

Applications and immobilization strategies of the copper-centred laccase enzyme; a review

Supplementary material

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Table S1: Dye and organic pollutant degradation by laccase immobilized on various supports

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>Alcaligenes faecalis</i> XFI	Chitosan clay composite beads	Methyl Red (MR) Remazol Brilliant Blue R (RBBR) Reactive Black 5 (RB5)	82 85 69	24 h	Incubated with the dye in the dark	[1]
<i>A. faecalis</i> XFI	Chitosan beads	MR, RBBR, RB5	55-73	24 h	Incubated with dye in the dark	[1]
<i>Trametes versicolor</i>	Hallow nanospheres (HNS) NH ₂ -MIL88(Fe)	RBBR	92	2 h	Incubated while shaking at 150 rpm at 30 °C	[2]
-	Hydrogel of mixture of sodium alginate (SA), acrylamide (AM), and hydroxyapatite (HA)	p-chlorophenol	80	24 h	Incubated with p-chlorophenol at 30 °C	[3]
<i>Micrococcus</i>	-	CI Acid black 210	96.4	72 h	Incubated with dye at	[4]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>luteus</i>		CI Acid black 234	92.2		pH 7.0 and 37 °C	
<i>Myceliophthora thermophila</i>	Silica particles	Catechol Phenol p-chlorophenol	95 76 60	2 h 24 h 24 h	Incubated at room temperature	[5]
<i>Pleurotus ostreatus</i>	-	Methyl orange Trypan blue Ramazol brilliant red (RBR) RBB	50	3 h	Incubated at room temperature	[6]
<i>P. ostreatus</i>	EUPERGIT C 250L	RBBR	40	-	Continuous fixed bed reactor	[7]
<i>T. versicolor</i>	TiO ₂ NPs/polyvinylidene fluoride (PVDF) sol-gel membrane	Bisphenol A	91.7	96 h	Stainless steel dead-end membrane cell	[8]
	Fe ₃ O ₄ @MoS ₂ @PEI	Malachite green Bisphenol A Bisphenol F	82.7 87.6 70.6		Mixed NC with dyes with ABTS as a mediator while shaking at 180 rpm	[9]
<i>T. versicolor</i>	CS-MNPs	Chlorpyrifos	99	12 h	Erlenmeyer flask while shaking at 150 rpm	[10]
<i>T. versicolor</i>	Cu (II)-chelated chitosan/poly (glycidyl methacrylate) nanoparticles	Phenol	82 96 with ABTS	4 h	Stirred batch assay at 100 rpm at 35 °C	[11]
<i>T. versicolor</i>	MNPs/polydopamine (PDA)	4-chlorophenol	86	2 h	Stirred batch assay at 150 rpm in the dark at 30 °C	[12]
<i>T. versicolor</i>	MNPs/polydopamine	2,4,6-trichlorophenol Triclosan Aqueous Acetaminophen Bisphenol A Diclofenac	84.7 (62.3*) 81.2 (56.5*) 88.3 (68.2) 82.8 (70.1)	12 h	Batch assay at room temperature	[13]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
			86.2 (64.8)			
	MnFe ₂ O ₄ /calcium alginate nanocomposite (NC)	Methylene blue Indigo Acid red 14	82.13 25.09 20.42	1 h	Stirred batch assay at 30 °C and 120 rpm Laccase based NC (L) were used at pH 7	[14]
<i>T. versicolor</i>	Fe ₂ O ₃ /copper alginate beads	Triclosan Remazol brilliant blue R (RBBR)	89.6 75.8	8 h 4 h	For TCS, batch assay with 1-hydroxybenzotriazole (HBT) as a mediator For RBBR, batch assay at room temperature and rotation of 50 rpm	[15]
<i>T. versicolor</i>	PMMA/Fe ₃ O ₄ electrospun nanofibers	Tetracycline	100	40 min	Batch assay at pH 5, 200 rpm, 25 °C in darkness and for 40 min	[16]
<i>Rhus verniciflua</i>	MNPs/chitosan	2,4-Dichlorophenol 4-Chlorophenol	91.4 75.5	12 h	Batch assays at room temperature	[17]
<i>Aspergillus oryzae</i>	CS-MNPs	2,4-dchlorophenol Bisphenol A Indole Anthracene	100 100 70.5 93.3	12 h	Batch assays at 25 °C	[18]
<i>T. versicolor</i>	CS-MNPs	Bisphenol A	85 (Cu(ii)-chelation) 88 (Mn(II)-chelation)	12 h	Batch assays with shaking at 150 rpm at room temperature and pH 5	[19]
<i>T. versicolor</i>	Polyethylenimine (PEI)-MNPs	Phenol	72.93	Stabilized after 150 min	Used a fixed bed reactor under high-gradient magnetic field. Continuous treatment after 18 h 2.38 times higher than batch treatment under the	[20]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
					same conditions.	
<i>T. versicolor</i>	MnFe ₂ O ₄ NPs/chitosan	Diclofenac	78	270 min	Batch assay at room temperature with ABTS as a mediator	[21]
<i>Bacillus sp.</i>	TiO ₂ NPs/alginate	Indigo carmine Alizarin red Trypan blue Malachite green	69.3 61 96 100	60 min	Batch assay at 30 °C under static conditions	[22]
<i>T. versicolor</i>	poly(4-vinylpyridine) grafted Cu(II) chelated magnetic beads	Reactive Green 19 Reactive Red 2 Reactive Brown 10	77 89 92	18 h	Incubated 50 mg/L dye at 30 °C in acetate buffer	[23]
<i>T. versicolor</i>	Mesoporous carbon nanospheres	Tetracycline hydrochloride Ciproflaxin hydrochloride	55, (99.4 with TSA and 99.1 with HBT) 77 (96.9 with TSA and 94 with HBT)	3 h	Incubated at 30°C and 150 rpm	[24]
<i>M. thermophila</i>	methyltrimethoxysilane and tetramethoxysilane sol-gel matrix	Acid Green 27 Estrone (E1) 17β-estradiol (E2) 17α-ethinylestradiol (EE2)	70, 58, 57, and 55 after four consecutive cycles 55 75 60		Continuous operation of packed bed reactor at 24 °C with 30 minutes hydraulic retention time	[25]
<i>Streptomyces psammoticus</i>	Copper alginate beads	Phenolic compounds (gallic acid, tannic acid, ferulic acid,	72 69.9	6 h	Batch studies in a packed bed column reactor	[26]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		resorcinol, guaiacol, catechol, vanillic acid and pyrogallol)				
<i>P. ostreatus</i>	Titania nanoparticles	bisphenol-A Carbamazepine	90 10	6 h 48 h	Stirred hybrid membrane reactor	[27]
<i>T. versicolor</i>	poly(3,4-ethylenedioxythiophene)-polypyrrole/Pt (PEDOT-PPy-COOH/Pt) micromotors	Procyon red Reactive green 5 Reactive brown 10 Reactive green 19 Cibracon blue F3GA Alkali blue 6B Brilliant blue 6	85 74 80 85 76 90 94	10 minutes	Incubated with laccase in presence of 2% of H ₂ O ₂ and 0.2% SDS for movement of micromotors	[28]
<i>T. versicolor</i>	3D chitin scaffolds	Tetracycline	80	24	Packed bed reactor for continuous removal	[29]
<i>T. versicolor</i>	Zinc oxide nanoarray	Tertiary butyl alcohol (TBA)	55.1	108 h	Dropped glass slides in TBA	[30]
<i>Weissella viridescens</i> LB37	CS-MNPs	Direct blue 15 Evans blue Reactive black 5 Acid red 37	95 96 95 97	120 min	Incubated with lac at room temperature in the dark	[31]
<i>T. versicolor</i>	Fe ₃ O ₄ -NH ₂ @MIL-101(Cr) metal organic framework	Reactive black 5 Alizarin red S	81 100	24 h	Incubated at 25 °C while shaking	[32]
<i>Coprinus comatus</i>	Maple biochar	4-hydroxy-3,5-dichlorobiphenyl	71.4	5 h	Incubated with lac in presence of sodium hydroxide	[33]
<i>M. thermophila</i>	Mesoporous amorphous silica (MOF)	Bisphenol A	92	60 min	Incubated at 21 °C while shaking	[34]
<i>M. thermophila</i>	NH ₂ -MIL-53(Al) MOF	Bisphenol A	100	3 min	Incubated at 21 °C while shaking	[34]
<i>T. versicolor</i>	Cellulose beads	Indole	99.7	18 h	Incubated at 30 °C	[35]
	Magnetic MOFs	Methylene blue	91 (96)	20 min	Batch incubation with	[36]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		Crystal violet	93 (98)	(15 min steady state)	stirring at room temperature (continuous treatment in parked bed)	
<i>S. coelicolor</i>	MNPs	Phenol 4-chlorophenol 4-fluorophenol	100 100 100	2 h	Incubated at at 37 °C in the dark with gentle shaking at 50 rpm	[37]
<i>Polyporus durus</i>	nanoporous Zeolite-X	Synthetic wastewater solution A (100 mg/l RB 19, 100 mg/l AB 225, 90 g/l sodium sulfate, and 20 g/l sodium carbonate)	100	45 min	Incubated at 50 °C with shaking at 150 rpm	[38]
		Solution B (100 mg/l RB 19, 100 mg/l RV 5 (Sunzol Brilliant Violet 5 R) a metal complex azo dye, 90 g/l sodium sulfate, and 20 g/l sodium carbonate) AB 225 RB 19	100	45 min		
			100 100	15 min 45 min		
<i>P. ostreatus</i>	<i>Luffa cylindrica</i> fibers	17 α -ethinylestradiol (EE2)	75	8 h	Incubated at pH5 at room temperature	[39]
<i>Pycnoporus sanguineus</i>	Titania NPs	Acetaminophen Diclofenac	90 68	2 h 8 h	Incubated at room temperature, pH 4 in the dark	[40]
<i>T. versicolor</i>	Dealuminated sodium zeolite	Bisphenol A	86.7	1 h	Incubated at 25 °C and	[41]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
					120 rpm	
<i>T. versicolor</i>	Polyimide aerogels	Carbamazepine in a secondary effluent from a WWTP	76	24 h	Incubated at room temperature while stirring at 200 rpm	[42]
<i>R. vernicifera</i>	MNPs	Bisphenol A	84.9	12 h	Incubated at room temperature with shaking at 100 rpm	[43]
<i>T. versicolor</i>	Silica gel	Amoxicillin Ciprofloxacin Carbamazepine Sulfamethoxazole	50 30 50 100	3 h 4 h 4 h 1.5 h	Incubation at 25 °C with continuous stirring in the dark	[44]
