



Resistance and Application of the Biomass from *Fusarium solani* in the Removal of Pentachlorophenol in Aqueous Solution

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Authors' contributions

This work was carried out in collaboration among all authors. Authors may use the following wordings for this section: Author ARP and Author IAR designed the study, Author JFCG and Author IAR, wrote the protocol, Author ARP, Author DCB, Author METB, and Author VMMJ, wrote the first draft of the manuscript. Author JFCG, Author DCB, Author FNC, and Author IAR, managed the analyses of the study. Author METB, Author IAR, and Author FNC managed the literature searcher. Author ARP, Author DCB, Author VMMJ, and Author IAR, Methodology. Author JTO, Author IAR, supervision. Author METB, and Author IAR, writing, review, and editing. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAMB/2022/v22i630463

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/85828>

Original Research Article

Received 02 February 2022
Accepted 12 April 2022
Published 18 April 2022

ABSTRACT

Recently, the removal and degradation capacity of different environmental contaminants such as heavy metals, organic solvents, oils, plastics, pesticides and herbicides, from sites contaminated by low-cost materials has been studied, with promising results. These adsorbents include agricultural

and industrial waste, clay minerals, live and dead microorganismos, and others materials. The objective of this investigation was study the tolerance and removal capacity of pentachlorophenol by the environmental polluting fungus *Fusarium solani*, by UV-visible spectrophotometry method. The fungal strain grew on LMM supplemented with 80 mg/L of PCP about 6% of growth relative to control (118 mg of dry weight without of pesticide) was obtained. The highest adsorption was obtained at pH 5.0, at 28°C after 24 hours of incubation with 1 g of fungal biomass, and 100 rpm. If we increase the PCP concentration, the removal capacity decrease, and if the biomass concentration is increase, the removal is most efficient, and the laccase activity is increase in presence of 10 mg/L of PCP, with a degradation of 63% at 15 days of incubation.

Keywords: Resistance; *Fusarium solani*; removal; pentachlorophenol.

1. INTRODUCTION

The indiscriminate and uncontrolled use of pesticides causes serious problems for ecosystems and their components such as deterioration of flora, fauna, and aquatic terrestrial, as well as contamination of soil and groundwater. On the other hand, uncontrolled use can generate microorganisms and pests resistant to pesticides, many of which can cause serious health problems for humans [1,2]. Pesticides reaching water bodies by runoff, infiltration, and soil erosion in places where they have applied. They can also be mobilized by both atmospheric transport and by runoff during rainfall or agricultural irrigation and thus transported into bodies of water, both surface and groundwater to pollute water and sediments [1,2].

In the case of Mexico, the use of pesticides shows a behavior that differentiates it from the rest of the world, for example, the three subgroups of pesticides: insecticides, herbicides, fungicides, and bactericides represent practically 100 % of what is consumed in the country, in contrast to 52 % globally [3]. In 2018, in our country it registered a total consumption of pesticides of 53.1 thousand tons, of which 54 % corresponded to fungicides and bactericides, 34 % to insecticides and 22 % to herbicides, and between 1990 and 2018, the growth in Mexican demand for pesticides doubled, and the subgroup of insecticides grew by 122 %, fungicides at 104 %, and herbicides at 72 %. Note that, in Mexico, herbicides have less absolute importance and relative than in the rest of the world [3]. Their most frequency use is in the agriculture, and it is estimated that about 65% of domestic consumption of pesticides applied to combat pests and diseases and prevent crops in corn, sorghum, soybeans, sugar cane, rice, vegetables, and grasses [4].

The pentachlorophenol (PCP) is the third pesticide most used in USA, preceded only by the atrazine and alachlor: its main use is to control termites and is frequently used as a ester (laureate pentachlorophenyl), to protect the wood of the putrefaction by fungus. This is also used as a microbicide for the skin, indoor spraying of railcar shipments formulating solutions insecticides [5]. This is present in the environment and has been detected in different water sources (superficial and rainwater, drinking water, etc.,) sediments in different organisms, soil, and food [5], and it was identified as a priority organic pollutant by the Environmental Protection Agency of the USA [6], because it is very toxic because it uncouples oxidative phosphorylation and forms adducts with DNA, and acute exposure to PCP causes local irritation, systemic effects, allergic reactions, alterations immunological and gastrointestinal and in the case of fatal poisonings have been severe damage to organs such as liver and kidneys. Symptoms of acute poisoning are increased body temperature, profuse sweating, abdominal pain and nausea, damage to the nervous system center and, in extreme cases, cardiac arrest. Too, has been linked with anemia and aplastic leukemia, is neurotoxic, affects the reproductive functions and fetal development, and has found evidence that can bioaccumulate in the human organism [7,8,9].

