.

**Keywords:** Biocontrol, Spent substrate, Phytonematodes, Edible fungi

## INTRODUCTION

The false root-knot nematode (*Nacobbus aberrans*) is one of the 10 main phytoparasites with the greatest economic importance due to its wide range of hosts (Jones *et al.*, 2013). The main crops it affects are the potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), beet (*Beta vulgaris*), chili pepper (*Capsicum annuum*), bean (*Phaseolus vulgaris*), cucumber (*Cucumis sativus*) and eggplant (*Solanum melongena*) (Manzanilla-López *et al.*, 2002). The losses it generates vary according to the host: 35% in bean, between 50 and 90% in tomato, 80% in potato, and in the chili pepper crop, the economic losses in Mexico are not recorded (Toledo *et al.*, 1992; Cristóbal-Alejo *et al.*, 2006). The chili pepper is a crucial crop in Mexican agriculture, not only for its high commercial value, but also for its impact on the diet and culture of the country. In 2020, Mexico was positioned as the world's second largest producer of chili pepper, with a harvest of 3,324,260 tons, increasing by 2.7% from the previous year (SADER, 2021). The use of *C. annuum* as a model plant for the study of *N. aberrans* is of great importance, due to the susceptibility of this phytoparasite and its economic relevance in Mexico. In diverse producing areas, the presence of this nematode can be a significant threat for yields, making it crucial to develop effective strategies for its control and handling crucial.

An alternative for the biocontrol of the nematodes is the use of edible fungi (EF) with nematocidal activity. In this regard, according to Li and Zhang (2014), there are 280 species belonging to 150 genera that display nematocidal activity, particularly against nematodes of agricultural importance, such as *Meloidogyne incognita* and *N. aberrans* (Rodríguez-Barrera *et al.*, 2021). The nematocidal activity found in the EF is related to compounds such as proteases (aspartic proteases), fatty acids (pentadecanoic acid, palmitic acid,  $\beta$ -sitosterol, stearic acid and linoleic acid), and secondary metabolites such as alkaloids, sesquiterpenoids, as well as other phenolic compounds (Beltrán-Delgado *et al.*, 2013; Carrillo-Lara *et al.*, 2017; Pineda-Alegría *et al.*, 2020).

In the process of production of the EF *Pleurotus ostreatus*, there is a subproduct called a spent substrate (SSPO), a term used in this study to refer to the organic subproduct generated by *P. ostreatus* (De León-Monzón *et al.*, 2004). The lignocellulosic biomass formed in the EF crop is composed mainly of lignin (5–35%), cellulose (9–80%) and hemicellulose (10–50%), and its biodegradability is highly influenced by the inputs that it is made up of (Aguilar-Marcelino *et al.*, 2024). Regardless of the substrate, SSPO has been reported to contain toxic compounds against nematodes of agricultural importance. Diverse authors have observed the predatory ability of the fungal mycelia, observing structures able to immobilize nematodes and later colonize them (Luo *et al.*, 2007; Armas-Tizapantzi *et al.*, 2019). This has been observed in free-living nematodes and in parasites of plants such as *Heterodera schachtii*, predated by the fungus *P. sajor-caju* (Palizi *et al.*, 2009).

In another context, the infection of the J2 of the root-knot nematode *Meloidogyne javanica* by the mycelium of the edible fungus of *Pleurotus* has been observed; in addition, their mycelia displayed nematocidal and nemostatic activity against *M. javanica* (Hahn *et al.*, 2019). Among the compounds found in the SSPO with the greatest nematocidal activity are the esters of fatty acids related to the mycelia (Chegwin and Nieto, 2013), phenolic compounds (Aslam and Saifullah, 2013), toxins (trans-2-decenodioic acid) (Abbasi *et al.*, 2014), and enzymes (proteases) (De Freitas-Soares *et*

*al.*, 2019). Likewise, SSPO has been observed to have antagonistic activity against phytopathogens. Such is the case of the suppressive effectiveness of SSPO on the inhibition of the growth of *Fusarium oxysporum* (Yusidah and Istifadah, 2018). Moreover, the aqueous extract of the spent substrate by *Lyophyllum decastes* was effective in the control of the anthracnose induced by *Colletotrichum orbiculare* in the cucumber crop (Parada *et al.*, 2011). On the other hand, the activation of defense mechanisms in chili pepper plants infected with *Phytophthora capsici* was estimated when these were confronted with aqueous extracts of the fungus *Lentinula edodes* (Kang *et al.*, 2017). Therefore, the aim of this investigation was to determine the *in vitro* effect of the SSPO hydroalcoholic extract against *N. aberrans* larvae, as well as to evaluate the *in situ* effectiveness in chili pepper (*C. annuum*) plants as an alternative for the biocontrol of the of the false root-knot nematode *N. aberrans*.

