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Remarks:

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(54) **Enzymatic method for textile dyeing**

(57) The present invention relates to methods of  
dyeing a material, comprising (a) soaking the material  
in an aqueous solution which comprises one or more  
mono-, di- or polycyclic aromatic or heteroaromatic  
compounds; and (b) treating the soaked material in an  
aqueous solution with (i) a hydrogen peroxide source

and an enzyme exhibiting peroxidase activity or (ii) an  
enzyme exhibiting oxidase activity on the one or more ar-  
omatic or heteroaromatic compounds; wherein the ma-  
terial is a fabric, yarn, fiber, garment or film made of fur,  
hide, leather, silk or wool.

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**Description**Field of the Invention

5 **[0001]** The present invention relates to methods of dyeing a material, comprising (a) soaking the material in an aqueous solution which comprises one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds; and (b) treating the soaked material in an aqueous solution with (i) a hydrogen peroxide source and an enzyme exhibiting peroxidase activity or (ii) an enzyme exhibiting oxidase activity on the one or more aromatic or heteroaromatic compounds; wherein the material is a fabric, yarn, fiber, garment or film made of fur, hide, leather, silk or wool.

Background of the Invention

10 **[0002]** Dyeing of textiles is often considered to be the most important and expensive single step in the manufacturing of textile fabrics and garments. In the textile industry, two major types of processes are currently used for dyeing, i.e., batch and continuous. In the batch process, among others, jets, drums, and vat dyers are used. In continuous processes, among others, padding systems are used. See, e.g., I.D. Rattee, *In* C.M. Carr (Ed.), "The Chemistry of the Textiles Industry," Blackie Academic and Professional, Glasgow, 1995, p. 276.

15 **[0003]** The major classes of dyes are azo (mono-, di-, tri-, etc.), carbonyl (anthraquinone and indigo derivatives), cyanine, di- and triphenylmethane and phthalocyanine. All these dyes contain chromophoric groups which give rise to color. There are three types of dyes involving an oxidation/reduction mechanism, i.e., vat, sulfur and azoic dyes. The purpose of the oxidation/reduction step in these dyeings are to change the dyestuff between an insoluble and a soluble form.

20 **[0004]** Oxidoreductases, e.g., oxidases and peroxidases, are well known in the art.

25 **[0005]** One class of oxidoreductases is laccases (benzenediol:oxygen oxidoreductases) which are multi-copper containing enzymes that catalyze the oxidation of phenols and related compounds. Laccase-mediated oxidation results in the production of aromatic radical intermediates from suitable substrates; the ultimate coupling of the intermediates so produced provides a combination of dimeric, oligomeric, and polymeric reaction products. Such reactions are important in nature in biosynthetic pathways which lead to the formation of melanin, alkaloids, toxins, lignins, and humic acids.

30 **[0006]** Another class of oxidoreductases are peroxidases which oxidize compounds in the presence of hydrogen peroxide.

**[0007]** Laccases have been found to be useful for hair dyeing. See, e.g., PCT applications Serial No. PCT/US95/06815 and PCT/US95/06816. European Patent No. 0504005 discloses that laccases can be used for dyeing wool at a pH in the range of between 6.5 and 8.0.

35 **[0008]** Saunders et al., *Peroxidase*, London, 1964, p. 10 ff. disclose that peroxidases act on various amino and phenolic compounds resulting in the production of a color.

**[0009]** Japanese Patent Application publication no. 6-316874 discloses a method for dyeing cotton comprising treating the cotton with an oxygen-containing medium, wherein an oxidation reduction enzyme selected from the group consisting of ascorbate oxidase, bilirubin oxidase, catalase, laccase, peroxidase, and polyphenol oxidase is used to generate the oxygen.

40 **[0010]** WO 91/05839 discloses that oxidases and peroxidases are useful for inhibiting the transfer of textile dyes.