<i>T. versicolor</i>	polyacrylamide-alginate cryogel	phenolic compounds in olive mill wastewater Dyes in textile wastewater Congo red Fast Green FCF Sunset Yellow FCF Trypan blue Chlorazol Black	70 55.6 99.1 94.1 97.9 95.7 93.3	5 h	Circulated the solution through laccase-bound cryogel at 25 °C at 100 µL/min flow rate	[45]
<i>T. versicolor</i>	Nanocellulose aerogel	Reactive red X-3B 2, 4-dichlorophenol	94.5% 85.2%	4 h	Incubated at pH 4.5 and 50 °C	[46]
<i>T. versicolor</i>	Geopolymer microspheres (GM)	Congo red	94.78	20 h	Incubated at 25 °C	[47]
<i>T. versicolor</i>	Magnetic CLEAs	Diclofenac	65	48	Incubated at pH 6	[48]
<i>T. versicolor</i>	metal-chelated magnetic silica NPs	Phenolic compounds in apple juice	34.7	2.5	Continuous clarification in a magnetically stabilized fluidized bed	[49]
<i>T. versicolor</i>	MNPs	Acid fuchsin dye	77.41	16 h	Incubated at pH 4.5 and 40 °C while stirring	[50]
<i>T. versicolor</i>	α-Cellulose-Fe ₃ O ₄ -CS	Sulfamethoxazole	82	20 h	Incubated at 30 °C	[51]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
					while shaking at 200 rpm	
<i>Escherichia coli</i>	magnetic zeolitic imidazolate MOFs	Indigo carmine	100	15 min	Incubated at 40 °C while shaking	[52]
<i>Bacillus subtilis</i>	Chitosan beads	Indigo carmine Malachite green	95.24 90	24 h	Incubated at 37 °C	[53]
	HPD-417	Indigo 2, 4-dichlorophenol	65 100	90 min 70 min	Incubated at 55 °C	[54]
	Diatomite	Indigo 2, 4-dichlorophenol	90 100	60 min 60 min	Incubated at 55 °C	[54]
<i>T. versicolor</i>	Glycopolymers microspheres	Paracetamol	96	24 h	Incubated in the presence of ABTS mediator at 40 °C and pH 7	[55]
	Meso-MIL-53(Al) MOF	Triclosan	99.24	120 min	Incubated at 30 °C while shaking at 150 rpm in the dark	[56]
<i>T. versicolor</i>	Fe ₃ O ₄ @SiO ₂ @Kit-6 magnetite NPs	Phenol Lignin in olive pomace	76.5 77.3	6 h	40 °C while shaking at 150 rpm	[57]
<i>T. versicolor</i>	Spent grain	Methyl orange Murexide Methylene blue	70 100 100	150 min 150 min 72 h	pH 5 and 30 °C in presence of ABTS	[58]
<i>Aspergillus sp.</i>	Microporous starch	Atrazine Prometryn	61	7 days	Incubated at 25 °C	[59]
<i>T. versicolor</i>	Fermented tea residues	Malachite green	95	2 h	Incubated at 25 °C while shaking at 150 rpm	[60]
<i>T. versicolor</i>	Micro biochar; pine wood	Diclofenac	100	5 h	Incubated at room	[61]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
	Pig manure Almond shell				temperature, pH 6.5 while shaking at 750 rpm	
<i>T. versicolor</i>	Nafion micelles PANI Copper alginate beads	Acid orange in a microbial fuel cell (MCF)	73 75.6 81		Used the lac system as a cathode and <i>Shewanella oneidensis</i> as the biocatalyst in the anode chamber	[62]
<i>T. versicolor</i>	PVA hydrogel capsules	Saturn Blue L4G	71 (batch) 48 continuous			[63]
<i>T. versicolor</i>	Xylan-PVA hydrogel beads	Reactive Black 5	98.45	6 h	Incubated at 40 °C	[64]
<i>Aspergillus sp.</i>	MOF/PVA cryogel	Alizarin green	95.86	12 h	Incubated at 25 °C while shaking at 150 rpm	[65]
<i>Aspergillus sp.</i>	PVA/HNTs	Reactive blue	93.41	8 h	Incubated at room temperature in presence of ABTS	[66]
<i>Bacillus sp.</i>	Cu-alginate beads	Textile effluent	60 (colour removal)	24 h	Used a continuous flow packed bed reactor	[67]
<i>T. versicolor</i>	poly(methyl methacrylate) (PMMA)/PANI electrospun fibers	Remazol Brilliant Blue R	87	24 h	Incubated at 30 °C and pH 5	[68]
<i>T. versicolor</i>	Eupergit C	Pulp bleaching effluent	40	18 h	Incubated in presence of sulphuric acid	[69]
<i>M. thermophila</i>	Eupergit C	Estrogen	90	50 min	Continuous operation in a fluidized bed reactor	[70]
<i>M. thermophila</i>	Eupergit C 250L	E1 E2 EE2 Acid green 27	65 80 80 88	30 min	Continuous operation in a PBR	[71]
<i>Brevibacterium halotolerans</i>	Alginate-gelatin	Congo red	85	24 h	Incubated at 40 °C pH 5.5	[72]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>P. ostreatus</i>	MANAE-agarose	Bisphenol A	100	1 h	Incubated at pH 5 while shaking at 120 rpm	[73]
<i>T. versicolor</i>	Chitosan beads	Bisphenol A	100	150 min	Incubated while shaking at 30 °C in the dark	[74]
<i>T. versicolor</i>	CS-Fe ₃ O ₄ /HNTs	Sulfamethoxazole	62	24 h	Incubated at 20 °C while shaking at 200 rpm in presence of syringaldehyde	[75]
<i>T. pubescens</i>	CS/genipin	Reactive brilliant blue X RBBR Acid black 127 Congo red Methylene blue Neutral red Indigo blue Naphthol green B Crystal violet	60.3 61.4 77.5 69.5 37.3 48.2 56.3 65.4 40.2	96 h	Incubated at 55 °C in the dark while shaking at 150 rpm	[76]
<i>T. versicolor</i>	MWCNTs/electrospun fibrous membrane	Bisphenol A	90	5 h	Incubated at 25 °C while shaking at 150 rpm	[77]
<i>T. versicolor</i>	Fe ₃ O ₄ -MWCNTs@SiO ₂	Eriochrome Black T (EBT) Acid Red 88 (AR 88) Reactive Black 5 (RB5)	99 98 66	3.5 h	Incubated at 60 °C while stirring	[78]
<i>A. oryzae</i>	Polyssulfone (PSf) membranes blended with MWCNTs	Phenol Resorcinol 4-methoxyphenol 4-chlorophenol Mixture	90 94 100 41 90	1 h 1 h 5 min 1 h 1 h	Incubated while stirring in presence of ABTS	[79]
<i>T. versicolor</i>	Graphene oxide (GO)	Dawood textile	85.69	24 h	Incubated at room	[80]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		Rashid textile Sitara textile Ishaq textile	75.6 88.65 71.25		temperature	
<i>B. subtilis</i>	Magnetic GO	Malachite green	99	5 h	Incubated at 30 °C, pH 6 while shaking at 150 rpm in presence of ABTS	[81]
<i>T. versicolor</i>	Graphene aerogel-Zr-MOF	Hydroquinone	79	24 h	Incubated at 30 °C, pH 3 while stirring	[82]
<i>B. subtilis</i>	Cu-MGO nano-sheets	Congo red	100	5 h	Incubated at 60 °C, pH 8 with shaking at 150 rpm	[83]
	Zeolite NPs/GO nanocomposites	Direct red 23	91	1 h	Incubated at 45 °C	[84]
<i>Phlebia brevispora</i>	Nanoporous alumina	Black liquor	40	40 min	Incubated at 25 °C	[85]
<i>T. hirsuta</i>	Light expanded clay aggregate (LECA)	Reactive Blue 4 RBBR Acid Blue 129	90 95 96	24 h	Incubated at 30 °C while shaking at 100 rpm	[86]
<i>T. hirsuta</i>	LECA	RBBR	94	24 h	Incubated at room temperature while shaking at 100 rpm	[87]
<i>T. versicolor</i>	Mesoporous bentonite clay	Tetracycline	60	3 h	Incubated at room temperature in presence of 1hydroxybenzotriazole (HBT)	[88]
<i>T. versicolor</i>	Clay-adamantylamine	Bromophenol blue Bromothymol blue Coomassie brilliant blue Methyl orange Phenol red	24 71 61 60	48 h	Incubated at 30 °C, pH 4.58 while shaking at 120 rpm	[89]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
			25			
<i>T. versicolor</i>	Clay-CNTs	Bromophenol blue Bromothymol blue Coomassie brilliant blue Methyl orange Phenol red	85 74 91 87 67	48 h	Incubated at 30 °C, pH 4.58 while shaking at 120 rpm	[89]
<i>T. versicolor</i>	Clay-GO	Bromophenol blue Bromothymol blue Coomassie Brilliant blue Methyl orange Phenol red	70 75 91 89 80	48 h	Incubated at 30 °C, pH 4.58 while shaking at 120 rpm	[89]
<i>Alcaligenes faecalis</i>	Chitosan-clay composite beads	Crude textile effluent	78		Used a packed bed reactor system	[90]
<i>T. hirsuta</i>	LECA	RBBR	99.29	3 h	Incubated at 30 °C while shaking at 100 rpm	[91]
<i>T. pubescens</i>	Ca-alginate beads	Bisphenol A	99	2 h	Incubated at 30 °C, pH 5 while shaking at 125 rpm	[92]
<i>M. thermophila</i>	Silica NPs	Lindane	70.5	24 h		[93]
<i>T. versicolor</i>	Mesoporous silica	Bisphenol A	90.1 81	8 h 7.2 mL/min	Incubated at room temperature while stirring at 150 rpm for batch and used a fluidized bed reactor for continuous flow	[94]
White-rot fungi	SBA-15-NH2	2,4-dichlorophenol	89	24 h	Incubated at 40 °C, pH	[95]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
					4	
<i>Pleurotus sp.</i>	Porous CLEAs	Acid violet Basic red Reactive violet Reactive orange	65 70 60 61	2 h 2 h 6 h 6 h	Incubated at 30 °C in complete darkness	[96]
<i>T. versicolor</i>	CLEAs	RBBR Crystal violet Reactive black 5	94.57 90.63 78.72	24 h	Incubated at room temperature pH 4.5	[97]
<i>T. versicolor</i>	Entrapped CLEAs in mesoporous silica	Phenol	100	40 min	Incubated at 25 °C, pH 4.5 and 100 rpm shaking	[98]
<i>Fomes fomentarius</i>	CLEAs	Malachite green Bromothymol blue Methyl red	90 90 95	10 h	Incubated at 22 °C, pH 4.5 in the dark	[99]
<i>T. versicolor</i>	CLEAs	Malachite green Bromothymol blue Methyl red	90 90 95	10 h	Incubated at 22 °C, pH 4.5 in the dark	[99]
