Effects of different culture media on biodegradation of triclosan by *Rhodotorula mucilaginosa* and *Penicillium* sp.

Burcu Ertit Taştan, Caner Özdemir and Turgay Tekinay

**ABSTRACT**

Triclosan is an antimicrobial agent and a persistent pollutant. The biodegradation of triclosan is dependent on many variables including the biodegradation organism and the environmental conditions. Here, we evaluated the triclosan degradation potential of two fungi strains, *Rhodotorula mucilaginosa* and *Penicillium* sp., and the rate of its turnover to 2,4-dichlorophenol (2,4-DCP). Both of these strains showed less susceptibility to triclosan when grown in minimal salt medium. In order to further evaluate the effects of environmental conditions on triclosan degradation, three different culture conditions including original thermal power plant wastewater, T6 nutrimedia and ammonium mineral salts medium were used. The maximum triclosan degradation yield was 48% for *R. mucilaginosa* and 82% for *Penicillium* sp. at 2.7 mg/L triclosan concentration. Biodegradation experiments revealed that *Penicillium* sp. was more tolerant to triclosan. Scanning electron microscopy micrographs also showed the morphological changes of fungus when cells were treated with triclosan. Overall, these fungi strains could be used as effective microorganisms in active uptake (degradation) and passive uptake (sorption) of triclosan and their efficiency can be increased by optimizing the culture conditions.

**Key words** | biodegradation, culture media, 2,4-DCP, fungus, high-performance liquid chromatography (HPLC), triclosan

**NOMENCLATURE**

AMS | Ammonium mineral salts medium
---|---
*C*<sub>0</sub> | Initial concentration of the triclosan (mg/L)
*C*<sub>f</sub> | Final concentration of the triclosan (mg/L)
MSMY | Minimal salt medium with yeast.
*q*<sub>m</sub> | Maximum amount of triclosan removal per unit dry weight of fungal cells (mg/g)
SE | Standard error
T6 | Nutrimedia
WW | Wastewater medium
*X*<sub>m</sub> | Dried cell mass (g/L)
Y | Degradation and sorption yield (%)
σ | Square root of the estimated error variance of the quantity
2,4-DCP | 2,4-Dichlorophenol

**INTRODUCTION**

Triclosan (5-chloro-2-(2,4-dichlorophenoxy)-phenol) is a common antimicrobial agent and a powerful bacteriostat. Triclosan is used as an ingredient in hundreds of industrial and personal care products; thus its levels in the environment increase each day because of its high use and persistence. Triclosan concentrations in personal care products are in the range of 0.1–0.3% (Sabaliunas *et al.* 2003; Dann & Hontela 2011). The US Geological Survey detected 2.5 μg/L triclosan in streams and rivers (Kolpin *et al.* 2002). Triclosan in wastewater (WW) is eliminated by biodegradation and sorption; however, the residual amount of triclosan causes an increase in the triclosan concentrations in surface water. Therefore, the removal of triclosan from WW is a necessary task to protect the quality of the environment (Lee *et al.* 2012; Lozano *et al.* 2013).

Some physical and chemical methods, including TiO<sub>2</sub>-UV irradiation (Constantin *et al.* 2015), ozonation (Chen *et al.* 2012), nanofibrous filters (Xu *et al.* 2014), and electrolysis (de Vidales *et al.* 2015), have previously been proposed for triclosan removal. Even though many physical, chemical and biological studies have been carried out on degradation of chlorinated phenols, there are only limited studies on the biodegradation of triclosan (Wang *et al.* 2013; Lee *et al.* 2014;...
Biological methods have cheap and environmentally friendly mechanisms. Due to the highly toxic character of triclosan, especially to aquatic organisms (Orvos et al. 2002; Gao et al. 2014), it is important to select the most triclosan-resistant microorganisms for biodegradation and the most effective triclosan treatment method.

Some fungi strains are already known to degrade different pesticides. For example, Penicillium chrysogenum degrades 2,4-dichlorophenoxyacetic (Ferreira-Guedes et al. 2012), Aspergillus oryzae degrades terbuthylazine (Pinto et al. 2012), Fusarium sp. degrades lindane (Sagar & Singh 2011) and A. versicolor degrades triclosan (Taştan & Dönmez 2013). Depending on these findings and lack of attempts on fungal triclosan degradation in the literature, selected fungal biomass could be better biodegraders due to their higher availability and high removal yields obtained at different chemicals in inexpensive media such as WW used here (Laçin et al. 2015).