Pollution of surface waters by PCP is due to direct and nonpoint sources of water as agricultural returns, industrial, and municipal surplus leachate dumps, and landfills downloads. Chlorinated phenolic compounds are present in aqueous effluents of different industrial, such as polymeric resins oil production, oil refining, iron and steel, paints, solvents, pesticides, pharmaceuticals operations and chemical wood preservation [10, 11].

In the literature, there is a variety of adsorbents for the removal of PCP from contaminated niches, like: three strains of *Pseudomonas* (*P. putida* S121, *P. rhizophila* S211, and *P. fuscovagiceae* S115), as bioremediation agents in depletion and detoxification of PCP in soil microcosms [10], the fungus *Aspergillus sydowii* and the plant *Typha angustifolia*, the fungal strain was isolated and identified from agricultural soil irrigated for 20 years with wastewater [12], carbon nanotubes [13], agricultural and industrial wastes [14], Bi₂O₃/TiO₂-montmorillonite nanocomposites [15], activated carbon [16,17], peat [18], modified chitosan [19], the PCP tolerance and removal by *Rhizopus nigricans* [20, 21], the fungi *Byssoschlamys nivea* and *Scopulariopsis brumptii* [22], some fungi strains isolated from the ascidian *Didemnum ligulum*, were evaluated according to their ability to grow in solid culture media (3% malt extract agar) in presence of different concentrations of PCP (10-50 mg/L) [23], the surfactant efficiency on pentachlorophenol-contaminated wastewater enhanced by *P. putida* AJ 785569 [24], *T. angustifolia* concerning PCP tolerance and removal from wastewater [25], the use of dead biomass of fungi like *R. nigricans* and *Rhizopus oryzae* [26, 27], *Trichoderma* and *Cunninghamella* strains [28], *A. niger* [29], *Anthracoxyllum discolor* [30], and *Pleurotus pulmonarius* [31].

Too, PCP is capable of being biodegradable by only a limited number of bacteria and fungi, like: *Acinetobacter* sp., [32], *Bacillus cereus* (DQ002384), two strains of *Serratia marcescens* (AY927692 and DQ002385) [33], *Bacillus* sp., [34], the white rot fungi *Pleurotus chrysosporium*, *Trametes* sp., and *Pleurotus* sp., [35], *Trametes versicolor* [36], *Phanerochaete chrysosporium* [37], *R. nigricans* [38], *T. versicolor* [39], different fungi [40], *Pleurotus ostreatus* [41], different microorganisms [42], and a consortia of specialized microorganisms [43], which, involve the use of lacasse-type enzymes [34, 35, 36, 37, 38, 39, 41, 42, 43]. For the above, the objective of this study was to analyze the capacity of removal of PCP by the fungal biomass of the environmental pollution fungus *F. solani* resistant to PCP, which is of universal distribution, ubiquitous and of great economic importance since this is common phytopathogens [44]. Sometimes he causes infections in the normal patient (keratitis, onychomycosis, etc.) [45]. However, each time describe more serious infections in immunosuppressed patients,

hence its importance has grown exponentially [46].

2. MATERIALS AND METHODS

2.1 Microorganism and Culture Conditions and PCP Resistant Test

We used the phytopathogenic fungus *F. solani*, isolated from a culture of tomato, located in the municipality of Villa de Arista, San Luis Potosí, México. The fungal isolate was routinely maintained in Potato Dextrose Agar (PDA) at 28°C. PCP-resistant tests of the strain, were performed on liquid Lee's minimal medium (LMM) [47], containing the appropriate nutritional requirements and different concentrations of PCP, and determining the dry weight.