<i>T. versicolor</i>	Cross linked enzyme crystals (CLECs)	Chenab textile effluent M-tax effluent Sitara effluent National silk & rayon mills effluent	78.6 75.6 85.5 63.3	24 h	Incubated at 30 °C, pH 4.5 while shaking at 150 rpm	[100]
<i>Aspergillus sp.</i>	GO nanosheets	Direct red 23 Acid blue 92	88.7 48.7	1 h	Incubated at 45 °C while stirring	[101]
<i>M. thermophila</i>	Epoxy- silica	Acid orange 156 acid red 52 Coomassie brilliant blue Methyl violet Malachite green	98 99 97 78 100	4 h	Incubated at 40 °C, pH 4.5	[102]
<i>T. hirsuta</i>	Polyvinylidene fluoride (PVDF)-	Carbamazepine	27	48 h	Incubated at 25 °C	[103]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
	MWCNT	Diclofenac	95	4 h]
<i>T. versicolor</i>	Gelatin ceramic membranes	Tetracycline	30	24 h	Carried out in an enzymatic membrane reactor at 25 °C at flow rate of 0.07 m/s	[104]
<i>Trichoderma harzianum</i>		Paper industry effluent; Color Turbidity Total suspended solids Total dissolved solids BOD COD Residual chlorine	76.74 83.91 71.37 51.49 91.16 88.07 81.08	10 days	Incubated under aerobic conditions	[105]
<i>P. florida</i>		Reactive blue 198	96	10 min	Incubated at 60 °C pH 4.5	[106]
<i>T. versicolor</i>	Magnetic biochar NPs	Bisphenol A	100	75 min	Incubated at room temperature while shaking at 100 rpm	[107]
<i>T. versicolor</i>	Microbiochar	Diclofenac spiked in waste water effluent	100	2 h	Incubated at room temperature, pH 6.5 in waste water effluent	[108]
<i>Sphingobacterium ksn-11</i>	sodium alginate-SiO ₂ -PVA beads	Diclofenac	81	90 min	Incubated at 40 °C, pH 4.5 in presence of ABTS mediator	[109]
<i>T. versicolor</i>	Sepharose-linked antibody	Phenol red	80	6 h	Incubated at 50 °C while stirring	[110]
	Nanocellulose	Malachite green Congo red	98 60	30 min	Incubated at 50 °C in presence of ABTS mediator	[111]
<i>P. ostreatus</i>	Ca-alginate beads	Reactive red 80 Reactive blue 21	67.2 88.05	11 days	Incubated ta room temperature pH 5.5	[112]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>T. villosa</i>	Fe ₃ O ₄ /SiO ₂ NPs	Procion Red MX-5B Azophloxine	80 80	20 min	Incubated at room temperature pH 7	[113]
<i>Paraconiothyrium variable</i>	Porous silica beads	Acid Blue 25 Acid Orange 7	76 64	65 min	Incubated at 40 °C while shaking at 50 rpm	[114]
<i>T. versicolor</i>	Hollow CLEAs	Trypan blue	100	270 min	Incubated at 20 °C, pH 10	[115]
<i>T. versicolor</i>	polyacrylonitrile/montmorillonite/graphene oxide (PAN/MMT/GO) nanofibers	Catechol	39		Used the fiber as a filtration membrane in a membrane reactor	[116]
<i>T. versicolor</i>	PAN-biochar composite nanofibrous membrane	Chlortetracycline	58.3		Carried out in continuous mode in a membrane reactor at a flux-rate of 1 mL/h.cm ²	[117]
<i>P. ostreatus</i>	Perlite (porous silica)	RBBR	71	50 min	Continuously operated fluidized bed reactor at pH 4.5	[118]
<i>Coriolopsis polyzona</i>	Mesoporous silica particles	Bisphenol A	90	1.85 h	Continuous stirred-tank membrane reactor (was efficient for 30 reactor volumes)	[119]
<i>T. versicolor</i>	Ca-alginate beads	Reactive T Blue dye	92	72 h	Incubated at 30 °C, pH 4.5 while shaking at 150 rpm	[120]
<i>T. versicolor</i>	Functionalized GO (fGO)	Pinacyanol chloride Anthracene	100 98.6	300 min 3 days	Incubated at 30 °C, pH 4.58 and stirring of 800 rpm in the dark	[121]
<i>T. versicolor</i>	CS/PVA nanofibrous membranes	2,4-dichlorophenol	87.6	6 h	Incubated at 50 °C and pH 6	[122]
<i>Cerrena sp.</i>	Magnetic CLEAs	Tetracycline Oxytetracycline Ampicillin Sulfamethoxazole	68 60 55 30	48 h	Incubated at 45 °C, pH 6. For tetracycline and oxytetracycline, ABTS was used as a mediator	[123]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		Erythromycin	25			
<i>T. versicolor</i>	Alumina	Melanoidins in industrial molasses effluents	71	48 h	Incubated at 30 ° and pH 8 on a rotating mixer	[124]
<i>T. versicolor</i>	Controlled pore glass	Melanoidins in industrial molasses effluents	74	48 h	Incubated at 30 ° and pH 8 on a rotating mixer	[124]
<i>Cyathus bulleri</i>	PVA beads	Acid red 27	95	5 days	Incubated at room temperature in presence of HOBT mediator	[125]
<i>Shewanella putrefaciens</i>	CLEAs	Malachite green	90	24 h	Incubated at room temperature in the dark	[126]
<i>P. florida</i>	poly(lactic-co-glycolic acid) (PLGA) nanofiber	Diclofenac	100	5 h	Incubated at 30 °C in the dark while shaking at 100 rpm	[127]
<i>T. versicolor</i>	Cu(II)-chelated chitosan NPs	Phenol	96	12 h	Incubated at 35 °C while shaking at 100 rpm in presence of ABTS	[11]
<i>T. versicolor</i>	Chitosan/CeO ₂ microspheres	Methyl red Orange (II)	83.3 92.6	9 days	Incubated at room temperature	[128]
<i>T. versicolor</i>	PVA/CS/MWCNTs	Diclofenac	100	6 h	Incubated at 60 °C, pH 6	[129]
<i>T. versicolor</i>	Fullerene MWNTs Oxidized-MWNTs GO	Bisphenol A	23 97.7 98.9 74.6	24 h	Incubated at room temperature in presence of ABTS at 160 rpm	[130]
<i>T. versicolor</i>	Fullerene MWNTs Oxidized-MWNTs GO	Catechol	33 99.9 99.5 87.1	24 h	Incubated at room temperature in presence of ABTS at 160 rpm	[130]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>Cerrena sp.</i>	CLEAs	RBBR	90	40 min	Incubated at 25 °C, pH 5	[131]
<i>T. versicolor</i>	Poly(methyl methacrylate-co-glycidyl methacrylate) (poly(MMA-co-GMA)) cryogels	Procion Red Reactive Green 5 Reactive Brown 10 Reactive Green 19 Cibacron Blue F3GA Alkali Blue 6B Brilliant Blue 6	81.53 59.81 73.59 66.33 62.95 59.71 61.68	10 min	Passed through a cryogel column using a peristaltic pump at a flow rate of 0.5 mL/min	[132]
<i>ascomycete Paraconiothyrium variabile</i>	Chitosan NPs on glass beads	Congo red	100	15 min	Incubated at 40 °C in presence of HOBT mediator	[133]
<i>T. versicolor</i>	Magnetic GO	Crystal violet Malachite green Brilliant green	94.7 95.6 91.4	180 min	Incubated at 35 °C while shaking at 250 rpm in the dark	[134]
<i>T. versicolor</i>	Fe ₃ O ₄ @C NPs	o-phenylenediamine (OPD)	88	10 h	Incubated at room temperature and 150 rpm	[135]
<i>P. florida</i>	Cellulose nanofiber	simulated dye effluent containing RBBR, RB5, RO16, RR120, and RV5R, NaCl, Na ₂ CO ₃ , NaOH and acetic acid	99	36 h	Incubated at 30 °C, pH 5 while shaking at 50 rpm, in the dark and in presence of HOBT	[136]
<i>T. versicolor</i>	Fe ₃ O ₄ -silica NPs	2,4-dichlorophenol 4-chlorophenol	80.9 64.2	12 h	Incubated at 30 °C, pH 7.9 and while shaking at 150 rpm	[137]
	Polyuria microspheres	RBBR	64.1	300	Incubated at room	[138]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
				min	temperature]
Fungi	MNPs	Reactive green 19A	100	6 h	Incubated at 25 °C, pH 6	[139]
<i>Echinodontium taxodii</i>	Concanavalin A-MNPs	Sulfadiazine Sulfamethazine Sulfamethoxazole	100 100 100	5 min	Incubated at room temperature with mild shaking in presence of mediators syringic acid, syringaldehyde and acetosyringone respectively	[140]
	EDTA-TMS-MNPs	Indigo carmine Congo red	28 44	4 h	Incubated at 40 °C while shaking at 80 rpm	[141]
<i>Aspergillus sp.</i>	Green coconut fiber	Reactive black 5 Reactive blue 114 Reactive yellow 15 Reactive yellow 176 Reactive red 239 Reactive red 180	90 90 70 2 30 28	24 h	Incubated at 35 °C, pH 7 while stirring at 240 rpm	[142]
<i>Cerrena sp</i>	CLEAs M-CLEAs Alginate Chitosan	Malachite green	90	3 h	Incubated at 30 °C and 60 °C	[143]
<i>Corioloopsis gallica</i>	Mesoporous silica spheres	Bisphenol A Diclofenac Mixture	95 70 90		Used a continuously stirred membrane reactor, pH 5	[144]
<i>T. versicolor</i>	ZnONPs MnO ₂ NPs	Alizarin S	95 85	60 min	Incubated at pH 7 under sunlight	[145]
<i>T. versicolor</i>	Polyethersulfone beads	Acid red	88	15 days	Incubated at room temperature	[146]
<i>T. versicolor</i>	Pine wood nanobiochar	Carbamazepine in	86	24 h	Incubated at 25 °C and	[147]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		secondary effluent			200 rpm]
	Polymerr/graphene hydrogels	RBBR	100	3.5 h	Incubated at room temperature	[148]
<i>T. versicolor</i>	Dopamine HNTs	2,4-dichlorophenol	94.6	24 h	Incubated at room temperature	[149]
<i>T. versicolor</i>	hydrogels	Malachite green	100	3 h	Incubated at 25 °C, pH 5 while stirring in presence of HOBT mediator	[150]