We evaluated the triclosan degradation potential of two fungal strains, Rhodotorula mucilaginosa and Penicillium sp., by optimizing culture conditions. Also, we checked the effect of different culture media compositions on the fate of triclosan degradation by fungi in order to find the most inexpensive media. Biodegradation and biosorption methods were both evaluated. This is the first report that shows degradation ability of triclosan by R. mucilaginosa and Penicillium sp. in different culture media compositions.

Four different culture media compositions were checked for triclosan degradation efficiency of fungi. The first medium was T6 nutrimedia (Maysa, Turkey Rev: NMT6.01.0113). The elemental composition of T6 nutrimedia determined by energy dispersive X-ray fluorescence was (%): 78 Ca, 17.25 P, 2.74 K, 0.78 Si, 0.72 S, 0.16 Fe, 0.14 Zn, 0.11 Sr, 0.07 Cu, 0.02 Mn, 0.02 Zr. The second medium was minimal salt medium with yeast (MSMY), which was composed of 1.7 g/L KH2PO4, 2.69 g/L (NH4)2SO4, 0.2 g/L CaCl2, 0.05 g/L MgSO4 and 1.6 g/L yeast extract. The third medium was ammonium mineral salts (AMS) (Chu & Alvarez-Cohen 1996), and the last medium was WW, which was obtained from cooling water of a thermal power plant in Nallihan, Ankara, Turkey. The cooling water design parameters were (ppm); calcium, 72–104; magnesium, 120–165; natrium, 320–440; HCO3, 73.2, CO3, 24; chlorides, 0–440; sulphates, 696–1,616; nitrates, 0–80; SiO2, 28–50; Fe, 0.4–0.8; organic matter, 4.56–8.28; total organic carbon, 4.8–12.

**Materials and Methods**

**Microorganisms and culture conditions**

*Rhodotorula mucilaginosa* was isolated from the WW of Eti Mine General Directorate – Emet Boron Work Kütahya, Turkey (Taştan et al. 2016). *Penicillium* sp. was isolated from the cheese samples from Erzurum, Turkey (unpublished work). The fungal isolates were identified as a result of 5.8S rRNA gene sequencing.

The isolated pure colonies were kept at 4 °C and were transferred to fresh nutrient agar every 3 months. At the final step, the purified cells were transferred to liquid media that are explained in detail below. The cultures were incubated in 100 mL media in 250 mL Erlenmeyer flasks at 100 rpm stirring rate (VWR 5000 Model Orbital Shaker) at 25 ± 2 °C for 10 days. The pH of the growth medium was adjusted to 5 by adding diluted (0.01 M) and concentrated (1 M) sulfuric acid or sodium hydroxide solutions.

**Chemicals**

Triclosan 97% (Irgasan CAS: 3380-34-5) was purchased from Sigma; 2,4-dichlorophenol (2,4-DCP) 99% (CAS: 120-83-2) was purchased from Sigma-Aldrich. High-performance liquid chromatography (HPLC) grade acetonitrile (CAS: 7505-8) and ammonium acetate (CAS: 631-61-8) were purchased from Sigma. The stock solutions were prepared in acetonitrile (80%)/ammonium acetate (20%) solution and were stored at 4 °C.

**Biodegradation experiments**

The effect of initial pH on the triclosan biodegradation was investigated at pH 4, 5, 6 and 7 in T6 and MSMY media supplied with 3 mg/L triclosan. The cells were cultured in light and dark conditions to detect the effect of photoperiod on triclosan degradation.

In two independent-type of biodegradation processes, the cells were first inoculated in T6 media at 3 mg/L triclosan concentration (t = 0) at 25 μmol/(m²s) (1,750 lux fluorescence) light intensity and incubated for 10 days. In the second type of biodegradation process, the cells were incubated in MSMY media for 5 days without triclosan in the dark, and then triclosan was added to the media (t = 5) and incubated for 5 days. Total incubation time was 10 days.