2.2 Obtain of the Fungal Biomass and Pentachlorophenol Solutions

For his propagation, were used 1 000 mL Erlenmeyer flasks containing 600 mL of thioglycolate broth (8 g/L). The prepared flasks were inoculated with 1 x 10⁶ spores/mL, and were incubated at 28°C, with constant stirring (100 rpm). After 5 days of incubation, the cells were filtered in Whatman paper No. 1, washed twice with trideionized water, and then dried at 80°C for 12 h in an oven. Finally, the fungal biomass was milled and stored in an amber bottle in the refrigerator until their use. PCP solutions are prepared from a stock solution of 1 000 mg/L and diluting it with trideionized water. The standard solution was prepared by adding 1000 mg of PCP to a volumetric flask of 1 000 mL and carrying to 1 L with 0.1 M NaOH solution.

2.3 Determination of PCP

The concentration of PCP in aqueous solution was determined by UV-visible spectrophotometry. The absorbance was determined in a Spectrophotometer Thermo Scientific, Genesys 10 S Uv-Vis, and was measured at a wavelength of 250 nm for concentrations of 0-10 mg/L and 320 nm for 10-100 mg/L. The spectrophotometer was calibrated to zero using as white, the solution that was used to prepare PCP solution. PCP analysis was performed in a sample by measuring the absorbance of the sample and calculating the concentration using a calibration curve [16]. Three dependent experiments were carried out and the mean value was shown.

2.3 Determination of Laccase Activity

The prepared flasks with basic medium for laccase: 0.4 g/L KH_2PO_4 , 0.2 g/L $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 1.0 g/L $\text{NH}_4(\text{NO}_3)$, 0.01 g/L FeSO_4 , 0.01 g/L ZnSO_4 , 0.01 g/L MnSO_4 , 0.2 g/L KCl, and 0.25% (w/v) saccharose [48], (with and without 10 mg/L of PCP), were inoculated with 1×10^6 spores/mL, and incubated at 28°C, with constant stirring (100 rpm). After 5 days of incubation, the cells were filtered at 4°C in Whatman paper No. 1, and the supernatant was used to determine the activity of laccase. Laccase activity was determined by the oxidation of ABTS (2,2-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid): the assay mixture contained 0.5 mM ABTS, 0.1 M Sodium acetate (pH 5.0), and 0.5 mL of enzyme (extracellular culture filtrate). The oxidation of ABTS was monitored by determining the increase in A_{420} . One unit of enzyme activity was equivalent to 1 μMol of the product formed per minute [49].

3. RESULTS AND DISCUSSION

The cells of the analyzed strain grew on LMM supplemented with 80 mg/L g/L of PCP about 6% of growth relative to control (118 mg of dry weight without metal) was obtained (Fig. 1) and therefore probably is resistant to the PCP. Different microorganisms that are PCP resistant

have been isolated from different contaminated sites: The bacterial strains *P. putida*, *P. rhizophila*, and *P. fuscovagiceae*, showed good capability to tolerate and degrade this [11], *R. nigricans* displayed a high tolerance to grow in the presence of up to 100 mg/L of PCP [20]. Too, *Trichoderma harzianum* CBMAI 1677 showed optimal growth at 50 mg/L, and toxicity resistance, and suggesting its potential for biodegradation of this pesticide [23], in mineral salt medium added with PCP (100 mg/L) by *P. putida* AJ 785569, showed a significant increase in the optical density value [24], a wild strain of *R. nigricans*, isolated from paper mill effluent, which grew 4.5 mg/mL with 12.5 and 25 mg PCP/mL, but decreased to 1.5 and 1.8 mg biomass/mL when 50 and 100 mg PCP/L was added [26], in *P. pulmonarius*, the addition of PCP inhibited considerably the growth of the fungus in the basal condition, and this caused only a slight inhibition of the fungal growth in the corn cob medium [50], *P. chrysosporium* grown in different culture mediums with 25 mg PCP/mL [37], *Bacillus* sp., tolerant to higher levels of PCP (500 mg/mL) [34], *E. coli*, *Pseudomonas aeruginosa*, and *Acinetobacter* sp., strains had higher growth on PCP [51], and 33 fungal isolates were isolated from the aging sawdust simple, which are grew with different concentrations of the same (5-100 mg/L) [48].