The strain of the fungus *P. ostreatus* (HEMIM-50) was provided by the Biological Research Center of the Universidad Autónoma del Estado de Morelos (CIB-UAEM). The inoculant was obtained from a pasteurized wheat seed and inoculated with mycelium fragments, grown for 21 days at 27 °C, a photoperiod of 12:12 h of light:darkness, 80-90% of relative humidity and forced ventilation. Wheat (*Triticum aestivum*) straw, where the fungus had grown, was pasteurized. Initially, water (133 L) was heated (75-80 °C), 1 kg of lime and 500 g of gypsum were added until they dissolved and the straw was submerged for one hour. Once pasteurization was complete, the excess moisture was drained from the substrate. The pasteurized and hydrated straw (70%) was placed in plastic bags along with the seed, where layers of substrate and seed colonized with mycelium were alternated, and incubated (25 °C) for 20 days in the dark (Sánchez, 2010).

After obtaining the fruiting bodies, the SSPO was dehydrated in the dark, supplying air currents until a constant weight was reached. The SSPO was stored in sterile bags in refrigeration (4 °C) until use to avoid contamination by microorganisms that could affect the physical and chemical properties (Postemsky and López-Castro, 2016). To obtain the hydroalcoholic extracts (70%), alcohol was added (1:3 g/v) to the SSPO and left to macerate for 24 h at 25 °C. It was subsequently filtered and concentrated using a rotaevaporator, then lyophilized to dry and stored at 4 °C until use (Pineda-Alegría *et al.*, 2017).

The *N. aberrans* inoculant was obtained from a pure population with galled tomato (*Solanum lycopersicum*) roots, which were collected in the Colegio de Postgraduados, Montecillo Campus, State of Mexico, Mexico. Eggs were obtained using the method described by Babaali *et al.* (2107). The fresh eggs were incubated at 27 °C for eight days in Petri dishes with sterile distilled water until hatching and juveniles were obtained in the second stage (J2) (Vázquez-Sánchez *et al.*, 2018).

The seeds from chili pepper var. California Wonder, susceptible to *N. aberrans*, were disinfested with sodium hypochlorite at 1% for 1 min, then rinsed, dried and placed in Petri dishes on paper towels, dampened with sterile water, and germinated at 27 °C. after the seedlings had remained on the Petri dishes for 60 days, they were transplanted into 1kg pots containing the treatments to be evaluated *in situ* and left for 30 days before establishing the experiment. They were kept under greenhouse conditions and irrigated on a daily basis until three pairs of true leaves developed (seven weeks of age). Thirty days after the transplant of each chili pepper plant, they were inoculated with 2 mL of water containing 2000 J2 on the base of the stem with a hypodermic syringe and a

moderate irrigation was maintained to guarantee moisture (Chavarro-Carrero *et al.*, 2017).

For the *in situ* evaluation, 1 L pots with a capacity for 10 repetitions were used with each one of the following treatments: T1= control (Peat moss), T2= Nematicide (Peat moss + Fluopiram) and T3= SSPO (Peat moss 80% + SSPO 20%). The variables evaluated were: number of galls, masses of eggs and eggs per gram of root 45 days after inoculation (dai). The number of galls was obtained using a magnifying glass. In order to obtain the number of egg masses, the eggs were submerged in a Floxina B solution (0.15 g L<sup>-1</sup> of water) for 20 min so the egg masses would become stained red and counting them became easier. The dye was removed and counting and they were counted using a magnifying glass. To determine the number of eggs per gram, the method described by Vrain (1977) was used. The count consisted of placing 10 µL aliquots with 10 repetitions per sample observing them under the microscope. Subsequently, the total number of egg masses was divided by the weight of the root in grams. The results were expressed as the number of eggs per gram of root (number of eggs g root<sup>-1</sup>). The assay was carried out under a completely randomized design with seven replicates per treatment and a total of 21 experimental units.