To determine the effect of initial triclosan concentrations, microorganisms were incubated in MSMY media for 5 days without triclosan, and then 2.7, 5.9, 7.7 and 10 mg/L triclosan was added to the media. The cells were cultivated in the dark at pH 5.
The effect of *Penicillium* sp. biomass concentrations on triclosan degradation was examined at three different initial biomass concentrations by the dry weight method. The experiments were performed in AMS media with approximately 5 mg/L triclosan at pH 5 with 0.25, 0.5 and 1.0 g/L dry weight biomass. Triclosan was added on the fifth day (t = 5), total incubation time was 10 days and the cells were cultivated in the dark.

To determine the effect of WW on triclosan degradation, *Penicillium* sp. was incubated in 100 mL WW medium containing approximately 5 mg/L triclosan at pH 5. Triclosan was added on the fifth (t = 5), total incubation time was 10 days and the cells were cultivated in the dark. 0.5 g/L of activated culture was inoculated into 100 mL of the media in all of the experiments.

**Biosorption experiments**

After the growth period, *Penicillium* sp. was harvested by centrifugation at 5,000 rpm for 10 min (Hettich Rotofix 32A model, Germany). The pellet was washed twice with distilled water and autoclaved at 121 °C for 15 min (ALP CLG-40M, Japan). Autoclaved cells were used directly as wet cells (Laçin et al. 2013). Their wet weight was converted to dry weight by means of wet/dry weight standardization method (R² = 99.8%).

To determine the optimum fungal triclosan biosorption time, experiments were performed in 100 mL aqueous solution containing 10 mg/L triclosan in 250 mL Erlenmeyer flasks for 5 min, 15 min, 30 min, 1 h, 2 h, 4 h, 5 h and 24 h.

**Analytical methods**

The remaining triclosan concentration was determined on 5 mL samples taken daily during the incubation period. Un-inoculated Erlenmeyer flasks containing triclosan were used as control samples to detect any reactions between media and triclosan.

The concentration of triclosan and 2,4-DCP in the supernatant was determined by high-performance liquid chromatography (Agilent 1200 Series, Germany) by using a C-18 column (4.6 × 250 mm 5-Micron 80 Å) at 50 °C. Acetonitrile and 10 mM ammonium acetate were used as mobile phase to produce a binary elution gradient with a flow rate of 1 mL/min. Pure water, obtained from an apparatus (JSR), was used to prepare solutions and buffers, which were filtered through 0.45 μm Agilent membrane filters prior to use. The sample solutions were filtered through 0.45 μm Minisart RC syringe filters before the injection into the chromatograph. The separation of triclosan was achieved with the following linear mobile phase gradient program: 80:20 (v/v) at 254 nm (Taşan & Dönmez 2015).

The percentage biodegradation of triclosan and the maximum specific triclosan uptake was calculated from Equations (1) and (2):

\[
\text{degradation (\%)} = \frac{(C_0 - C_t)}{C_0} \times 100 \tag{1}
\]

\[
q_m = \frac{(C_0 - C_t)}{X_m} \tag{2}
\]

where \(C_0\) is initial concentration of triclosan (mg/L), \(C_t\) is final concentration of triclosan (mg/L), \(q_m\) is maximum amount of triclosan removal per unit dry weight of fungal cells (mg/g), and \(X_m\) is dried cell mass (g/L).

Cell growth rate of microorganisms was determined by measuring dried cell mass for any set of growth conditions. The dried cell mass was saved by the measurement of the pellets, which were dried at 80 °C overnight (Nüve FN 400 model sterilizer) after centrifugation step (3,421 g = 5,000 rpm for 10').

Scanning electron microscopy (SEM, Quanta SEM 400, FEI, USA) was used to observe the morphology of the *Penicillium* sp. as described previously (Balusamy et al. 2015).

All of the experiments were performed in triplicate. The standard error of the data was calculated according to Equation (3) formulated by Kenney & Keeping (1951).

\[
SE = \sqrt{\sigma^2} \tag{3}
\]

where SE is standard error and \(\sigma\) is square root of the estimated error variance of the quantity.