<i>Corioloopsis gallica</i>	Ca-alginate beads	RBBR Reactive Black 5 Bismark Brown R Lanaset Grey G	90.3 78.2 52.8 86.5	90 min 24 h 24 h 24 h	Incubated at 30 °C in the dark in presence of HOBT mediator except for RBBR	[151]
<i>T. versicolor</i>	Layer-by-Layer-Assembled membranes	2,4,6-trichlorophenol	80	36 s	Used a pressure cell housing membrane	[152]
<i>P. florida</i>	Agarose gel	Reactive Blue 172	83	10 min	Incubated at 30 °C	[153]
<i>P. ostreatus</i>	poly(methacrylate) beads	Phenol in juice	45	30 min	Incubated at room temperature	[154]
	Cu ²⁺ -chelated silica particles	Pentachlorophenol	82.89	30 min	Incubated at 25 °C at 100 rpm in the dark	[155]
<i>T. versicolor</i>	Porous silica beads	Sulfathiazole Sulfamethoxazole	85 80	60 min	Incubated at 40 °C, pH 5 and 50 rpm in presence of HOBT mediator	[156]
<i>T. versicolor</i>	ZnO/SiO ₂ nanocomposite	Remazol Brilliant Blue B Acid Blue 25	93 82	2 h	Incubated at 25 °C and pH 5.5	[157]
<i>T. versicolor</i>	FeCl ₃ -pecan nutshell	Acid orange 7	70	48 h	Incubated at 30 °C, pH 6 and agitation of 150 rpm	[158]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>T. versicolor</i>	MNPs	Acid Blue 225 Direct Blue 78 Phenol Red Reactive Red 195 Acid Blue 74	83.93 46.2 24.5 8.2 0.0	120 min	Incubated at pH 5 room temperature	[159]
<i>T. versicolor</i>	Magnetic microplates	Acid Blue 225 Direct Blue 78 Phenol Red Reactive Red 195 Acid Blue 74	40.49 100 9.3 20.47 4.34	120 min	Incubated at pH 5 room temperature	[159]
<i>T. versicolor</i>		Acid Blue 225 Direct Blue 78 Phenol Red Reactive Red 195 Acid Blue 74	100 90.15 57.96 52.27 97.04	60 min	Incubated at pH 5 room temperature	[159]
Papaya	Chitosan beads	Indigo carmine	100	8 h	Incubated at 37 °C	[160]
<i>T. versicolor</i>	Chitosan macro beds	Anthracene	60	24 h	Incubated at pH 5 in presence of ABTS	[161]
<i>C. unicolor</i>	Porous silica beads	Bisphenol A Nonylphenol, Triclosan	80 40 60	60 min	Incubated at 30 °C with gentle agitation	[162]
<i>T. versicolor</i>	Poly(2-chloroethyl acrylate), p(CEA) grafted zeolite particles	Reactive red	100	120 min	Incubated at 35 °C while shaking at 150 rpm	[163]
<i>Aspergillus sp.</i>	Magnetic silica NPs	Guaiacol	100	30 min	Incubated at 40 °C, pH 3.5 while stirring	[164]
	Cu ²⁺ -chelated silica particles	2,4-dichlorophenol	91.4	12 h	Incubated at 25 °C, pH 5 in the dark while rotating at 100 rpm	[165]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>T. versicolor</i>	Poly(MA-alt-MVE)- g -PLA/ODA-MMT nanocomposite	Reactive red 3	65	90 min	Incubated at 20 °C, pH 5	[166]
<i>P. ostreatus</i>	Fe ₃ O ₄ /SiO ₂ NPs	Procion Red MX-5B	96	1 h	Incubated at 25 °C, pH 7	[167]
<i>M. thermophila</i>	MWCNTs-cellulose membrane	Reactive black 5	84.26	24 h	Incubated at 25 °C, pH 5 while shaking at 100 rpm in presence of HOBT mediator	[168]
<i>T. versicolor</i>	CS-epichlorohydrin (CHX)-itaconic acid (CHX-g-p(IA))-Cu ²⁺ membranes	Reactive black 5 Cibacron blue F3GA Methyl Orange	43 69 87	8 h	Incubated at 35 °C, pH 5.5 while shaking at 150 rpm in presence of acetosyringone mediator	[169]
<i>Trichoderma harzianum</i>	Sol-gel matrix	Malachite green Methylene blue Congo red	100 90 60	16 h 18 h 20 h	Incubated at 30 °C, pH 6 while shaking at 150 rpm in presence of HOBT mediator	[170]
<i>T. versicolor</i>	PAN–biochar nanofibrous membrane	Chlortetracycline Carbamazepine Diclofenac	63.3 48.6 72.7	8 h	Incubated at room temperature	[171]
<i>T. versicolor</i>	poly(glycidylmethacrylate)-grafted polypropylene film (PP-g-pGMA)	Procion Green H4G Brilliant Blue G Crystal Violet	90 100 99	120 min 60 min 30 min	Incubated at 30 °C, pH 5.5 while shaking at 150 rpm	[172]
<i>T. versicolor</i>	CS grafted polyacrylamide hydrogel	Malachite Green	100	4 h	Incubated at 25 °C, pH 5 while stirring	[173]
	Alginate beads	Direct Blue 2	86	25 h	Incubated at 45 °C	[174]
<i>Pycnoporus sanguineus</i>	Immobead-150 lentikats	m-cresol	88 85	24 h	Incubated at room temperature, pH 3.5 while shaking	[175]
<i>Paraconiothyrium variable</i>	Alginate-gelatin gel	Amido black 10B Bromothymol blue	86.9	20 min	Incubated at 45 °C	[176]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		Coomassie blue G-250 Crystal violet Eosin Malachite green Methyl green Methyl red	53.8 71.4 58.1 32.8 76.3 77.5 52.1			
<i>T. versicolor</i>	Bimodal carbon-based mesoporous magnetic composites (CMMC)	Phenol p-chlorophenol	78 84	12 h	Incubated at 25 °C, pH 6 while shaking at 100 rpm	[177]
<i>T. pubescens</i>	Chitosan beads	Reactive Blue 4 Reactive Blue 19 Direct Red 28 Acid Black 172 Basic Blue 9 Basic Red 5 Vat Blue 1 Acid Green 1 Direct Blue 199 Basic Violet 3	52.26 48.23 54.24 68.84 25.39 44.58 45.12 37.18 56.28 20.81	48 h	Incubated at 50 °C, pH 5 while rotating at 150 rpm in the dark	[178]
<i>T. versicolor</i>	Green coconut fiber	Apple juice	61% colour 29% turbidity		Used a continuous packed bed reactor at 38 °C	[179]
	Titania NPs	Direct Red 31 Acid Blue 92 Direct Green 6	80 60 85	60 min	Incubated at 45 °C, pH 3	[180]
	Mesoporous silica	Alizarin red indigo	73 90	3.5 h 15 min	Incubated at 40 °C, pH 3.4 while shaking at 180 rpm in presence of ABTS mediator	[181]
<i>T. pubescens</i>	Alumina pellets	RBBR	44	42 h	Incubated at room	[182]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
					temperature in the dark]
<i>T. versicolor</i>	Chitosan	Triclosan	100	6 h	Incubated at room temperature pH 5	[183]
<i>Coriolopsis polyzona</i>	CLEAs	Nonylphenol Bisphenol A Triclosan	90 90 90	40 min 130min 40 min	Used a fixed bed reactor at room temperature and pH 5	[184]
<i>T. versicolor</i>	SBA-15	Anthracene	88	48 h	Incubated at 37 °C, pH 7 while shaking at 150 rpm in the presence of ABTS mediator	[185]
White-rot fungi	Sol-gel silica	2,4-Dichlorophenol 2,4,6-trichlorophenol	87.3 99.6	3 h	Incubated at room temperature	[186]
<i>T. versicolor</i>	poly(D,L-lactide) (PDLLA)/ PEO-PPO-PEO (F108) electrospun microfibers	Crystal violet	88	5 h	Incubated at 30 °C, pH 6 while shaking at 100 rpm in presence of ABTS	[187]
<i>P. ostreatus</i>	Chitosan membrane PVDF membrane	Acid black 10 BX	98.2 99.3	120 min	Incubated at 30 °C, pH 6 while shaking at 100 rpm in the dark	[188]
<i>T. versicolor</i>	Poly(vinylamine) microbeads	Direct Blue 1 Direct Red 128	73 87	18 h	Incubated at 30 °C, pH 5.5	[189]
<i>T. versicolor</i>	Poly(acrylamide-N-isopropylacrylamide)/alginate semi-IPNs	Acid orange	75	6 h	Incubated at 30 °C, pH 4.5 while stirring at 90 rpm in presence of ABTS	[190]
<i>T. versicolor</i>	Silica beads	Reactive blue 19	97	3 h	Used a recirculating packed bed reactor at 23 °C, pH 5	[191]
<i>C. unicolor</i>	Silica gel	Indigo carmine	100	50 h	Incubated at 25 °C, pH 5.3 while shaking at 100 rpm	[192]
			96-98	9.7 min	For packed bed reactor	

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
				residence time		
<i>T. versicolor</i>	PAN beads	Bisphenol A Bisphenol B Bisphenol F Tetrachlorobisphenol A	100 100 100 96	90 min	Used a fluidized bed reactor at 25 °C	[193]
	alginate/gelatin beads/PEG	Reactive Red B-3BF	95	60 min	Incubated at 60 °C and pH 5	[194]
<i>C. versicolor</i>	Chitosan	2,4-DCP	88.5	6 h	Incubated at room temperature and pH 6	[195]
<i>T. versicolor</i>	Porous glass beads	Reactive blue 19 Dispersed blue 3 Acid blue 74 Acid red 27 Reactive black 5	82.4 76.2 85.2 27.8 10.3		Used a recirculating packed bed reactor	[196]
<i>T. versicolor</i>	SBA-15	Naphthalene	39	5 h	Incubated at room temperature pH 4.5	[197]
<i>T. versicolor</i>	Magnetic chitosan beads	Reactive yellow 2 Reactive blue 4	82 59	18 h	Incubated at 30 °C and pH 5.5	[198]
<i>M. thermophila</i>	Sepabeads EC-EP3	Reactive Black 5 Acid Blue 25 Methyl Orange RBBB Methyl green Acid Green 27	60 30 45 60 75 75	24 h	Incubated at 30 °C, pH 4.5 while shaking at 90 rpm	[199]
<i>C. unicolor</i>	Mesostructured cellular forms	Indigo carmine	80	5 h	Incubated at 25 °C, pH 5.3 while shaking at 125 rpm	[200]
<i>Aspergillus sp.</i>	Green coconut fiber	Reactive black 5 Reactive Blue 114 Reactive Yellow 15 Reactive Red 180	90 90 80	24 h	Incubated at 35 °C, pH 7	[201]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		Reactive Red 239	30 30			
<i>R. vernificera</i>	Non-porous poly(GMA/EGDMA) beads	Reactive red 120	91	10 h	Incubated at 30 °C and pH 5.5	[202]
