Degradation of 4,4'-Dichlorobiphenyl, 3,3',4,4'-Tetrachlorobiphenyl, and 2,2',4,4',5,5'-Hexachlorobiphenyl by the White Rot Fungus Phanerochaete chrysosporium

DIANE DIETRICH,* WILLIAM J. HICKEY,† AND RICHARD LAMAR‡

Institute for Microbial and Biochemical Technology, Forest Products Laboratory, U.S. Forest Service, U.S. Department of Agriculture, Madison, Wisconsin 53705-2398,* and Department of Soil Science, University of Wisconsin, Madison, Wisconsin 53706-1299

Received 22 May 1995/Accepted 29 August 1995

The white rot fungus Phanerochaete chrysosporium has demonstrated abilities to degrade many xenobiotic chemicals. In this study, the degradation of three model polychlorinated biphenyl (PCB) congeners (4,4'-dichlorobiphenyl [DCB], 3,3',4,4'-tetrachlorobiphenyl, and 2,2',4,4',5,5'-hexachlorobiphenyl) by P. chrysosporium in liquid culture was examined. After 28 days of incubation, 14C partitioning analysis indicated extensive degradation of DCB, including 11% mineralization. In contrast, there was negligible mineralization of the tetrachloro- or hexachlorobiphenyl and little evidence for any significant metabolism. With all of the model PCBs, a large fraction of the 14C was determined to be biomass bound. Results from a time course study done with 4,4'-[14C]DCB to examine 14C partitioning dynamics indicated that the biomass-bound 14C was likely attributable to nonspecific adsorption of the PCBs to the fungal hyphae. In a subsequent isotope trapping experiment, 4-chlorobenzoic acid and 4-chlorobenzyl alcohol were identified as metabolites produced from 4,4'-[14C] DCB. To the best of our knowledge, this the first report describing intermediates formed by P. chrysosporium during PCB degradation. Results from these experiments suggested similarities between P. chrysosporium and bacterial systems in terms of effects of congener chlorination degree and pattern on PCB metabolism and intermediates characteristic of the PCB degradation process.

Bacterial degradation of polychlorinated biphenyls (PCBs) has been studied in detail (for reviews, see references 1 and 12). In comparison, relatively little is known about the potential of fungi to degrade various types of PCBs or the metabolic mechanism(s) by which this process might be effected. Degradation of technical PCB mixtures by Aspergillus spp. appeared to vary depending on the level of PCB chlorination and the strain being tested (9, 18). For example, Aspergillus niger metabolized PCB mixtures with ≤ 42% chlorine by weight, but more heavily chlorinated mixtures (> 54% chlorine by weight) were not degraded (18). In contrast, Aspergillus flavus failed to effect any metabolic changes in PCB mixtures with chlorine concentrations ranging from 32 to 60% by weight (18). In cases in which PCB degradation had been observed, little information concerning the identities of metabolic intermediates that might provide insights into the degradative pathways has been provided. Dmochewitz and Ballschmiter (9) detected trace amounts of hydroxylated trichlorobiphenyls as well as dichloro- and trichloro-benzoic acids during Clophen A 30 (a technical PCB mixture averaging 42% Cl by weight) degradation by A. niger (9); isomeric configurations were not specified for any of these compounds. Wallnöfer et al. (22) reported that a soil fungus, Rhizopus japonicus, metabolized 4-chlorobiphenyl and 4,4'-dichlorobiphenyl (DCB) to hydroxylated metabolites. As with the A. niger study, these compounds were detected only in trace amounts and were not conclusively identified.

The white rot fungus Phanerochaete chrysosporium has been examined for its ability to degrade many xenobiotic chemicals, including PCBs. Prior investigations have shown that P. chrysosporium can degrade some technical PCB mixtures and single congeners (6, 7, 10, 20, 21, 23). In general, the extent of PCB mineralization appears to decrease as the degree of PCB chlorination increases. Thus, mineralization levels determined by Thomas et al. (20) decreased in the following order (with percent mineralization given in parentheses): [14C]biphenyl (up to 23%) > 2-[14C]chlorobiphenyl (up to 16%) > 2,2',4,4'-[14C]tetrachlorobiphenyl (TCB) (up to 10%). There is also evidence indicating that PCB degradation by P. chrysosporium is influenced by the congeners’ chlorination patterns. Thus, in experiments conducted under similar conditions, 10% of 2,2',4,4'-[14C]TCB was mineralized in 32 days, while <1% of 3,3',4,4'-[14C]TCB was mineralized in 30 days (7, 20). The effects of chlorination pattern on PCB degradation are well documented for bacteria and are believed to reflect restrictions on 2,3- or 3,4-dioxygenase attacks (7, 9, 23). A mechanistic interpretation of the chlorination pattern effect in P. chrysosporium is prevented by a lack of information regarding the enzymatic basis of PCB degradation by this organism.