**RESULTS**

**Effects of pH**

The effects of pH on triclosan degradation by *R. mucilaginosa* sp. and *Penicillium* sp. in T6 and MSMY media are shown in Figure 1. *R. mucilaginosa* showed different triclosan degradation ability at different conditions. In the first series of experiments, triclosan degradation yield (Y) was tested in continuous light in T6 nutrimedia (Figure 1(a)). The remaining triclosan concentration in media could not be quantified by HPLC at pH 4, and only 19% of 2,4-DCP catabolize yield was quantified. The maximum
triclosan degradation yield was 48% at pH 5. The maximum catabolize yield of triclosan to 2,4-DCP was obtained at this pH value as 34%. On the other hand the same degradation yield was obtained at pH 5 in MSMY media (Figure 1(b)). As seen in Figure 1(b), triclosan degradation yields were close to each other between pH 4 and 7. The highest yield was obtained at pH 5 and the highest catabolize yields of triclosan to 2,4-DCP were obtained at pH 7 as 3%.

Figure 1(c) and 1(d) show the triclosan degradation yields of Penicillium sp. Triclosan degradation yields of Penicillium sp. were higher than R. mucilaginosa. In the first series of experiments in T6 nutrimedia, the highest degradation yield obtained at pH 5 was 75%. In the second series of experiments, the highest triclosan degradation yield obtained was 82% in MSMY media. There was no significant catabolize yield of triclosan to 2,4-DCP in both culture media for Penicillium sp. As seen in Figure 1, only R. mucilaginosa showed appreciable releases of 2,4-DCP.

Effect of varying triclosan concentrations

In the first series of experiments, increasing triclosan concentrations from 2.7 mg/L to 10.00 mg/L were tested for both R. mucilaginosa and Penicillium sp. As seen in Figure 2, triclosan degradation yields decreased with increasing concentrations of initial triclosan for both of the microalgae. The maximum degradation yield of R. mucilaginosa was achieved at 2.7 mg/L triclosan concentrations as 48%. The minimum degradation yield was obtained at the highest triclosan concentration as 5.9%. As seen in Figure 2(b), Penicillium sp. was more tolerant to triclosan than R. mucilaginosa. Maximum degradation yield was 82% at 2.7 mg/L triclosan concentration. The minimum degradation yield was obtained at the maximum triclosan concentration tested.

As seen in Table 1, the maximum specific triclosan uptake of R. mucilaginosa cells was 6.8 mg/g, at 2.7 mg/L triclosan concentration. On the other hand, maximum specific triclosan uptake yields were higher in Penicillium sp. The highest maximum specific triclosan uptake, obtained at 7.7 mg/L triclosan concentration, was 9.6 mg/g.

Catabolization of triclosan to 2,4-DCP was also observed at the first day of the experiments. Conversion yields were 1.4%, 1.3%, 1.3% and 2.5% at 2.7 mg/L, 5.9 mg/L, 7.7 mg/L and 10.00 mg/L triclosan concentrations for R. mucilaginosa, respectively. Corresponding conversions were 2.2%, 2.1%, 3.6% and 2.3% for Penicillium sp.
Figure 3 shows the morphological changes of *Penicillium* sp. cells with and without triclosan. As seen in SEM micrographs in Figure 3(a), *Penicillium* sp. filaments were normal and had no deformity; however, cells incubated with 10 mg/L triclosan had morphological deformities in their filaments and cell structure (Figure 3(b)).

![Figure 2](image)

**Figure 2** Effects of increasing triclosan concentrations on Y % of *R. mucilaginosa* (a) and *Penicillium* sp. (b) (culture conditions: dark; triclosan adding time t = 5; MSMY medium; incubation period, 10 days; T, 25 ± 2°C; shaking, 100 rpm; pH 5).

<table>
<thead>
<tr>
<th></th>
<th>2.7</th>
<th>5.9</th>
<th>7.7</th>
<th>10.00</th>
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<tr>
<td><em>R. mucilaginosa</em></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$q_m$ (mg/g)</td>
<td>6.8 ± 1.9</td>
<td>5.3 ± 1.5</td>
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<tr>
<td>Y %</td>
<td>48 ± 5.2</td>
<td>21 ± 2.5</td>
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<tr>
<td>2,4-DCP %</td>
<td>1.4 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>2.5 ± 0.6</td>
</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td><em>Penicillium</em> sp.</td>
<td></td>
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<tr>
<td>$q_m$ (mg/g)</td>
<td>4.5 ± 1.5</td>
<td>8.40 ± 0.7</td>
<td>9.56 ± 0.4</td>
<td>7.90 ± 0.4</td>
</tr>
<tr>
<td>Y %</td>
<td>82 ± 4</td>
<td>61 ± 3.9</td>
<td>53 ± 4.1</td>
<td>41 ± 4.1</td>
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<tr>
<td>2,4-DCP %</td>
<td>2.2 ± 0.1</td>
<td>2.1 ± 0.5</td>
<td>3.6 ± 0.7</td>
<td>2.3 ± 0.1</td>
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</table>
Effects of concentrations of fungal biomass