<i>T. versicolor</i>	Semi-IPN gels	Methyl orange	70	62 h	Incubated at 30 °C, pH 4.5 in presence of ABTS	[203]
<i>T. versicolor</i>	Poly(glycidylmethacrylate) brush grafted poly(hydroxyethylmethacrylate) films	Phenol p-chlorophenol Aniline	72 81 58	10 h	Incubated ta 30 °C while stirring	[204]
	Alginate/chitosan microcapsules	Alizarin red	66	1 h	Incubated at 40 °C, pH 4.2 while shaking at 120 rpm in presence of ABTS	[205]
<i>M. thermophila</i>		Direct Red 28 Acid Blue 74 Acid Blue 2 Acid Green 27 Reactive Blue 19	9.6 15.2 5 53.3 67.0 31.2	16 h	Incubated at 30 °C while shaking at 100 rpm	[206]
<i>Polyporus pinisitus</i>		Direct Red 28 Acid Blue 74 Acid Blue 2 Acid Green 27 Reactive Blue 19	46.9 90.4 59.8 71.0 58.5	16 h	Incubated at 30 °C while shaking at 100 rpm	[206]
<i>T. versicolor</i>		Direct Red 28 Acid Blue 74 Acid Blue 2 Acid Green 27 Reactive Blue 19	11.9 88.4 66.0 76.0 64.5	16 h	Incubated at 30 °C while shaking at 100 rpm	[206]
<i>T. versicolor</i>	Alginate beads	Indigo carmine Phenol red	96 69	24 h	Incubated at room temperature, pH 5 in presence of HOBT mediator	[207]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
<i>Lentinula edodes</i>	Eupergit® C	Olive mill waste phenolics	78	2 h	Used a packed bed column at 35 °C	[208]
<i>C. versicolor</i>	Celite R-637	2,4,6-trichlorophenol	100	24 h	Incubated at 50 °C, pH 7 in presence of 2,2,6,6-Tetramethylpiperidine-N-oxy (TEMPO)	[209]
<i>T. hirsuta</i>	Alumina	Reactive Blue 221 Reactive Black 5 Direct Blue 71 Basic Red 9 Base Reactive Blue 19 Acid Blue 225 Acid Blue 74	4.1 11.4 39.0 62.26 84.4 78.0 53.7	10 h	Incubated at 30 °C, pH 5 on a rotary shaker	[210]
<i>T. villosa</i>	Alumina	Reactive black 5	83	24 h	Incubated at 45 °C, pH 5 on a rotary shaker	[211]
<i>Bacillus</i> SF	Alumina pellets	Mordant Black 9 Mordant Brown 96 Mordant Brown 15 Acid Blue 74	100 100 100 100	90 min	Incubated at 60 °C while shaking at 40 rpm	[212]
<i>T. versicolor</i>	Kaolinite	Anthracene Benzo[a]pyrene	80 80	24 h	Incubated at 30 °C, pH 4.5 in presence of ABTS	[213]
<i>Panus conchatus</i>	PVA	2,4,6-trichlorophenol	72.5	3 h	Used a recirculating glass column reactor	[214]
<i>P. ostreatus</i>	Eupergit®C	2,6-dimethoxyphenol	100		Used a packed bed reactor at pH 7 and room temperature	[215]
<i>T. versicolor</i>	Silica	RBBR Remazol Black B Reactive Orange 122 Reactive Red 251	45 10 30 50	30 min	Incubated in presence of HOBT	[216]
<i>T. versicolor</i>	PVDF microfiltration membrane	N',N'-(dimethyl)-N-	98	2 h		[217]

Laccase source	Immobilization support	Pollutant	Removal efficiency (%)	Time	Mode of action	Ref
		(2-hydroxyphenyl)urea (2-HF)]
<i>Polyporus versicolor</i>	Cu ²⁺ -chelated sepharose	Phenols Flavanols	39 48		Passed through enzyme carrier at a flow rate of 40 mL/h at 22 °C	[218]
<i>Lentinula edodes</i>	Chitosan	Phenols Ortho-phenols (in olive mill waste)	67 72	24 h	Used a recirculating glass column	[219]
<i>C. versicolor</i>	Activated carbon	Colour in pulp mill bleach effluent Colour in cotton cleaning mill effluent	57 34.7	72 h 7 h	Incubated at pH 5	[220]

Table S2: Storage stability, reusability and kinetic parameters of laccase enzyme immobilized on various supports

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>T. versicolor</i>	CLEAs		85	8.58 0.999*		80% at pH>6 from pH 3 t _{1/2} increased from 40 to 420 min at 50 °C	82% after 7 cycles	[221]
<i>Alcaligenes faecalis XFI</i>	Chitosan clay composite beads (CCB)	88.4	75.5	0.5 0.48*	96 U/mL/min 111*	Increased optimum pH from to a range of 7-10 Retained 65% after 20 days storage	64% and 42% after 9 th and 15 th cycles	[1]
<i>Alcaligenes faecalis XFI</i>	Chitosan beads (CB)	83.6	70	0.663 0.48*	86 U/mL/min 111*	Increased optimum pH from to a range of 7-10 Retained 50% after 20 days storage	Sharp decrease in activity after 5 th cycle	[1]
<i>T. versicolor</i>	Hallow nanospheres (HNS) NH ₂ -MIL88(Fe)	-	75	0.71 0.46*	1.51 times higher than free lac	t _{1/2} increased by 300% at 40 °C and 148% at 80 °C	Maintained >75% activity in range of 30-60 °C, 73.8% after 30 days storage at 4 °C and 89.2% after 6 cycles	[2]
<i>T. versicolor</i>	Mesoporous carbon nanospheres	-	88	-	-	74% after 180 minutes at 60 °C	80% after 8 cycles	[24]
	Hydrogel of mixture of sodium	100	-	665.39 116.95*	-	80% after 72 hours of storage		[3]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
	alginate (SA), acrylamide (AM), and hydroxyapatite (HA)					(21*).		
	Microencapsulated n-docosane with a SiO ₂ shell (SiO ₂ -MEPCM)	92.4	80	-	-	Retained 83% after 15 days storage (38%), 70% at 65 °C (opt=40°C) (30%)	81% and 62% after 6 and 10 cycles respectively	[222]
<i>M. thermophila</i>	Silica particles	-	-	0.0253 0.024*	1.56 U/mL/min 10*	96% after 1 h at 35 °C (35%*)	93% and 65% after 3 and 5 cycles respectively	[5]
<i>T. versicolor</i>	poly(4-vinylpyridine) grafted Cu(II) chelated magnetic beads	56.4 mg enzyme/g beads	936 U/g	0.41 0.32*	17.8 U/mg 23.1*	Retained 74% after 120 minutes incubation at 55 °C (optimum is 30 °C) and 59% after 5 weeks of storage at 4 °C	93% after 7 cycles	[23]
<i>M. thermophila</i>	methyltrimethoxysilane and tetramethoxysilane sol-gel matrix	82.92		0.645 0.056*		98.5% after 3 months storage at 4 °C (95%*)	80% after 10 cycles	[25]
<i>S. psammoticus</i>	Copper alginate beads		61				50% after 8 cycles	[26]
<i>P. ostreatus</i>	Titania nanoparticles	80	125.8	0.0373 ~0.0373		85% after incubation for 2 h at 50 °C (50%*) (optimum temperature is 25 °C)	75% after 30 days storage (0%* after 23 days for free enzyme)	[27]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>T. versicolor</i>	Chitosan (CS) coated MNPs	94.36		11.41 5.69*	14.11 U/mL/min 7.7*	Over 70% in pH range of 3-5 (55% of free enzyme at pH 5)	81% after 30 cycles	[223]
<i>T. versicolor</i>	Titania nanoparticles	51	79	22.3	92.7 U/mL/min		50% after 6 days storage at 25 °C	[224]
<i>T. versicolor</i>	TiO ₂ blended polyethersulfone (PES) membranes		7.4	22.3	60 U/mL/min		75% after 5 days of storage at 25 °C	[224]
<i>T. versicolor</i>	Metal ion chelated CS-MNPs; Cu(II) Mn(II)	100 mg/g 105 mg/g		205 215 98*	578 U/mL/min 293 337*	99% (Cu(II)) and 89% (Mn(II)) after 14 days (17% for free lac)		[19]
<i>A. oryzae</i>	Cu chelated ionic liquid CS-MNPs	62.6	165.6			70.1% after 7h of incubation at 60 °C (7% for free lac). 95 % after 30 days storage (<10% for free lac)	93.2% after 6 cycles	[18]
<i>R. verniciflua</i>	MNPs/chitosan		51.8	30.1 26.3*	112.4 U/mL/min 216.8*	75.2% after 4 weeks storage (40.2% for free lac)	72% after 10 cycles	[17]
<i>T. versicolor</i>	Magnetic polydopamine NPs	81	69	0.546 0.604*	97.85 U/mL/min 204.08*	75% activity in high urea concentrations (0% for free lac). 87% after 6 weeks	77% after 8 cycles	[13]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
						storage (23% free lac)		
<i>T. versicolor</i>	MNPs/polydopamine (PDA)		88.17	0.161 0.157*	0.989 (mM/min) 1.185*	60% after 6 h incubation at 50 °C. 89% after 40 days storage (48% for free lac)	70% after 10 cycles (23% for free lac)	[12]
<i>T. versicolor</i>	Cu (II)-chelated chitosan/poly (glycidyl methacrylate) nanoparticles		52.6	0.07 0.055*	0.14 U/mg 0.19*		50% after 8 cycles	[11]
<i>T. versicolor</i>	CS-MNPs		70	0.58 0.25*	0.25 mM/min 0.9*		95% after 5 cycles	[10]
	Fe ₃ O ₄ @MoS ₂ @PEI		90	0.05843 0.05815*	0.03031 mM/min 0.03175*	68% after 18 days storage (18% for free lac)	80% and 64% after 8 and 10 cycles respectively	[9]
<i>T. versicolor</i>	poly(3,4-ethylenedioxythiophene)-polypyrrole/Pt (PEDOT-PPy-COOH/Pt) micromotors		82.4	0.888 0.401*	0.191 μM/min 0.199*	Increased optimum temperature from 45 to 75 °C. 85% after 30 days storage (25% for free lac)	90% and 81% after 5 and 10 cycles respectively	[28]
<i>T. versicolor</i>	3D chitin scaffolds	91	89	0.113 0.093*	2.7 mM/min 2.88*	93% and 85% after 15 and 30 days storage at 25 °C (80% and 50% for free laccase)	90% after 10 cycles	[29]
	CS-MNPs	28		0.1406 0.0311*		85% after 10 cycles	85% after 4 weeks of	[225]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
							storage (30% for free laccase)	
<i>T. versicolor</i>	Magnetic mesoporous silica nanoparticles (MMSNPs)		92.5	3.28 1.26*		86.6% after 10 cycles. 95% over pH range of 4-5.5	92% after 7 weeks of storage (0% for free lac)	[226]