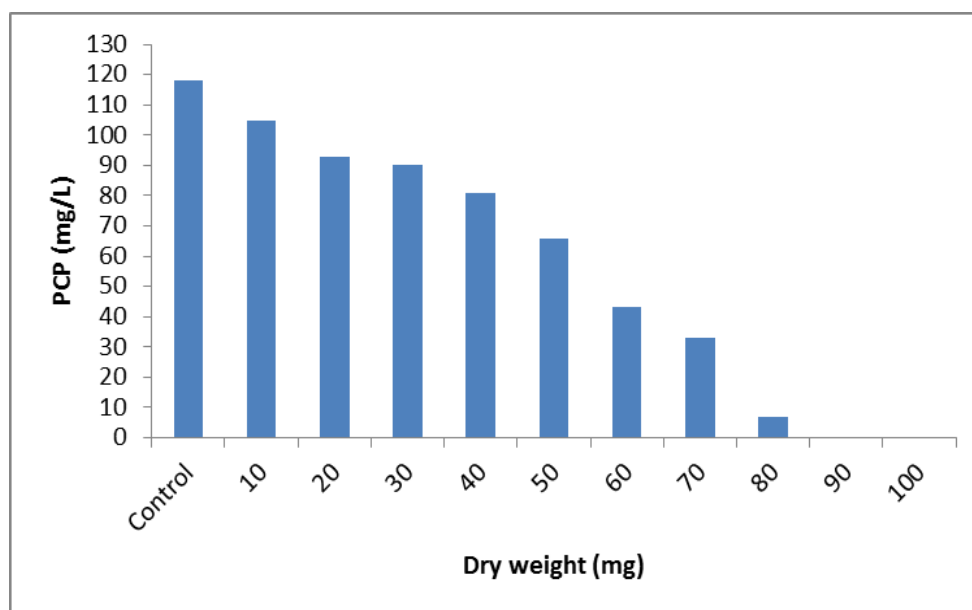


Fig.1. Growth in dry weight of *F. solani* with different concentrations of PCP, 1×10^6 spores/mL, 28°C, seven days of incubation, 100 rpm

In the Figs. 2 and 3 we show the effect of incubation time and pH on the removal of 10 mg/L of PCPC by the death biomass of *F. solani*. It was found that a higher removal (90%) occurs at 24 hours a pH 5.0. With respect to incubation time, for three strains of *Pseudomonas* was reported a removal of 85% with 500 mg/kg of PCP and 55 days of incubation [11], *R. nigricans* degrades 60% (12.5 mg PCP/L) in 24 h, [20], The fungi *B. nivea* and *S. Brumptii*, removal 60% and 62% during 28 days of incubation, respectively [22], a strain of *P. putida* AJ 785569 could bioadsorb 30 mg/L and remove 600 mg/L of PCP in 168 h of incubation [24], the efficiency of *T. angustifolia* phytoremediation treatments of the different effluents artificially contaminated with 200 mg/L of PCP after 20 days [25], Mathialagan and Viraraghavan [29] report an incubation time of 6 hours, when working with biomass from *A. niger*, too, 8 hours for *R. oryzae* ENHE [27], 4h hours for *Bacillus* sp., [34], 3 days for *E. coli*, *P. aeruginosa*, and *Acinetobacter* sp., strains isolated of tannery effluents [51], and 15 days for *Trichoderma* and *Cunninghamella* strains isolated from sawdust [48]. The differences in the incubation time may be due to changes in the permeability of the cell wall of unknown origin, providing greater or lesser exposure of the functional groups of the cell wall of biomass analyzed [1].

We observe the effect of pH on PCP sorption, to seven different values of pH (2.0-8.0), and the most effective was 5.0 (90% of removal, 10 mg/L, 24 hours). In isolated microorganisms of