To find a suitable biomass concentration of *Penicillium* sp., experiments were performed at 5 mg/L triclosan concentration with three different initial biomass concentrations (0.25, 0.5, 1.0 g/L). As seen in Figure 4, triclosan degradation yield was 22.6% at 0.25 g/L biomass concentration at the fifth day of the process. It took 1 day to reach the same degradation yield (20%) for 0.5 g/L biomass concentration. *Penicillium* sp. achieved its higher degradation yield at the highest biomass concentration. The degradation yield was 63%, and the triclosan degradation yield increased when biomass concentration was increased from 0.25 to 1.0 g/L.

The maximum amount of triclosan uptake per unit dry weight of fungal cells was determined (Table 2). The effect of biomass concentrations on $q_m$ showed that the microalgal uptake capacity and biodegradation yield of triclosan at 1.0 g/L biomass concentration was higher than for other biomass concentrations.

**Effects of WW media**

The results obtained in different media described above and the ones obtained in WW medium were summarized in Table 3. The degradation yield obtained in WW medium was higher than the obtained yield of AMS medium, but it was lower than the yields that were obtained in T6 and MSMY media. MSMY medium was more suitable for triclosan degradation and also its $q_m$ value was higher (4.5 mg/g). On the other hand, the maximum triclosan biodegradation yield was obtained in MSMY medium and the maximum $q_m$ was obtained in the T6 medium. The minimum $q_m$ value was obtained in the AMS medium due to its high triclosan concentration.
Biosorption studies

To find a suitable biosorption time, experiments were carried out at 10 mg/L triclosan concentration at pH 5. The data obtained after incubation for 24 h are summarized in Figure 5. As shown in Figure 5, triclosan biosorption yield of *Penicillium* sp. after 5 minutes was 10% and it increased to 20% after 30 minutes. The maximum biosorption yield was 75% after 24 hours. This confirms that cells could sorb triclosan with a high yield.

**DISCUSSION**

Triclosan degradation process at different photoperiods and different application times for different microorganisms was tested. Results demonstrated that fungal triclosan degradation could be achieved more effectively in MSMY in the dark. These results revealed the importance of the presence of light (photoperiod) and application time on the triclosan degradation process. On the other hand, Reinhold et al. (2010) showed that triclosan in light and chemically-inactivated duckweed reactors decreased from approximately 4 μM to 1 μM, and 2,4-DCP increased from approximately 1 μM to 8 μM. Triclosan in dark and chemically inactivated duckweed reactors decreased from approximately 4 μM to 2 μM (Reinhold et al. 2010).

A previously reported highest triclosan degradation yield was obtained at pH 5 by *A. versicolor* in synthetic WW (Taştan & Dönmez 2015), and higher concentrations were studied by Hay et al. (2001). In this study, 35% of 500 mg/L triclosan was degraded by a bacterial consortium in 13 days (Hay et al. 2001). The present study is the first report detecting the triclosan removal process by *R. mucilaginosa* and *Penicillium* sp.