The degradation of technical PCB mixtures by P. chrysosporium appears to follow the trend expected on the basis of PCB chlorination levels. Thus, mineralization of [14C]Aroclor 1242 (42% chlorine by weight) was reported to be about 20% (6), while that of [14C]Aroclor 1254 (54% chlorine by weight) ranges from 10 to 14% (6, 10). The mineralization patterns of these mixtures presumably reflected the relative availabilities of the more lightly chlorinated congeners, which were preferentially degraded. Consistent with this assumption are the results of Zeddle et al. (23) that indicated that the degradation of a nonspecified PCB mixture by P. chrysosporium was limited to mono- and dechlorinated congeners. Other reports, however, offer conflicting evidence. For example, the disappearance of highly chlorinated congeners, including a pentachlorinated bi-

* Corresponding author. Mailing address: Institute for Microbial and Biochemical Technology, Forest Products Laboratory, U.S. Forest Service, U.S. Department of Agriculture, One Gifford Pinchot Dr., Madison, WI 53705-2398. Phone: (608) 231-9469, Fax: (608) 231-9262. Electronic mail address: dmdietr1@facstaff.wisc.edu.
phenyl (50% decrease) and a hexachlorinated biphenyl (53% decrease), was reported to occur in P. chrysosporium-inoculated sand cultures (21). In a liquid culture system spiked with [14C]Aroclor 1254, gas chromatography (GC) analysis showed total depletion of the PCBs following growth of P. chrysosporium (10). The 14C partitioning determined for the latter experiment indicated that, while only 8% of the radioactivity was evolved as 14CO2, almost 40% was accounted for as either polar products or hypha-bound 14C. The author suggested that the latter fraction could represent PCBs covalently bound to biomass, presumably via some fungus-mediated reaction(s).

The results of these studies illustrate that to adequately evaluate a microbe’s abilities to degrade PCBs (or any other organic compound), it is important to assess the occurrence of transformations that may not immediately result in mineralization. Indeed, the best PCB-degrading bacteria yet described would fare poorly in PCB degradation assays that used mineralization as the sole measure of catecholable competency. Yet, the current assessment of PCB degradation by P. chrysosporium is largely based on the occurrence and extent of mineralization. Furthermore, to the best of our knowledge, no PCB metabolites that could provide insights into potential degradation pathways utilized by P. chrysosporium have been identified. The present study was undertaken to address some of these issues and thereby gain an improved understanding of PCB degradation by P. chrysosporium. The objectives were to (i) assess the potential of P. chrysosporium to transform model di-, tetra- and hexachlorinated PCBs, (ii) conduct time course studies elucidating the 14C partitioning dynamics of congeners determined to have significant degradation potentials, and (iii) identify metabolites produced from model PCB congeners.

MATERIALS AND METHODS

Chemicals. Chemicals and reagents used in these studies and their sources were as follows: 4-chlorobenzyl alcohol (4-CBA) (Aldrich Chemical Company, Milwaukee, Wis.), BSA [N0-biotinylated] (Sigma Chemical Co., St. Louis, Mo.), and 14C-DCCB. Ultra Scientific (North Kingstown, R.I.).

Fungus. P. chrysosporium Burdt et Esen (BKM F-1767: ATCC 24275) was grown on yeast-malt-peptone-glucose (YMPG) slants at 30°C for 1 week and then stored at -20°C. The YMPC medium contained (per liter) glucose (10 g), thiamine·HCl (1 mg), ammonium lactate (221 mg), KH2PO4 (1 g), MgSO4·7H2O (500 mg), and CaCl2·2H2O (1 g) and 10 ml of mineral solution (16) in tris acetic acid buffer (1.74 g liter-1, pH 4.5). Five inoculated and four noninoculated cultures for each congener were prepared in 125-ml Erlenmeyer flasks and incubated without shaking at 30°C. Cultures were harvested on day 15 after inoculation.