tannery effluent, the percentage removal decreased with an increase in pH for all types of *A. niger* biomass, except for the conditioned *A. niger* biomasses. In the case of this treated biomass, almost 100% removal was achieved between pH 3 and 10, but at pH 11, the removal slightly decreased to 95% [51], too, was reported a pH of 3.0 for a laccase mutant of *T. versicolor* [39], under strong alkaline conditions (pH 9–12), for *P. osteratus* [41], and *R. oryzae* ENHE, the optimum pH was 5.0 [27]. Viraraghavan and Slough (1999), reported that the removal of PCP at an initial concentration of 1 mg/L by a peat-bentonite mixture, decreased from approximately 96 to 79%, and 85 to 30% when the pH was increased from 2 to 8 [50], and for *Bacillus cereus* RMLAU1, the PCP degradation by live cells at the initial pH range of 3 to 8. As the pH increased from 3 to 5, there was a concomitant increase in PCP degradation from 2.5% (w/v) to 7.5% (w/v) followed by gradual decrease approaching 5.5% (w/v) at pH 8.0, with a optimum pH of 5.0 with 7.5% of degradation (w/v) [52]. The solution pH can also affect the surface characteristics (e.g., surface charge and potential) of the adsorbent i.e., the biomass [53]. Generally, a bacterium or fungi exhibits a net negative charge at neutral and basic pH conditions. At the same time, PCP exists entirely in the anionic form at those pH ranges. Therefore, electrostatic repulsion between the negatively charged biomass surface and the anionic PCP may lead to a lower biosorption. But when the pH is lowered, the net negative charge on the biomass decreases and PCP tends to exist in the molecular form [53].

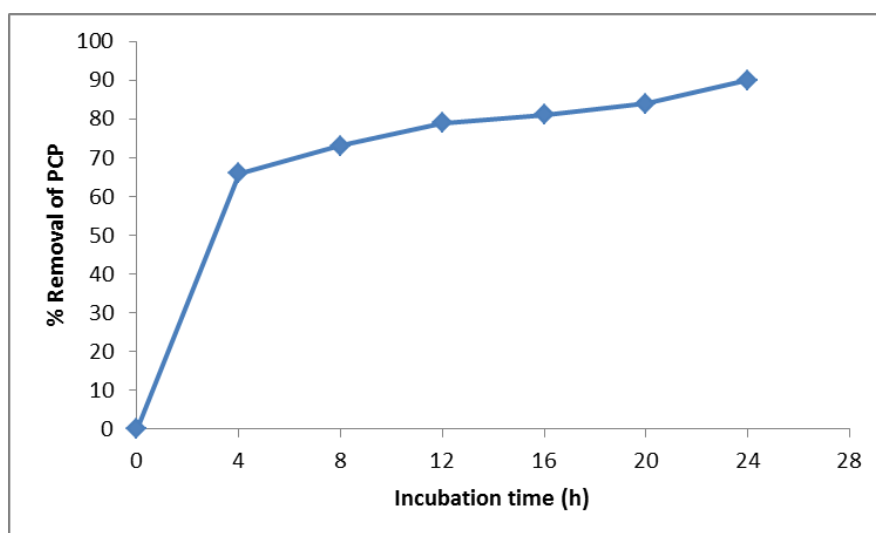


Fig.2. Effect of incubation time on PCP removal by *F. solani* of 10 mg/L PCP, 100 rpm, 28°C, pH 5.0, and 1.0 g of fungal biomass.

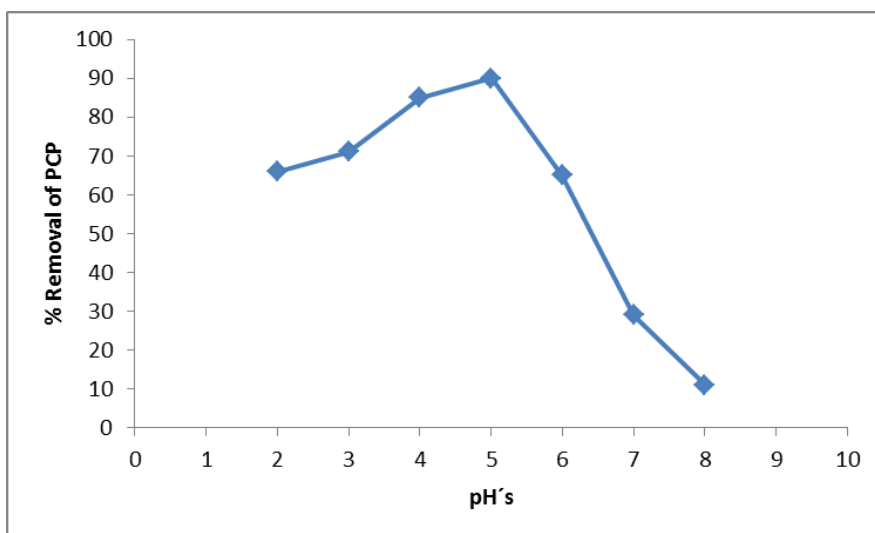


Fig.3. Effect of pH on PCP removal by *F. solani* of 10 mg/L PCP, 100 rpm, 28°C, 24 h, and 1.0 g of fungal biomass.