For the *in vitro* tests, 96-well microtiter plats were used, in which six serial dilutions of the hydroalcoholic extract of SSPO were placed at concentrations of 0.6, 1.2, 2.5, 5 and 20 mg mL<sup>-1</sup> in a final volume of 100 µL, each containing 50 *N. aberrans* nematodes (J2). A negative control using PBS (Phosphate-Buffered Saline, pH 7.4) and a positive control using a commercial positive nematicide (Verango Prime®) (50 mg mL<sup>-1</sup> Fluopiram) were included. The bioassay was performed in duplicate using a completely randomized design with four replicates per treatment. The plates were covered with aluminum foil and incubated at 27 °C. Finally, mortality readings were taken 72 hours post-confrontation following the method described by Pineda-Alegría *et al.* (2017).

**Statistical analysis.** All experimental data were analyzed under a completely randomized design. In the *in vitro* tests an ANOVA was performed, followed by a means comparison with Tukey's test (p<0.05), adjusted with Schiller-Orelli. For the *in situ* assay, variances were homogenized, the data transformed by square root (x+1), and analyzed with the General Linear Model (GLM) procedure and Fisher's Least Significant Difference (LSD) to compare the means of each treatment. All analyses were carried out in the Statistical Analysis System program SAS 9.0.

The greatest percentage of mortality of J2 was obtained with the T6 (20 mg mL<sup>-1</sup>) with a mortality of 98% and had no significant difference with the positive control Fluopiram (99.3%), followed by T5, which caused an 88.3% mortality. In the concentrations of 0.6, 1.2 and 2.5 mg mL<sup>-1</sup>, they presented a low percentage of mortality and there were no significant differences between their measurements and the control with PBS (Table 1).

**Table 1.** Mortality of *N. aberrans* (J2) in presence of the spent substrate *P. ostreatus* (SSPO) at 72 h post confrontation.

| Treatments                   | Concentration (mg mL <sup>-1</sup> ) | Adjusted mortality (%) ± SD * |
|------------------------------|--------------------------------------|-------------------------------|
| T1                           | 0.6                                  | 2.8 ± 3.3 <sup>cd</sup>       |
| T2                           | 1.2                                  | 4.6 ± 5.0 <sup>cd</sup>       |
| T3                           | 2.5                                  | 5.0 ± 4.4 <sup>cd</sup>       |
| T4                           | 5.0                                  | 12.0 ± 10.9 <sup>c</sup>      |
| T5                           | 10                                   | 88.3 ± 5.1 <sup>b</sup>       |
| T6                           | 20                                   | 98.0 ± 2.3 <sup>a</sup>       |
| Fluopiram (positive control) | 50                                   | 99.3 ± 1.4 <sup>a</sup>       |
| PBS (negative control)       | 1x                                   | 0.9 ± 1.3 <sup>d</sup>        |

SD=Standard deviation. \* means with different letters are statistically different (Tukey, \**p*<0.05), adjusted with Schiller-Orelli.

In the *in vitro* mortality evaluations performed in this study, the *N. aberrans* population was reduced by up to 98% with the SSPO extract with 20 mg mL<sup>-1</sup>, which suggested that mortality is related to the increase in concentration. This effect may be attributed to the presence of secondary metabolites in the extract, which have been broadly notified for their nematocidal activity. Secondary metabolites such as 1) phenols, 2) flavonoids, 3) saponins and 4) terpenoids may be involved in the depolarization of the cell membrane of the parasitic nematodes, affecting their homeostasis and causing their death. For example, phenols have been notified to induce damage in the cell membranes and alter enzyme activity (peroxidases, cysteine proteases or chitinases), essential for the survival of the nematodes (Chitwood, 2002). Flavonoids have proven to be toxic to diverse nematodes, as they interfere with crucial biochemical processes, such as the inhibition of antioxidant enzymes, which causes oxidative stress (oxygen reactive species) (Chin *et al.*, 2018). Saponins have been identified as disruptors of cell permeability, promoting the lysis of membranes and altering the energetic metabolism of nematodes (Francis *et al.*, 2002). On the other hand, terpenoids have displayed nematocidal activity through the inhibition of motility and the induction of paralysis, probably due to its interaction with neuronal receptors and ionic channels in the cell membrane (Ntalli and Caboni, 2012). In addition, the *in vitro* results of this study were greater than those reported by Hahn *et al.* (2019), with aqueous *P. djamor* and *P. erygii* extracts, where they achieved a mortality of 78 and 90 % in *M. incognita* J2. A CL<sub>50</sub> of 2.7 mg mL<sup>-1</sup> (2.64-2.82) has also been notified when *N. aberrans* J2 larvae were confronted with hydroalcoholic extracts of spent substrate by *P. ostreatus* made up of coffee pulp (*Coffea canephora*), pangola grass (*Digitaria eriantha* Steud) and maize cobs (*Zea mays*) (Cruz-Arévalo *et al.*, 2024).