PC transformation assays. The ability of P. chrysosporium to degrade 4,4'-DCCB, 3,3',4,4'-TCB, and 2,2',4,4',5,5'-HCB in liquid culture containing 20 ml of culture medium inoculated with 2 ml of filtered conidial suspensions (4 × 106 spores ml-1) obtained from 1-week-old slants was evaluated. Culture medium contained (per liter) glucose (10 g), thiamine·HCl (1 mg), ammonium lactate (221 mg), KH2PO4 (1 g), MgSO4·7H2O (500 mg), and CaCl2·2H2O (1 g) and 10 ml of mineral solution (16) in tris acetic acid buffer (1.74 g liter-1, pH 4.5). Culture medium contained (per liter) glucose (10 g), thiamine·HCl (1 mg), ammonium lactate (221 mg), KH2PO4 (1 g), MgSO4·7H2O (500 mg), and CaCl2·2H2O (1 g) and 10 ml of mineral solution (16) in tris acetic acid buffer (1.74 g liter-1, pH 4.5). Five inoculated and four noninoculated cultures for each congener were prepared in 125-ml Erlenmeyer flasks and incubated without shaking at 30°C. Cultures were harvested on day 15 after inoculation.
RESULTS

P. chrysosporium mineralized 11.6% of the added 4,4'-$^{14}$C]DCB but only negligible amounts of 3,3',4,4'$^{14}$C]TCB and 2,2',4,4',5,5'$^{14}$C]HCB after 28 days of incubation (Fig. 1). No $^{14}$CO$_2$ was evolved from the noninoculated flasks, indicating that mineralization in the inoculated flasks was caused by the fungus. The rate of mineralization increased up to day 20 and leveled off at day 25 for the DCB, whereas with the other congeners there was no change throughout the 28 days. The amount of $^{14}$C volatilized was greatest in flasks containing DCB (ca. 15% in inoculated cultures and 45% in control cultures). Less than 1% of the $^{14}$C from flasks containing the TCB or HCB volatilized (Table 1). There was a major difference between congeners in amounts of hypha-bound radioactivity: 11% of the $^{14}$C in the DCB cultures was biomass bound, whereas >60% of the TCB and HCB congeners was sorbed to the mat. In the DCB cultures, about 9% of the $^{14}$C was not extracted with ethyl acetate; with the TCB or HCB, radioactivity in this fraction was negligible.

In the time course study, the mass balance analyses of $^{14}$C from 4,4'-[$^{14}$C]DCB indicated that during the first 12 days, most (up to 60%) of the $^{14}$C was adsorbed by the hyphae and the glassware (Table 2). As the experiment progressed, the amounts of $^{14}$C converted to $^{14}$CO$_2$ and volatilized increased. On day 40, mineralization of the DCB appeared to decrease. However, it was noted that from day 14 forward mineralization levels in the three P. chrysosporium cultures harvested on the last day lagged behind those for the rest of the cultures (data not shown). The amount of aqueous $^{14}$C (i.e., extractable and nonextractable) increased until day 26, after which time the amount of $^{14}$C recovered in these fractions remained relatively stable. After an initial increase to 54% during the first week, the amount of hypha-bound $^{14}$C decreased to 17% at day 26. Subsequently the amount of radioactivity sorbed to the hyphae did not change appreciably. The amount of $^{14}$C associated with the glassware decreased after 1 week (Table 2). However, there was always a significant fraction (i.e., 6 to 11%) of radioactivity adsorbed to the glassware. Total $^{14}$C recoveries for the time course study averaged 72% ± 6.47%.