<i>T. versicolor</i>	CS-manganese-ferrite nanoparticles	49				100% after 20 days (28% for free enzyme)	50% after 4 cycles	[21]
<i>Trichoderma asperellum</i>	CS-Fe ₃ O ₄ @SiO ₂	92.41	91.23	0.05992	9.18 μM/min/mg		70% after 8 cycles	[227]
<i>T. versicolor</i>	Zinc oxide nanoarray	88.6	91.3	0.916 0.452*	0.506 μM/min 0.331*		89.2% after 3 cycles	[30]
-	Nano-zeolite carbon nanotubes		145			80% after 8 days. Reserved 84% at 80 °C incubation	95% and 69% after 5 and 10 cycles respectively	[228]
<i>Weissella viridescens</i> LB37	CS-MNPs			0.91 1.05*	62.57 μM/min 77.9*	85% after 7 days storage	47% after 10 cycles	[31]
<i>T. versicolor</i>	Fe ₃ O ₄ -NH ₂ @MIL-101(Cr) metal organic framework	93.9		0.7 0.1*	1.2 μM/min 1.9*	95% and 88% after 10 and 28 days respectively (80% and 61% for free lac). 49% with incubation at 85 °C for 6 h	92% after 5 cycles	[32]
<i>C. comatus</i>	Maple biochar	64.23	66.5	2.68 0.223*			39.8% after 7 cycles	[33]
<i>Aspergillus sp.</i>	Fe-BTC	100		0.035	0.17	16% after 8 days	18.2% after	[229]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
				0.013*	μmol/min/mg 7.7*		10 cycles	
<i>Aspergillus sp.</i>	ZIF-zni	99		0.022 0.013*	1.32 μmol/min/mg 7.7*	82% and 50% after 8 and 30 days respectively	6.2% after 3 cycles	[229]
<i>T. versicolor</i>	Cellulose beads					96% after 100 days	91.9% and 86.3% after 5 and 10 cycles respectively	[35]
<i>Polyporus durus</i>	nanoporous Zeolite-X	83		2.3 mg/mL 1.7*		100% and 80% after 1 and 2 months respectively (80% and 40% for free lac)	100% and 52% after 7 and 11 cycles respectively	[38]
	Magnetic MOFs	95	95	0.74 mg/mL 0.49*	43.48 μmol/min 29.85*	100% and 95% after 25 and 30 days respectively	100% and 89% after 4 and 10 cycles respectively	[36]
<i>P. ostreatus</i>	<i>Luffa cylindrica</i> fibers					39% after 30 days	24.9% after 4 cycles	[39]
<i>T. versicolor</i>	Dealuminated sodium zeolite	81.12	98.56	0.26 1.01*	1.11 μmol/min 0.24*	82.56% and 73.23% after 14 and 20 days respectively at 4 °C 67.55% and 58.55% after 14 and 20 days at room temperature	91.2% after 10 cycles	[41]
<i>T. versicolor</i>	Polyimide aerogels	17.2				80% and 20% after 5 and 20 days	22% after 7 cycles	[42]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
						(42% and 4% for free lac)		
<i>R. vernicifera</i>	MNPs	81.4	84.3	1.84 1.69*	61.7 μmole/min/mg 68.1*		82.9% after 10 cycles	[43]
<i>T. versicolor</i>	Silica gel	35.4				72% and 47% after 1 and 2 months (44% and 0% for free lac)		[44]
<i>T. versicolor</i>	polyacrylamide-alginate cryogel			0.234 0.0071*	0.0072 U/mg 3.546*	70% after 50 days		[45]
<i>Bacillus sp.</i>	Iron MNPs		99			80% after 100 h (30% for free lac)		[230]
<i>T. versicolor</i>	Nanocellulose aerogel			1.37 0.78*	301.5 μmol/mg•min 403.60*	60.3% after 20 days	76% after 5 cycles	[46]
<i>T. versicolor</i>	Copper ferrite NPs		94.68	3.61 3.63*	34.77 U/mL 33.59*	Increased half-life by 5.7 times 70% after 20 days	70% after 6 cycles	[231]
<i>T. versicolor</i>	Magnetic CLEAs	51		3.95 5.34*	714.29 U/g 8333.33*	90% and 62% after 14 and 60 days storage	50% after 4 cycles	[48]
<i>T. versicolor</i>	Metal-chelated magnetic silica NPs			3.17 1.22*		95.1% after 10 weeks (0% for free lac)	90.3% after 10 cycles	[49]
<i>Ganoderma Lucidum</i>	Electrospun nanofiber membrane			1.84 0.78*	286.5 μmol/mg/min 403.6*	25% after 20 days storage (64.6% for free lac)	83% and 47% after 3 and 10 cycles	[232]
<i>T. versicolor</i>	α-Cellulose-Fe ₃ O ₄ -CS	93.28	99.16			83%, 76% and 68% after 10, 20 and 30 days	80.65% after 10 cycles	[51]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
						storage		
<i>M. thermophila</i>	Poly(glycidyl methacrylate) microspheres			7.3 5.7*	395.1 μmol/min/mg 676.4*	80% after 25 days storage	60% after 6 cycles	[233]
<i>T. versicolor</i>	Poly(glycidyl methacrylate) microspheres			2.5 2.3*	110.2 μmol/min/mg 355.6*	75% after 25 days storage	60% after 6 cycles	[233]
<i>Aspergillus sp.</i>	Poly(glycidyl methacrylate) microspheres			5.4 8.3*	165.1 μmol/min/mg 614.1*	75% after 25 days storage	60% after 6 cycles	[233]
<i>E. coli</i>	magnetic zeolitic imidazolate MOF		75.7%	0.306 0.436*		87.1% after 10 days (50% for free lac)	100% after 5 cycles	[52]
<i>T. versicolor</i>	Glycopolymers microspheres		77.1	1.802			63% and 40% after 6 and 10 cycles	[55]
	Meso-MIL-53(Al) MOF		93.8	0.490 mmol/g 0.415*	297.4 mmol/g/min 325.8*	87.5% after 30 days storage	60% after 8 cycles	[56]
<i>T. versicolor</i>	Fe ₃ O ₄ @SiO ₂ @Kit-6 magnetite NPs			0.345 0.211*	39.59 mmol/g/min 121.25*	70% after 20 days storage	70% after 11 cycles	[57]
<i>T. versicolor</i>	PMMA/Fe ₃ O ₄ electrospun nanofibers	79	88	0.134 0.059*	0.032 mM/s 0.043*	80% after 40 days storage	80% after 5 cycles	[16]
<i>T. versicolor</i>	Spent grain	37	4	0.079 0.041*	4.2 μM/min		42% after 4 cycles	[234]
<i>T. versicolor</i>	Spent grain	33	6.22	0.022 0.041*	3.57 μM/min	100% after 1 month	84% after 7 cycles	[58]
<i>Aspergillus sp.</i>	Microporous starch	64.8				90% after 8 days storage (30% for free lac)		[59]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>T. versicolor</i>	Fermented tea residues						81.3% after 6 cycles.	[60]
<i>T. versicolor</i>	Micro biochar; pine wood Pig manure Almond shell	14.58 31.4 24.3				76% 79% 68% after 60 days storage		[61]
<i>T. maxima</i>	Chicken feathers	74.24	93			94.32% after 3 weeks	95% after 8 cycles	[235]
<i>T. versicolor</i>	Egg shell membrane		57				45% after 6 cycles	[236]
<i>T. versicolor</i>	Xylan-PVA hydrogel beads		16.1			97.48% after 6 days	55% after 8 cycles	[64]
<i>T. versicolor</i>	PVA-alginate beads		76.4	0.012 0.07*	962 U/mL 720*	90% after 28 days		[237]
<i>Aspergillus sp.</i>	MOF/PVA cryogel			0.063 0.022*	0.536 μ M/min 2.191*		68% after 6 cycles	[65]
<i>Aspergillus sp.</i>	PVA/HNTs		79.15			81.17% after 5 weeks (60% for free lac)	80% and 60% after 3 and 6 cycles	[66]
<i>T. versicolor</i>	PVA microspheres					86.3% after 100 days		[238]
<i>Bacillus sp.</i>	Cu-alginate beads	80	120			95% after 15 days	100% after 4 cycles	[67]
<i>T. versicolor</i>	Poly(methyl methacrylate) (PMMA)/PANI electrospun fibers		82	0.098 0.059*	0.029 U/mg 0.045*	86% after 30 days	66% after 10 cycles	[68]
<i>T. versicolor</i>	Eupergit C	51	100				90% after 5 cycles	[69]
<i>M. thermophila</i>	Eupergit C 250L	99	88.4	0.15 0.056*	0.693 mM/min	98.5% and 98% after 1 and 2	65% after 10 cycles	[71]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
					3.33*	months		
<i>P. ostreatus</i>	MANAE-agarose	100	138	0.15 0.091*	0.017 mM/min 0.0107*	80% and 70% after 40 ad 170 days storage (40% for free lac on 40 days)	90% after 15 cycles	[73]
<i>T. versicolor</i>	Chitosan beads		84.7			90% after 28 days	71.24% after 10 cycles	[74]
<i>T. versicolor</i>	CS-Fe ₃ O ₄ /HNT		95.13			70% after 30 days	60% after 10 cycles	[75]
<i>T. pubescens</i>	CS/genipin	49.34		0.128 0.105*		84.43% after 30 days	55% after 11 cycles	[76]
<i>T. versicolor</i>	MWCNTs/electrospon fibrous membrane		85.3	0.063 0.016*		80% after 60 days	90% after 10 cycles	[77]
<i>T. versicolor</i>	Fe ₃ O ₄ -MWCNTs@SiO ₂			0.447 0.502*	20.785 mM/min 8.663*	79% after 30 days (48% for free lac)	87% after 10 cycles	[78]
<i>T. versicolor</i>	Graphene oxide	96.87	74.18	0.053 0.062*	932.7 U/mL 765.1*		40% after 7 cycles	[80]
<i>B. subtilis</i>	Magnetic GO			0.404 0.237*	1.76 mM/min 1.54*	80% after 30 days	90% and 75% after 5 and 10 cycles respectively	[81]
<i>B. subitillis</i>	Cu-MGO nano-sheets		114	1.62 1.57*	9.7 μmol/min.mg 5.99*	80.7% after 32 days storage (9.8% for free lac)	89.4% after 10 cycles	[83]
	Zeolite NPs/GO nanocomposites					80% after 8 days	95% after 5 cycles	[84]
<i>T. versicolor</i>	Fe ₃ O ₄ /GO nanocomposite		86	0.073 0.045*	1.4 mM/min 2.9*	88% after 20 days storage	85% after 8 cycles	[239]
<i>T. versicolor</i>	Fe ₃ O ₄ /GO		88	1.8	26 mM/min	83% after 30 days	80% after 10	[240]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
	nanocomposite			1.3*	56*	storage (45% for free lac)	cycles	
<i>T. versicolor</i>	Mesoporous alumina		60	0.11 0.18*	84.03 μmol/min 26.95*	65% after 30 days	80% and 60% after 8 and 10 cycles respectively	[241]