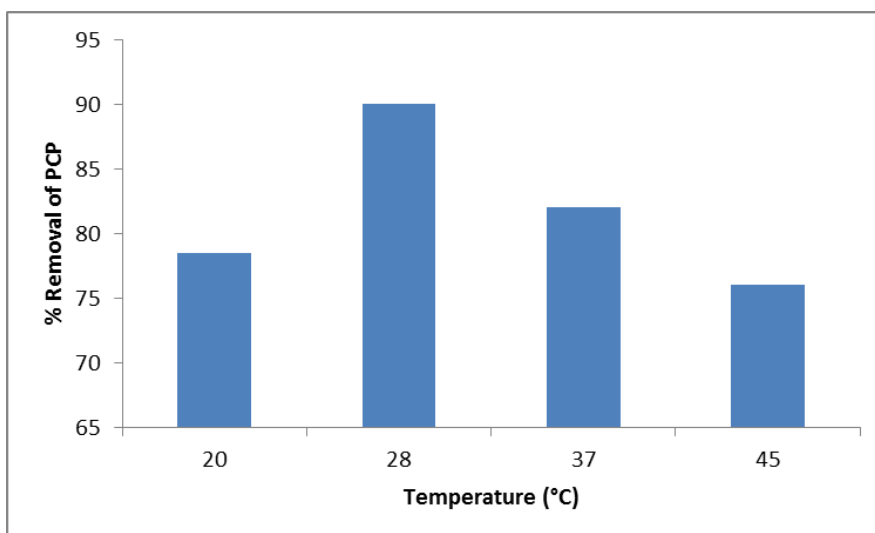


Fig.4. Effect of the temperature on PCP removal by *F. solani* of 10 mg/L PCP, 100 rpm, pH 5.0, 24 h, and 1.0 g of fungal biomass.

The temperature is very important in the removal of this pesticide (Fig. 4), because we observe greater removal as 28°C, 90% of the metal is removal at 24 hours. These results are similar to those reported for the conditioned *A. niger* biomass [51] and for *B. cereus* RMLAU1, the degradation of PCP to the extent of 3.5 to 7.5% (w/v) was noted in the temperature range of 25°C to 35°C by live biomass only, which was reduced to more than half (3.0%, w/v), when temperature was further elevated to 40°C [32], and there are different for non-viable *R. oryzae* biomass, in which the capacity of removal was

assayed at pH 5.0 and five temperatures (20, 25, 30, 35, and 40°C), founded that the values of removal increased with an increase in temperature [27]. One of the reasons for the decreasing trend of adsorption with temperature may be mainly due to the weakening of adsorptive forces between the active sites of the biomass and PCP, and between the adjacent molecules of the adsorbed phase [34].

The results obtained for the removal, depend on the concentration of PCP, at lower concentration of the same, removal is faster, 10 mg/L are

removal in an 90%, and 50 mg/L a 31%, at 24 hours, respectively, (Fig. 5), which may be due to sorption at low concentrations (which is a very fast process) happens. These results are similar those reported with *A. sydowii* and *T. angustifolia*, which removal 200 mg/L of PCP in 30 days of incubation [12], for the removal of 0.127, 0.168, 0.214 and 0.296 (mg/g) for the sunflower seed hulls, milk thistle seeds, hazelnut shells and pine sawdust, respectively [14], too, *R. nigricans* degrades 60% at an initial concentration of 12.5 mg PCP/L [20]. Co-inoculation of *B. nivea* and *S. brumptii* showed a synergetic effect on PCP removal resulting in 95% and 80% decrease when initial concentrations were 12.5 and 25 mg/kg, respectively [22], for *Trametes hirsuta* in PCP treated ammunition boxes (0, 5, 10, 15, 20 and 25 ppm of PCP) [35] and are different for the biomass of *R. nigricans* [20]. For other contaminants, indicated that the removal of this increases in direct proportion to the increasing concentration of the contaminant in solution [54, 55]. This may be due to the

increased number of competing for the functional groups of the surface of the biomass ions [56].