Radioactivity profiles of HPLC fractions from the time course study showed degradation of 4,4'-DCB and formation of metabolites during the 40-day incubation. The most prominent radioactive peak occurring in all samples was identified as 4,4'-DCB by GC-MS analysis of the relevant fractions. Metabolite accumulation was apparent by day 12, as evidenced by the increasing amounts of radioactivity in 30- to 35-ml fractions. By day 26, a significant radioactive peak was observed and subsequently identified as 4-CBA by GC-MS analysis of its TMS derivative (Fig. 2). The TMS derivative yielded a weak molecular ion at m/z 228 and an abundant ion at m/z 213 (-CH$_3$, loss); this pattern is typical for mass spectra of 4-CBA.
TMS ethers and esters. Also characteristic of a TMS-aromatic acid mass spectrum was the loss of CO$_2$ following skeletal rearrangement of the silicon atom to the aromatic ring, in this case yielding m/z 169. Other diagnostic ions were m/z 139 (loss of the silicon-centered analog of acetone from m/z 213) and m/z 111 (carbon monoxide loss from m/z 139). A TMS derivative of an authentic 4-CBA standard gave an identical fragmentation pattern. The radioactive 4-CBA peak was no longer present in samples analyzed on days 34 and 40; at these time points other compounds had formed that eluted much later (i.e., 30- to 40-ml fractions) than did 4-CBA, indicating the conversion of 4,4'-DCB to more polar products.

The presence of hydroxylated metabolites of 4,4'-DCB in derivatized HPLC fractions was assessed by selected ion monitoring. Hydroxylated 4,4'-DCB transformation products scanned for, but not detected, were dichlorodihydroxy-, dichlorohydroxy-, chlorohydroxy-, and chlorodihydroxy-biphenyls. The ring cleavage product expected to be produced from 4,4'-DCB by the meta pathway, 2-hydroxy-3-chloro-6-oxo-(4-chlorophenyl)hexa-2,4-dienoic acid, was also scanned for but not found.

The identification of 4-CBA as a transformation product of 4,4'-DCB was confirmed by the isotope trapping experiment in which 4-CBA was detected in HPLC-fractionated culture extracts by GC-MS analysis and by TLC-autoradiographic analysis of the ethyl acetate extracts. The GC-MS analyses of HPLC-fractionated extracts confirmed the presence of 4-[14C]CBA in both the nonacidified and acidified ethyl acetate extracts from cultures that received only 4,4'-[14C]DCB and in the nonacidified extracts from cultures that received both 4,4'-[14C]DCB and nonlabeled 4-CBA (Fig. 3). In addition, 4-CBAlc was identified by GC-MS in fractions from the latter cultures (Fig. 3). The mass spectrum of the TMS derivative of this compound showed a weak molecular ion at m/z 214 and an abundant fragment ion at m/z 199 (Fig. 4). As described above, this pattern is consistent with methyl radical loss from the center of TMS derivatives. A skeletal rearrangement similar to that described above for TMS-aromatic acids is also expected for the benzyl-TMS ether; this results in the loss of formaldehyde from the M-CH$_3$ precursor and gives the ion m/z 169. Other diagnostic ions in the mass spectrum were m/z 179 (Cl loss from m/z 214) and m/z 125 (loss of the silicon-centered analog of acetone from m/z 199). The mass spectrum of a TMS-derivatized authentic standard of 4-CBAlc was identical to that shown in Fig. 4.

Further confirmation that 4-CBA and 4-CBAlc were 4,4'-DCB metabolites was provided by the identification of 4-[14C]CBA and 4-[14C]CBAlc in culture extracts. Extracts analyzed by TLC and autoradiography showed that two analytes comigrated with 4-CBA and 4-CBAlc standards. Mass spectra of these compounds were identical to those of TMS-derivatized standards of 4-CBA and 4-CBAlc.
DISCUSSION

Results from the present study were consistent with those of others (7, 20) and indicated that the potential for *P. chrysosporium* to mineralize PCBs decreases as the degree of congener chlorination increases. Moreover, while the $^14$C partitioning analysis indicated fairly extensive degradation of 4,4'-DCB, there was little evidence for significant metabolism of either 3,3',4,4'-TCB or 2,2',4,4',5,5'-HCB. For the latter two congeners, the greatest difference between the inoculated and noninoculated treatments was the large amount of biomass-bound $^14$C. As others have suggested (10, 20), this radioactivity could represent PCBs transformed by the fungus into compounds that are covalently bound to cellular macromolecules. While this possibility cannot be ruled out, it seems more likely that, in the present study, biomass uptake of the radioactivity resulted largely from the phase partitioning rather than fungal metabolism of the PCBs. Indirect support for this hypothesis was the finding that in the time course study, ca. 40% of the $^14$C was sorbed on the same day it was added, and $<$1 h passed between label addition and biomass harvest. The increase to 54% during the subsequent 7 days could also reflect further partitioning and/or metabolic activity resulting in PCB uptake.