<i>Phlebia brevispora</i>	Nanoporous alumina	18.1					95.6% after 4 cycles	[85]
<i>T. versicolor</i>	Clay-adamantylamine	73		0.06 0.13*	0.23 μM/min.μg 9.31		58.6% after 6 cycles	[89]
<i>T. versicolor</i>	Clay-CNTs	69		0.15 0.13*	1.62 μM/min.μg 9.31		56.5% after 6 cycles	[89]
<i>T. versicolor</i>	Clay-GO	72		0.09 0.13*	2.39 μM/min.μg 9.31*		47.6% after 6 cycles	[89]
<i>T. hirsuta</i>	LECA		78.78	384 mg/L 500*	218.2 mg/L/h 195.2*		79.67% after 6 cycles	[91]
<i>T. pubescens</i>	Ca-alginate beads	80.4		0.325 0.0951*	1.296 mM/min 9.921*	90% after 35 days storage	70% after 10 cycles	[92]
<i>M. thermophila</i>	Silica NPs	68.3					70% after 7 cycles	[93]
<i>T. villosa</i>	Functionalized ionic liquid SBA-15 (FIL-SBA-15)	85				100% and 85% after 5 and 30 days storage at 25 °C	85% after 4 cycles	[242]
<i>T. versicolor</i>	Mesoporous silica	30.3	12.1	0.032 0.020*	0.023 μM/min 0.045*		50% after 6 cycles	[94]
White-rot fungi	SBA-15-NH2		59.6	47.3 32.9*			56% after 5 cycles	[95]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>T. versicolor</i>	Single enzyme nanoparticles (SEN)		66.33	0.3955 0.5765*	1.451 U/mg 2.404*	90% after 15 days		[243]
<i>Pleurotus sp.</i>	Porous CLEAs		185	0.67 0.93*	0.0248 mM/min 0.0122*	100%, 92.8% and 82% after 2, 3 and 4 moths respectively	60% after 15 cycles	[96]
<i>T. versicolor</i>	CLEAs	78.18	72.85	0.122 0.168*	516.8 U/mL 452.7*		60% after 8 cycles	[97]
<i>T. versicolor</i>	Entrapped CLEAs in mesoporous silica		87.7			100% and 50% after 5 and 21 days storage	79% after 20 cycles	[98]
<i>Fomes fomentarius</i>	CLEAs			0.39 0.087*	0.4 U/mg 0.029*	74% after 70 days	50% after 6 cycles	[99]
<i>T. versicolor</i>	CLEAs			0.8 1.9*	0.3 U/mg 0.027*	80% after 70 days	50% after 8 cycles	[99]
<i>T. versicolor</i>	Cross linked enzyme crystals (CLECs)			0.0552 0.0586*	934.41 U/mL 840.3*		70% and 50% after 3 and 5 cycles respectively	[100]
<i>Aspergillus sp.</i>	GO nanosheets	64.6		1.16 0.71*	0.0459 mM/min 0.0621*		75% after 6 cycles	[101]
<i>M. thermophila</i>	Epoxy- silica			5.3 1.5*	0.6 IU/mg 9.4*		78% and 61% after 6 and 8 cycles respectively	[102]
<i>T. hirsuta</i>	Polyvinylidene fluoride (PVDF)-MWCNT		38.31				45% and 10% after 3 and 8 cycles respectively	[103]
<i>T. versicolor</i>	Magnetic biochar					81.8% after 30	85% after 7	[107]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
	NPs					days storage	cycles	
<i>Trametes sp</i>	Magnetic bacterial cellulose	70		0.94 0.03*	7.24 μ M/min 11.39*		65% after 8 cycles	[244]
<i>T. versicolor</i>	Microbiochar					80% after 5 weeks storage	46% after 5 cycles	[108]
<i>Sphingobacterium ksn-11</i>	sodium alginate-SiO ₂ -PVA beads			2.12*	33.33 U/mg*	100% after 20 days storage	70% after 3 cycles	[109]
<i>T. versicolor</i>	Sepharose-linked antibody	83.4		0.055 0.0439*	4.098 mM/min 4.938*	75% after 30 days (36% for free lac)	44% after 10 cycles	[110]
<i>T. versicolor</i>	PAN-biochar composite nanofibrous membrane					71% after 1 month storage	50% after 7 cycles	[117]
<i>Ganoderma lucidum</i>	Cu-chelated amidoxime PAN (Cu-AOPAN)			0.84 0.114*		65% after 20 days	49.17% after 10 cycles	[245]
<i>T. versicolor</i>	Fe ₃ O ₄ -HNTs	90.2		0.09 0.08*		87% after 30 days storage (50% for free lac)	80.49% after 9 cycles	[246]
<i>Agaricus bisporus</i>	Semi-interpenetrating polymer networks (semi-IPNs) of polyacrylamide/ κ -carragennan			0.131 0.088*	0.00497 mM/min 0.00283*	80% and 68% after 27 and 60 days storage	67.5% after 35 cycles	[247]
<i>T. versicolor</i>	Ca-alginate beads	89		0.0775 0.0799*	0.8764 mM/min 0.7207*	72.8% after 28 days (46.5% for free lac)	68% after 3 cycles	[120]
<i>T. versicolor</i>	Poly(amido amine) (PAMAM) Dendrimers			2.97 0.2*	0.25 μ mol ABTS/min/mg	100%, 75%, 60% and 50% after 30, 60, 90 and 120		[248]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
					6.32*	days storage respectively		
<i>T. versicolor</i>	CS/PVA nanofibrous membranes		69.1	0.019 0.014*		60% after 10 days (0% for free lac)	54% after 7 cycles	[122]
<i>Ganoderma lucidum</i>	PVA membrane		65.71	3.82 6.08*	0.617 mM/min 0.323*	100% after 15 days		[249]
<i>T. versicolor</i>	Alumina	87.5	97	0.00313 0.00345*	0.0662 mM/min 0.022*		75% after 7 cycles	[124]
<i>T. versicolor</i>	Controlled pore glass	69	92	0.0069 0.00345*	0.00134 mM/min 0.022*		65% after 5 cycles	[124]
<i>Cyathus bulleri</i>	PVA beads	90		65 37*		80% and 70% after 4 and 5 months	90% after 20 cycles	[125]
<i>Shewanella putrefaciens</i>	CLEAs			0.55 0.75*			60% after 5 cycles	[126]
<i>P. florida</i>	poly(lactic-co-glycolic acid) (PLGA) nanofiber		82	0.809 0.422*	2.1 U/mg 3.4*	100% after 6 weeks (50% for free lac)	100% after 3 cycles	[127]
<i>T. versicolor</i>	Cu(II)-chelated chitosan NPs		52.6	0.07 0.055*	0.14 U/mg 0.19*		50% after 8 cycles	[11]
White-rot fungi	Cu-MOF		95.2	0.157 0.29*	0.058 mM/min 0.068*	18.8% after 3 weeks storage	48.45 after 7 cycles	[250]
<i>T. versicolor</i>	Bacterial nanocellulose	42.3	8.6				69% after 7 cycles	[251]
<i>T. versicolor</i>	Chitosan/CeO ₂ microspheres		66.9	0.101 0.028*	0.226 mmol/mg/min		60% after 10 cycles	[128]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
					0.38*			
<i>T. versicolor</i>	PVA/CS/MWCNTs		76.7			80% after 30 days	62.7% after 7 cycles	[129]
<i>T. versicolor</i>	Fullerene MWNTs Oxidized-MWNTs GO			0.51 0.08 0.12 0.14 0.055*				
<i>T. versicolor</i>	Poly(methyl methacrylate-co-glycidyl methacrylate) (poly(MMA-co-GMA)) cryogels			11.11 5.26*	0.013 $\mu\text{M}/\text{min}$ 0.016*	85.5% after 30 days (52.8% for free lac)	90% after 10 cycles	[132]
<i>ascomycete Paraconiothyrium variable</i>	Chitosan NPs on glass beads	68.6	32.2				98% after 25 cycles	[133]
<i>T. versicolor</i>	Magnetic GO		97.9				59.8 after 10 cycles	[134]
<i>T. versicolor</i>	Fe ₃ O ₄ @C NPs			0.117 0.0737*	0.344 mmol/mg.min 0.417*	70% after 30 days storage (0% for free lac)	60% after 10 cycles	[135]
<i>P. florida</i>	Cellulose nanofiber		88	0.343 0.161*	2.76 U/mg 2.93*		67% after 10 cycles	[136]
<i>T. versicolor</i>	PGMA microspheres			12.31 13.88*	49.12 mg/L.min 127.7*	81.8% after 20 days (60% for free lac)	73.3% after 5 cycles	[252]
<i>T. versicolor</i>	Fe ₃ O ₄ -silica NPs			5.32 1.86*		62.5% after 28 days (41.1% for free lac)	70.4% after 11 cycles	[137]
<i>Alternaria</i>	Ca ²⁺ (AlgChG)	93		4.375	1250	84% after 42 days	68% after 19	[253]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>tenuissima</i>	beads			0.666	U/mL/min 1110*		cycles	
	Polyuria microspheres	95				60% and 40% after 10 and 30 days storage at room temperature	92% and 65% after 3 and 7 cycles	[138]
<i>T. versicolor</i>	Cu ²⁺ chelated PEI-Fe ₃ O ₄ NPs		107.41	0.598 0.527*	2.22 μmol/min.mg 12.37*	95.45% after 1 month storage	58.89% after 5 cycles	[254]
Fungi	MNPs	97.6	65.32			70% after 25 days	80% and 45% after 5 and 10 cycles respectively	[139]
<i>Echinodontium taxodii</i>	Concanavalin A-MNPs	82.4	60.7	0.0352 0.0414*	4.3 μM/min 5.9*		85% after 10 cycles	[140]
<i>Echinodontium taxodii</i>	MNPs	93.8	98.0	0.0427 0.0414*	7.0 μM/min 5.9*		60.1% after 10 cycles	[140]
	EDTA-TMS-MNPs		97	0.0375 0.0234*	0.00612 mM/min 0.0376*		73% after 5 cycles	[141]
	TiO ₂ -Montmorillonite Complexes		88.46	1.303 0.257*	7.01 μmole/mg/min 62.112*		80% and 45% after 5 and 20 days	[255]
<i>Aspergillus sp.</i>	Green coconut fiber	70		0.7651 0.0044*	0.24 mM/min 0.024*	60% after 1 day storage	120% after 10 cycles	[142]
<i>C. sp</i>	CLEAs		68.1	0.0375 0.0259*	171.4 mM/min.mg 123*			[143]
<i>C. sp</i>	M-CLEAs		46.8	0.0524 0.0259*	111.2 mM/min.mg 123*			[143]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>C. sp</i>	Alginate		29.8	0.0425 0.0259*	16.9 mM/min.mg 123*			[143]
<i>C. sp</i>	Chitosan		50.1	0.0525 0.0259*	8.3 mM/min.mg 123*			[143]
<i>T. versicolor</i>	Polyethersulfone beads		78	0.196 0.0495*	2.15 μ mol/min 2.75*	100% after 20 days		[146]
<i>T. versicolor</i>	Pine wood nanobiochar					69% and 15% after 5 and 30 days at room temperature (42% and 0% for free lac)	70% after 3 cycles	[147]
<i>T. versicolor</i>	Amberlite IR-120 H beads		78.7	4.7 0.051*	5.27 μ M/s 27.7*	98.6% after 7 days (81.5% for free lac)	30% after 7 cycles	[256]