To evaluate the removal of 10 mg/L of PCP with different concentrations of biomass, it was found that the higher concentration of the latter, the removal of this pesticide is greater and faster. With 1 g of biomass, the maximum elimination was at 24 hours of incubation, whereas with 5 g, removal time was at 4 hours (Fig. 6). This could be explained as the amount of added bioadsorbent determines the number of sites available for biosorption of PCP. This is different for the degradation of this by the bacteria *P. putida*, *P. rhizophila*, and *P. fuscovagiceae*, which showed good ability to degrade PCP with 108 UFC/g soil inoculum size of each strain [11], by *B. cereus* RMLAU, the removal was not significantly affected by the concentration of biomass, and a maximum remediation (7.5%, w/v) of initial 500 mg/L PCP, was with 2 g/L of live biomass [52], and similar results have been reported for other contaminants [57,58].

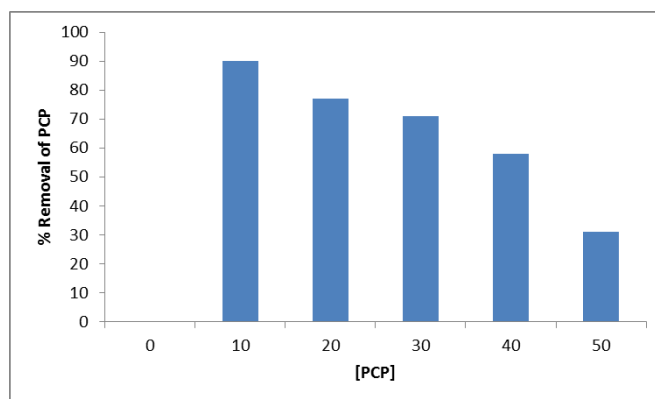


Fig.5. Effect of the initial PCP concentration on the removal of PCP by *F. solani*. 100 rpm. 28°C, pH 5.0, 24 h, and 1.0 g of fungal biomass.

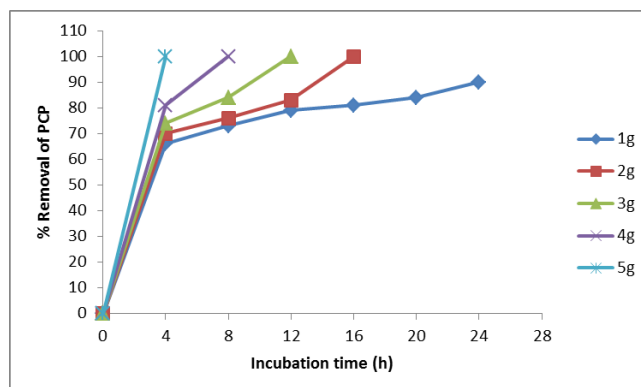


Fig.6. Effect of biomass concentration on PCP removal by *F. solani*. 10 mg/L PCP. 28°C, 24 h, and pH 5.0, 100 rpm.

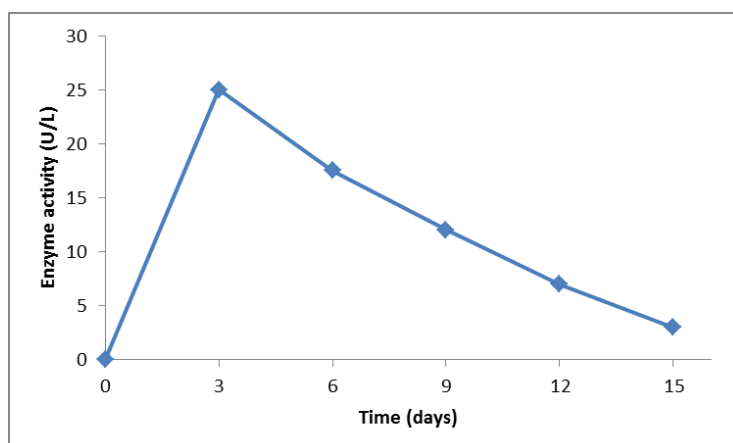


Fig.7. Laccase activity in *F. solani* cultures. 28°C, and pH 5.0, 100 rpm.