The experiments revealed that the maximum triclosan degradation yield is related to the fungal species. As previously reported, the maximum triclosan biodegradation yield of *A. versicolor* was 71.91% at 7.5 mg/L concentration in semi-synthetic medium and was 37.47% in simulated WW (Taştan & Dönmez 2015). In a previous study,

<table>
<thead>
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<th>Medium</th>
<th>C₀ (mg/L)</th>
<th>Y %</th>
<th>qₘ (mg/g)</th>
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<tr>
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<td>82</td>
<td>4.5 ± 1.5</td>
</tr>
<tr>
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<td>5.4</td>
<td>41</td>
<td>2.1 ± 0.2</td>
</tr>
<tr>
<td>WW</td>
<td>3.6</td>
<td>49</td>
<td>2.7 ± 0.1</td>
</tr>
</tbody>
</table>

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degradation of terbuthylazine, difenoconazole and pendimethalin pesticides by different fungal species including Fusarium oxysporum, Aspergillus oryzae, Lentinula edodes, P. brevicaespactum and Leccanicillium sakensae was detected. Maximum terbuthylazine biodegradation of selected fungi cultures was between 35 and 60%, difenoconazole biodegradation was 60–80% and pendimethalin biodegradation was 60–100% (Pinto et al. 2012). In another study, degradation of the pesticide lindane at 100 mg/L concentration in a liquid culture by Fusarium poae and F. solani fungal isolates after 10 days of incubation was 56.7% and 59.4% (Sagar & Singh 2011). In another study, P. chryso- genenum in solid medium was able to grow at concentrations up to 1,000 mg/L of 2,4-dichlorophenoxyacetic acid with sucrose (Ferreira-Guedes et al. 2012).

Results showed that Penicillium sp. has an efficient triclosan degradation mechanism with high removal yields and high $q_m$ values. Because the reports are very limited about triclosan biodegradation, this study has an importance that shows Penicillium sp. as an efficient biomaterial in the triclosan removal process for the first time.

Penicillium sp. was capable of degrading higher triclosan concentrations faster than other known triclosan degraders (Meade et al. 2001). The triclosan degradation process was detected in M9 mineral salts medium with Pseudomonas putida and Alcaligenes xylosoxidans subsp. denitrificans. Longer time periods of 4–9.5 days were needed to degrade 0.15–0.18 mg/L triclosan (Meade et al. 2001). Kim et al. (2011) studied the triclosan degradation process with Sphingomonas sp., S. wittichii and Burkholderia xenovorans. Only Sphingomonas sp. was able to catabolize triclosan to 2,4-DCP, and 2,4-DCP was less toxic to Sphingo- monas sp. than was triclosan.

Analysis of the effects of different media in the triclosan degradation process is highly important. For example, after triclosan degradation, 2,4-DCP continued to be metabolized into chloride in the MSMY media, which was also observed in the Sphingopyxix strain KCY1 (Lee et al. 2012). These authors explained that 3 mols of chloride are theoretically released per 1 mol of triclosan degraded. The strain was unable to grow on triclosan, but it could grow with glucose, sodium acetate, sodium succinate and phenol. When they used complex nutrient media with 5 μg/L triclosan, $q_m$ was 0.15 mg triclosan/(mg protein-day). Lee & Chu (2013) observed the effects of growth substrate on triclosan biodegradation potential. While no triclosan degradation metabolites were detected in propane and LB + dicyclopopylketone with Rhodococcus jostii, 2,4-DCP metabolites were detected when using biphenyl.

In previous studies the biosorption time of some other pollutants has been restricted to minutes (Hu et al. 2015). In the present work we aimed to obtain higher sorption yield at shorter time. Therefore optimum and shorter time was selected as 24 hours with 75% yield and no elongated time has been studied. Pinto et al. (2012) explained that the biosorption of pesticides, attributed to relatively high surface area of the fungi and its high binding affinity, was a process more dependent on the species, influenced probably by fungal morphology. Due to the high surface area of Penicillium sp. in passive uptake, biosorption potential was higher than biodegradation potential.

**CONCLUSIONS**

In this study two fungi strains, R. mucilaginosa and Penicillium sp., showed high ability to degrade triclosan to 2,4-DCP. A series of optimization studies including pH, increasing triclosan and biomass concentrations, photoperiod and different culture media were carried out. Penicillium sp. showed less susceptibility to triclosan. This strain can grow in T6 nutrimedia, MSMY, AMS and WW media at high triclosan levels. Also, its triclosan degradation ability could be increased when the biomass concentration was increased. Biosorption studies also revealed that triclosan degradation could be achieved by both active and passive uptake. Consequently, different culture media compositions can both directly and indirectly affect the fate of triclosan degradation by fungus. Studies about triclosan biodegradation are very limited. Thus, these results may be important data for future studies involving triclosan and the microorganisms.

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**REFERENCES**


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