<i>T. versicolor</i>	Dopamine HNTs		92			90% after 30 days (32.31% for free lac)	70% after 10 cycles	[149]
<i>Coriolopsis gallica</i>	Ca-alginate beads	90	83			82.7% after 20 days storage	70% after 3 cycles	[151]
<i>T. versicolor</i>	Layer-by-Layer-Assembled membranes			0.088 0.0138*		95% after 25 days storage	86% after 4 cycles	[152]
<i>P. florida</i>	Agarose gel	88		0.0025	1.65 μ M/min	96%, 93%, 90%, 85%, 81% and 65% after 7, 14, 21, 28, 35 and 61 days storage		[153]
<i>P. ostreatus</i>	poly(methacrylate)	98		0.032		95% and 90%	67% after 10	[154]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
	beads			0.16*		after 4 and 6 months storage	cycles	
<i>T. versicolor</i>	Fe ₃ O ₄ -rGO	91.1	112	0.0303 0.2933*		90.1% after 30 days storage	92.6% after 10 cycles	[257]
<i>T. versicolor</i>	Porous silica beads			0.056 0.082*	190 mM/min.mg 240*	65.3% after 14 days storage at 25 °C (5% for free lac)	82.6% after 10 cycles	[156]
<i>T. versicolor</i>	ZnO/SiO ₂ nanocomposite					80% after 100 days storage at 25 °C	42% after 10 cycles	[157]
<i>T. versicolor</i>	MNPs	62.9	2.82	9.02 10.55*			55% after 9 cycles	[159]
<i>T. versicolor</i>	Magnetic microplates	48.7	2.81	11.14 10.55*			47% after 9 cycles	[159]
	Polyacrylonitrile (PAN) nanofibrous membrane					60% after 20days	70% and 30% after 3 and 10 cycles	[258]
Papaya	Chitosan beads	100	98	0.14 0.04*	0.02 mM/min 0.04*	80% after 30 days	44% after 3 cycles	[160]
<i>T. versicolor</i>	Poly(2-chloroethyl acrylate), p(CEA) grafted zeolite particles			0.47 0.36*	21.9 U/mg 15.5*	78% after 8 weeks storage	79% and 67% after 5 and 8 cycles	[163]
<i>Aspergillus sp.</i>	Magnetic silica NPs		53.4			90%, 79.25% and 60.35% after 9, 18 and 30 days storage (60%, 0% and 0% for free lac)	60% after 5 cycles	[164]
	MNPs		40	0.0062 0.0015*	0.062 mM/min	87% after 35 days storage	75% after 6 cycles	[259]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
					0.315*			
<i>Aspergillus sp.</i>	Spent grain	94	75	0.355 0.028*		100% after 35 days storage	95% after 10 cycles	[260]
<i>T. versicolor</i>	Poly(MA-alt-MVE)-g-PLA/ODA-MMT nanocomposite					65% after 30 days storage (18% for free lac)	77% after 10 cycles	[166]
<i>A. oryzae</i>	MWCNTs	98		0.192 0.0068*	0.586 mM/min 1.416*	90% after 34 days storage (60 % for free lac)	70% after 10 cycles	[261]
<i>P. ostreatus</i>	Fe ₃ O ₄ /SiO ₂ NPs			0.74 0.13*	0.051 mM/min 0.022*	96% after 5 months storage	80% and 50% after 20 and 50 cycles respectively	[167]
<i>M. thermophila</i>	MWCNTs-cellulose membrane					49% after 6 h of incubation in acetone (21% for free lac).	95% after 10 cycles	[168]
<i>T. villosa</i>	SBA-15 mesoporous silica						78% after 4 cycles	[262]
<i>T. versicolor</i>	CS-epichlorohydrin (CHX)-itaconic acid (CHX-g-p(IA))-Cu ²⁺ membranes	9.7		41.6 19.7*	16.5 U/mg 20.4*	63% after 8 weeks (0% for free lac after 5 weeks)	81% after 30 cycles	[169]
<i>Trichoderma harzianum</i>	Sol-gel matrix		93	2 0.5*	500 U/mg 285*	98% after 8 days of storage	82% after 6 cycles	[170]
<i>T. versicolor</i>	PAN-biochar nanofibrous membrane					94% after 30 days storage (32% for free lac)	17% after 10 cycles	[171]
<i>T. versicolor</i>	PEI-CS films			0.51 0.23*	71.2 U/mg 96.4*	64% after 7 weeks		[263]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
White-rot fungi	Mesoporous Zr-MOF		95.9	0.217 0.33*	0.072 mM/min 0.08*	55.4% after 3 weeks storage	50% after 10 cycles	[264]
<i>T. versicolor</i>	poly(glycidylmethacrylate)-grafted polypropylene film (PP-g-pGMA)		72.3	0.53 0.38*	17.5 U/mg 23.4*	91% and 57% after 15 and 30 days storage (0% for free lac)	53% after 8 cycles	[172]
<i>M. thermophila</i>	Bacterial cellulose		49.3			78% and 54% after 7 and 42 days storage (90% and 94% for free lac)	86% after 7 cycles	[265]
<i>T. versicolor</i>	CS grafted polyacrylamide hydrogel		40.8	1.68 0.156*	3.91 μ M/min 2.15*		40% after 6 cycles	[173]
	Alginate beads		94			80.83% after 10 days storage	80% after 4 cycles	[174]
<i>Pycnoporus sanguineus</i>	Immobead-150	97.1					86% after 5 cycles	[175]
<i>Pycnoporus sanguineus</i>	Eupergit-C	83.2					89% after 5 cycles	[175]
<i>Pycnoporus sanguineus</i>	LentiKats	89					90% after 5 cycles	[175]
<i>T. pubescens</i>	Chitosan beads					50% and 40% after 10 and 30 days storage	60% after 6 cycles	[178]
<i>T. versicolor</i>	Green coconut fiber	98	59				100% after 10 cycles	[179]
<i>T. versicolor</i>	Silica NPs	75.8	92.9	0.0456 0.0293*	1.63 mmol/min.m g 1.89*		82.6% after 10 cycles	[266]
<i>T. versicolor</i>	Chitosan	94					96% and	[183]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
							92% after 5 and 10 cycles	
<i>Trametes sp.</i>	PEI microcapsules printed on paper substrate	94				70% after 5 months storage		[267]
	PEG-g-F68 hydrogels	99.6	100			90% after 3 months		[268]
<i>T. villosa</i>	Aluminium hydroxide			0.15 0.18*	12.77 mmol O ₂ /min 14.35*	80% after 7 days		[269]
White-rot fungi	Sol-gel silica	99.1	70	9.91	5 mM/h	72.1% after 6 weeks storage		[186]
<i>T. versicolor</i>	poly(D,L-lactide) (PDLLA)/ PEO–PPO–PEO (F108) electrospun microfibers		67			75% and 50% after 1 and 2 weeks storage	53% after 10 cycles	[187]
<i>Pycnoporus sanguineus</i>	ZnTAPc-Fe ₃ O ₄ nanocomposite	25		0.0201 0.0126*		85% after 1 month (30% for free lac)	80% after 5 cycles	[270]
<i>R. vernicifera</i>	Chitosan microspheres	56	45			90% after 3 months	85% after 15 cycles	[271]
<i>T. versicolor</i>	Poly(vinylamine) microbeads	76	76	4.65 0.276*	15.8 U/mg 20.7*	74% after 8 weeks	37% after 5 cycles	[189]
<i>T. versicolor</i>	Poly(acrylamide-N-isopropylacrylamide)/alginate semi-IPNs		90	18 6.7*	0.0061 mM/min 0.0018	86% after 56 days storage	84% after 10 cycles	[190]
<i>T. versicolor</i>	PAN beads			0.23 0.18*	0.97 μmole/min/mg 11.94*	85% after 30 days with everyday reuse for 90 min		[193]
<i>T. versicolor</i>	Nanoporous gold					100% after 1	65% after 8	[272]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
	(NPG)					month (70% for free lac)	cycles	
<i>T. versicolor</i>	Magnetic mesoporous silica		79.4				70% after 10 cycles	[273]
<i>T. versicolor</i>	Magnetic chitosan beads		79.6	0.0197 0.0094*	15.6 U/mg 21.7*	80% after 8 weeks	87% after 10 cycles	[198]
<i>M. thermophila</i>	Sepabeads EC-EP3	32.6				97.5% and 96.2% after 2 and 4 months storage	84% after 17 cycles	[199]
<i>C. unicolor</i>	Mesostructured cellular forms	45.5	48.8	0.1334 0.0394*		74.2% after 1 month storage		[200]
<i>T. versicolor</i>	Ceramic honeycomb					57% after 3.5 months storage	41% after 21 cycles	[274]
<i>Aspergillus sp.</i>	Green coconut fiber	13	45.7	0.0501 0.0044*	0.133 mM/min 0.024*		70% and 55% after 5 and 13 cycles	[201]
<i>R. vernificera</i>	Non-porous poly(GMA/EGDM A) beads	88		0.47 0.23*	77.6 U/min 96.4*	52% after 8 weeks storage (0% for free lac)	50% after 6 cycles	[202]
<i>C. unicolor</i>	DEAE-Granocel 500	42.7	92.7			98% after 4 months		[275]
<i>T. versicolor</i>	Semi-IPN gels	94		10.8 0.0067*	0.0044 mM/min 0.0018*	80% after 42 days storage	50% after 10 cycles	[203]
<i>T. versicolor</i>	Poly(glycidylmethacrylate) brush grafted poly(hydroxyethyl methacrylate) films	71		23 10*	15.4 U/mg 21.7*	74% after 10 weeks storage	98% after 5 cycles	[204]
	Alginate/chitosan microcapsules	88.12		0.187 0.068*			35.73% after 3 cycles	[205]
<i>Pycnoporus</i>	Magnetic CS			0.171	5.9 mM/min	70% after 1 month	80% after 10	[276]

Laccase source	Support matrix	Immobilization yield (%)	Retained enzyme activity (%)	Kinetic parameters		Storage stability	Reusability	Ref
				Km (mM)	Vmax (U/mL/min)			
<i>sanguineus</i>	microspheres			0.0368*	6.6*	storage	cycles	
<i>Lentinula edodes</i>	Chitosan	60	35	0.256	0.077*	60% after 6 months storage	80% after 30 cycles	[219]
<i>R. vernicifera</i>	p-benzoquinone-activated agarose	27	150			95% after 14 months storage		[277]
<i>Coriolopsis gallica</i>	Agarose					70% after 3 months	85% after 10 cycles	[278]
<i>Phlebia radiata</i>	Controlled porosity glass	98	96			100% after 2 weeks storage at 4°C and 95% after 2 weeks storage at 25 °C		[279]
<i>C. versicolor</i>	Activated carbon					62% and 50% after 4 and 126 days	30% after 7 cycles	[220]

*corresponds to a value for free laccase

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