The negligible amount ($<$1%) of 3,3',4,4'-TCB mineralization determined in this study was consistent with that determined by Bumpus et al. (7). Comparing the lack of 3,3',4,4'-TCB mineralization with the 10% mineralization of 2,2',4,4'-TCB reported by Thomas et al. (20) further substantiated the possibility that the extent of PCB mineralization by *P. chrysosporium* is affected by the congeners' chlorination patterns. The apparent differential susceptibilities of 2,2',4,4'- and 3,3',4,4'-TCB to degradation by *P. chrysosporium* were similar to that of the PCB-degrading bacteria examined by Bedard et al. (4). These investigators hypothesized that the presence of chlorines in the ortho positions may have facilitated dioxygenase attack, thus allowing for greater bacterial degradation. Whether or not a similar mechanism could account for differential mineralization of PCBs by *P. chrysosporium* remains to be determined.

The importance of congener chlorination patterns in affecting PCB degradation by aerobic bacteria is well established (3, 13). Theories on the effects of chlorination patterns on fungal degradation of PCBs, however, are not as well developed as those for bacteria: the main trend suggested by the literature is a greater resistance of doubly para chlorinated congeners to fungal degradation. For example, analysis of Clophen A 30 incubated with *A. niger* indicated that congeners with chlorines in the 4,4'-positions showed little, if any, degradation; this phenomenon was referred to as "para recalcitrance" (9). Zeddel et al. (23) examined the degradation of a nonspecified technical PCB mixture by three white rot fungi, including *P. chrysosporium*; in all cases 4,4'-DCB was the most recalcitrant DCB congener. However, in the present study, mineralization of 4,4'-DCB was roughly equivalent to that reported by Thomas et al. (20) for 2-chlorobiphenyl, an apparent contradiction of the para recalcitrance theory. With aerobic bacteria, the extent to which 4,4'-DCB and most other PCB congeners are degraded can be strain dependent (4, 17). Similar cultural variability could occur with fungi and may partially explain the relatively high level of 4,4'-DCB degradation observed here.

Mass balances from the congener transformation studies showed that a significant fraction (i.e., up to 61%) of the [$^14$C]PCBs added to the cultures was hypha bound. Results from other investigators have also indicated that substantial amounts of PCBs can be sorbed into fungal mycelia. Thomas et al. (20) reported that about 40% of the radioactivity added as 2,2',4,4'-[$^14$C]TCB was hypha associated, whereas Eaton (10) determined that 23% of the [$^14$C]Aroclor 1254 incubated with *P. chrysosporium* was mycelium bound. In the latter report, an even greater amount of PCB binding might have been expected given that Aroclor 1254 is composed of tri- through heptachlorinated biphenyls. Collectively, results of the present study and those of other investigators demonstrate that absorption of PCBs by fungal biomass, if not accounted for, may cause PCB biodegradation to be overestimated.

The dynamics of $^14$C partitioning between the liquid, solid, and gas phases were elucidated by mass balance analysis of the time course study. During the first 12 days, most (40 to 50%) of the radioactivity added as 4,4'-[$^14$C]DCB was associated with the fungal mats. Subsequently, there was a steady decrease in this fraction with concomitant increases in the amounts of $^14$C recovered in ethyl acetate extracts and as $^14$C0. Although the nature of the mat-bound $^14$C is unknown, this radioactivity could be [$^14$C]PCBs or transformation products nonspecifically sorbed to mycelia and/or $^14$C that has been assimilated into cellular macromolecules. Thomas et al. (20) speculated that the latter possibility probably accounted for the biomass-associated $^14$C (40% of the radioactivity added as 2,2',4,4'-[$^14$C]TCB) measured at the end of their experiment. In the present study, the progressive decrease in mat-bound $^14$C could have reflected catabolism of cellular macromolecules containing $^14$C assimilated from 4,4'-[$^14$C]DCB. Yet, it seems more likely that the progressive decrease in the hypha-bound radioactivity reflected an initial high level of nonspecific sorption of 4,4'-[$^14$C]DCB (or transformation products) followed by degradation to various metabolic intermediates (i.e., as represented by increasing $^14$C in ethyl acetate-extractable and nonextractable fractions) and $^14$C0.