The *in situ* evaluation of this work with SSPO against *N. aberrans* found that treatment T3 with Peat moss 80 % + SSPO 20 % (v/v) is satisfactory, since the number of galls formed in the root system of the chili pepper plants 45 dai decreased significantly by 82%, the masses of eggs decreased by 99%, and the number of eggs did so by 98% in comparison to treatment T1 (Peat moss), and no significant differences were observed in comparison to treatment T2 (Peat moss + Fluopiram) (Table 2). These results are similar using different percentages of SSPO (30, 50 and 70%), for the control in *Meloidogyne*

spp. In pots in different greenhouse conditions, where the nematode population was reduced significantly by up to 70% (Abbasi *et al.*, 2014).

**Table 2.** *In situ* effect of the spent substrate *P. ostreatus* against *N. aberrans* 45 days after inoculation in chili pepper plants.

| Treatments | Composition of treatments | Galls g root <sup>-1 z</sup> | Eggs mass g root <sup>-1 z</sup> | Eggs g root <sup>-1 z</sup> |
|------------|---------------------------|------------------------------|----------------------------------|-----------------------------|
| T1         | Peat moss                 | 3.5 <sup>a</sup>             | 4.0 <sup>a</sup>                 | 390 <sup>a</sup>            |
| T2         | Peat moss + Fluopiram     | 0.0 <sup>b</sup>             | 0.0 <sup>b</sup>                 | 0.0 <sup>b</sup>            |
| T3         | Peat moss 80% + SSPO 20%  | 0.6 <sup>b</sup>             | 0.3 <sup>b</sup>                 | 6.0 <sup>b</sup>            |

<sup>z</sup>Averages with the same letter indicate that there is no significant difference (Tukey, \*=  $p < 0.05$ ).

With the use of SSPO planted in wheat bran and rice when applying 1200 g m<sup>-2</sup>, the number of *M. incognita* galls and eggs decreased from 86.2 to 80.2% (Mostafa *et al.*, 2019). Other reports have shown that the nematocidal activity of SSPO against *N. aberrans* helps achieve a significant reduction when applying a dose of 10, 20 and 30 g mL<sup>-1</sup> in greenhouse pots with sterilized sandy loam soil (Aslam and Saifullah, 2013). In addition, *in vitro* evaluations reported that a concentration of 10.7 µg mg<sup>-1</sup> of SSPO was effective to reduce the hatching of eggs and eliminating root-knot nematode juveniles.

On the other hand, investigations have been carried out on the use of different agricultural substrates for the plantation of *P. ostreatus*, which may influence the nematocidal activity of the spent substrate. For example, one study evaluated the productive capacity of *P. ostreatus* using dehydrated alfalfa (*Medicago sativa*) as a supplement in different agricultural substrates and found that supplementing with alfalfa increased the biological efficiency and the rate of biodegradation of the substrates (Romero *et al.*, 2018). Another study evaluated the production of *P. ostreatus* in different agroresidual substrates, such as barley (*Hordeum vulgare*) straw, plantain (*Musa paradisiaca*) leaf and maize (*Zea mays*) forage, and found that the mixture of these substrates can influence the production of the edible fungus and, potentially, the properties of the spent substrate (Vázquez-Vázquez *et al.*, 2020). Although these studies do not cover a study on the nematocidal activity of the spent substrate *P. ostreatus* against *N. aberrans*, the search for effective natural inputs is important to reduce the use of commercial nematicides. This step is crucial for a sustainable agricultural production, although it is essential to know how the active metabolites that are present act and to analyze their efficiency under real field conditions.

The results of this investigation allow us to conclude that the SSPO has a nematocidal activity of 98% of *in vitro* mortality against second-stage *N. aberrans* juveniles. Additionally, in the *in situ* assay, the best treatment was the combination of Peat moss 80% + SSPO 20 %, since the number of galls was reduced by 82 % and the number of *N. aberrans* egg masses by 98 %. It is worth pointing out that the wheat straw in which the fungus was grown is an economic input and its residue can be used as a source of secondary metabolites for the control of gall nematodes. Therefore, the results support the potential of SSPO as a sustainable and environmentally friendly tool for the

management of *N. aberrans* affecting chili pepper crops in Mexico, offering natural control alternatives.

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