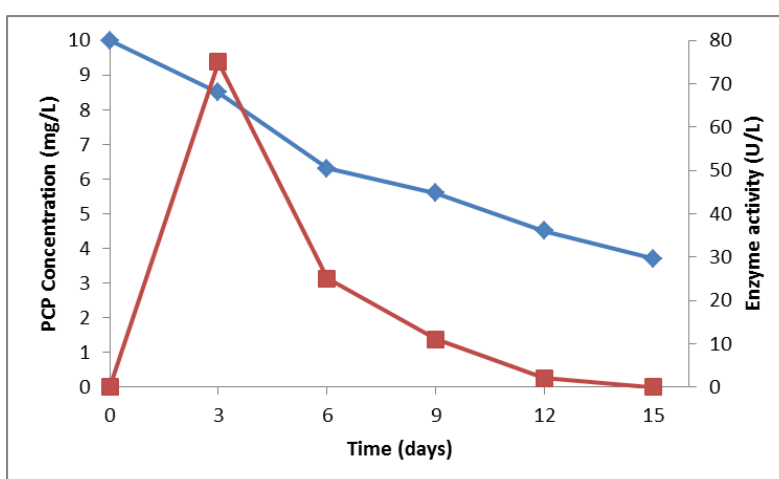


Fig.8. Laccase activity extracellular and biodegradation of 10 mg/L PCP in *F. solani* cultures. 28°C, and pH 5.0, 100 rpm

The extracellular enzyme activity of *F. solani*, induced in basic medium for laccase [48], was tested. Oxidation of ABTS indicates the presence of laccase enzyme activity, and the maximum activity was 25 u/L, at 3 days, without PCP (Fig. 7), and with 10 mg/L of PCP, the maximum enzymatic activity was 75 u/L on the 3rd day of incubation, at which 15 % of the initial amount of the pesticide was degraded (Fig. 8). The degradation reached to the maximum level of 63% after 15 days of incubation. These data indicated that PCP was degraded under these conditions. *F. solani* and other *Fusarium* sp., can colonize, modify, and degrade lignin [59], and his physiological variability led us to examine the production of different extracellular ligninolytic enzymes by strains isolated from different sources [41], and the laccase enzyme activity was reported in some *Fusarium* species [59, 60,

61,62,63,64,and65]. On the other hand, the enzymes of the lignin degradation system of white rot fungi have been indirectly implicated in the degradation process of several organic compounds including PCP [66,67].

Our results indicate that this fungus can biosorb and degrade PCP. There are some reports of different fungi, which can remove and degrade this, like *R. oryzae* [27], *Trichoderma* and *Cunninghamella* bacteria Isolated from sawdust [48], *Anthraco-phyl-lum discolor* [51], *P. Pulmonarius* [50], *B. cereus* (DQ002384), *S. marcescens* (AY927692 and DQ002385) [53], *Bacillus* sp., [34], *P. chrysosporium* (IFO 31249), *Trametes* sp. (KFCC 10941), *Pleurotus* sp. (KFCC 10943) [35], *T. versicolor* [36] *P. chrysosporium* [37], *B. cereus* RMLAU1 [52], *P. chrysosporium* and *P. sordida* [35]. Finally, in has

been reported that a strain of *Fusarium* was able to degrade PCP only if tyrosine was present in the culture medium [68]. Moreover, *in vitro* experiments, was showed phenol degradation by tyrosinase [69], and these fungi have an interesting potential to be used in processes for biodegradation of chlorophenols.

Finally, the analyzed biomass can be applied in the future to remove this compound from contaminated niches, although more studies are required to apply it correctly, since a large amount of biomass and a prolonged contact time would be required for good removal efficiency.

4. CONCLUSION

In this study, PCP uptake *in vitro* by fungal biomass of *F. solani* was investigated. The performance of the biosorbent was studied in different conditions, like incubation time, initial pH, metal ion and fungal biomass initial concentration. The maximum biosorption capacity values showed that this biosorbent is very effective in removal PCP, under the conditions analyzed. It was observed that the fungal biomass of *F. solani*, is a very promising biomaterial for removal of the pesticide. It was found that the biomass was very efficient in removal this in solution, determined by UV-visible spectrophotometry. The highest adsorption was obtained at pH 5.0, at 28°C after 24 hours of incubation with 1 g of fungal biomass, and 100 rpm. If we increase the PCP concentration, the removal decrease, and if the biomass concentration is increase, the removal is most efficient. The laccase activity is increase in presence of 10 mg/L of PCP, with a degradation of 63% at 15 days of incubation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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