Recoveries of $^14$C in the present study were generally greater than those reported in previous investigations on PCB degradation by *P. chrysosporium*. Eaton (10) reported a 66% recovery of radioactivity from [$^14$C] Aroclor 1254 after a 19-day incubation in liquid culture. In the liquid culture experiments conducted by Thomas et al. (20), $^14$C recoveries ranged from 35% for 2-[ $^14$C]chlorobiphenyl to 53% for 2,2',4,4'-[$^14$C]TCB. By comparison, $^14$C recoveries in inoculated cultures from the mineralization studies presented here were 57 to 85% and averaged 72% in the time course study with 4,4'-[$^14$C]DCB.

Improved $^14$C balances were obtained by accounting for volatilized radioactivity-and $^14$C adsorbed to the culture flasks and associated glassware. In this study, glassware adsorption was a significant sink for PCBs; neither Eaton (10) nor Thomas et al. (20), however, reported glassware adsorption. PCBs may also be lost by volatilization during extended incubation, and the
potential for volatile losses increases as the chlorination level decreases (11). In the present study, significant volatile losses of 4,4'-[14C]DCB occurred in both the mineralization and time course experiments but were much greater in the former. While the reason(s) for this variability was not fully determined, isotope dilution effects might have at least partially accounted for the decreased level of volatilization measured in the time course experiment. The results from the present study suggest that volatile losses can be significant, particularly for the more lightly chlorinated congeners such as 4,4'-DCB. In contrast, Thomas et al. (20) reported negligible volatilization of biphenyl and 2-chlorobiphenyl from noninoculated cultures during a 32-day incubation; more extensive volatilization might have been expected. Eaton (10) did not quantify volatile losses of [14C] Aroclor 1254.

In the present study, 4-CBA and 4-CBAalc were identified as metabolites produced from 4,4'-DCB by *P. chrysosporium*. To the best of our knowledge, this is the first report providing information on degradation products generated from PCBs by a white rot fungus. We also believe that this is the first report implicating a chlorinated benzyl alcohol as a metabolite produced during PCB degradation. Collectively, results of prior investigators’ works and those from the present study suggest that chlorobenzoates may be characteristic intermediates in fungal PCB degradation pathways.

Although chlorobenzoates may be metabolites common to both bacterial and fungal PCB degradation pathways, the mechanisms leading to the formation of these compounds may not necessarily be the same. In bacteria, PCBs are metabolized to chlorobenzoates by the *meta* cleavage pathway (2, 13). Dioxygenases are key enzymes of the *meta* pathway, effecting both the initial 2,3-dihydroxylation and subsequent extradiol (i.e., *meta*) ring fission. Fungi also appear to transform PCBs to hydroxychlorobiphenyls (9, 22); the enzymes effecting ring hydroxylation, however, have not been identified. The mechanism(s) by which fungal effect PCB ring fission is also unknown. Fungal dioxygenases that mediate intradiol (i.e., *ortho*) cleavage of aromatic compounds like 1,2,4-trihydroxybenzene have been described previously (8, 19). Information concerning the potential of such enzymes to mediate ring cleavage of hydroxychlorobiphenyls is, however, lacking. Phenol oxidases produced by white rot fungi have also been reported to effect ring fission of phenolic substrates (15). Further study is needed to determine which, if any, of these or other mechanisms are utilized by PCB-degrading fungi.

Another issue raised by this study concerns the relation of 4-CBAalc to 4-CBA in the fungal PCB degradation pathway. At least three possibilities can be proposed. First, the PCB ring fission product may first be transformed to 4-CBA, which is then reduced to 4-CBAalc. Second, 4-CBAalc may be formed first and subsequently oxidized to 4-CBA; lignin-degrading fungi are known to produce extracellular aryl alcohol oxidases that mediate such transformations (14). Third, 4-CBA and 4-CBAalc may be produced independently by parallel metabolic pathways. Additional information is needed to delineate the most likely reaction series.

The present study provides further insights into the degradative activities of *P. chrysosporium* with model PCB congeners. Results from these experiments suggest a number of similarities in PCB biodegradation between *P. chrysosporium* and the well-described bacterial systems. Further work is needed, however, to elucidate the mechanisms by which *P. chrysosporium* effects PCB degradation and to develop a framework within which the susceptibilities of various PCBs to degradation by this organism can be rationalized. Mechanistic information would also further bio Remediation applications by allowing optimal conditions for PCB degradation by *P. chrysosporium* to be determined.

REFERENCES