**[0011]** It is an object of the present invention to provide an enzymatic method of dyeing textile fabrics.

Summary of the Invention

45 **[0012]** The present invention relates to method of dyeing a material, comprising (a) soaking the material in an aqueous solution which comprises one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds, each of which is optionally substituted with one or more functional groups or substituents, wherein each functional group or substituent is selected from the group consisting of halogen; sulfo; sulfonato; sulfamino; sulfanyl; amino; amido; nitro; azo; imino; carboxy; cyano; formyl; hydroxy; halocarbonyl; carbamoyl; carbamidoyl; phosphonato; phosphonyl; C<sub>1-18</sub>-alkyl; C<sub>1-18</sub>-alkenyl; C<sub>1-18</sub>-alkynyl; C<sub>1-18</sub>-alkoxy; C<sub>1-18</sub>-oxycarbonyl; C<sub>1-18</sub>-oxoalkyl; C<sub>1-18</sub>-alkyl sulfanyl; C<sub>1-18</sub>-alkyl sulfonyl; C<sub>1-18</sub>-alkyl imino or amino which is substituted with one, two or three C<sub>1-18</sub>-alkyl groups; and (b) treating the soaked material in an aqueous solution with (i) a hydrogen peroxide source and an enzyme exhibiting peroxidase activity or (ii) an enzyme exhibiting oxidase activity on the one or more aromatic or heteroaromatic compounds; wherein the material is a fabric, yarn, fiber, garment or film made of fur, hide, leather, silk or wool.

Detailed Description of the Invention

**[0013]** The use of oxidoreductases for dyeing materials has several significant advantages. For example, the dyeing system used in the process of the present invention utilizes inexpensive color precursors. Moreover, the mild conditions in the process will result in less damage to the fabric.

**[0014]** The methods of the present invention can be used to dye materials such as fabrics, yarns, fibers, garments and films. Preferably, the material is made of fur. In another preferred embodiment, the material is made of hide. In another preferred embodiment, the material is made of leather. In another preferred embodiment, the material is made of silk. In another preferred embodiment, the material is made of wool.

**[0015]** In the methods of the present invention, the material is soaked in an aqueous solution which comprises one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds, each of which is optionally substituted with one or more functional groups or substituents, wherein each functional group or substituent is selected from the group consisting of halogen; sulfo; sulfonato; sulfamino; sulfanyl; amino; amido; nitro; azo; imino; carboxy; cyano; formyl; hydroxy; halocarbonyl; carbamoyl; carbamidoyl; phosphonato; phosphonyl; C<sub>1-18</sub>-alkyl; C<sub>1-18</sub>-alkenyl; C<sub>1-18</sub>-alkynyl; C<sub>1-18</sub>-alkoxy; C<sub>1-18</sub>-oxycarbonyl; C<sub>1-18</sub>-oxoalkyl; C<sub>1-18</sub>-alkyl sulfanyl; C<sub>1-18</sub>-alkyl sulfonyl; C<sub>1-18</sub>-alkyl imino or amino which is substituted with one, two or three C<sub>1-18</sub>-alkyl groups. All C<sub>1-18</sub>-alkyl, C<sub>1-18</sub>-alkenyl and C<sub>1-18</sub>-alkynyl groups may be mono-, di or poly-substituted by any of the preceding functional groups or substituents. A polycyclic compound for purposes of the present invention has 2, 3 or 4 aromatic rings. Examples of such mono-, di- or polycyclic aromatic or heteroaromatic compounds include, but are not limited to, acridine, anthracene, azulene, benzene, benzofuran, benzothiazole, benzothiazoline, carboline, carbazole, cinnoline, chromane, chromene, chrysene, fulvene, furan, imidazole, indazole, indene, indole, indoline, indolizine, isothiazole, isoquinoline, isoxazole, naphthalene, naphthylene, naphthylpyridine, oxazole, perylene, phenanthrene, phenazine, phtalazine, pteridine, purine, pyran, pyrazole, pyrene, pyridazine, pyridazone, pyridine, pyrimidine, pyrrole, quinazoline, quinoline, quinoxaline, sulfanyl, thiophene, and triazine, each of which are optionally substituted. Examples of such compounds include, but are not limited to, aromatic diamines, aminophenols, phenols and naphthols.

**[0016]** Examples of aromatic and heteroaromatic compounds for use in the present invention include, but are not limited to:

3,4-diethoxyaniline  
 2-methoxy-p-phenylenediamine,  
 1-amino-4-b-methoxyethylamino-benzene (N-b-methoxyethyl p-phenylenediamine),  
 1-amino-4-bis-(b-hydroxyethyl)-aminobenzene (N,N-bis-(b-hydroxyethyl)-p-phenylenediamine),  
 2-methyl-1,3-diamino-benzene (2,6-diaminotoluene),  
 2,4-diaminotoluene,  
 2,6-diaminopyridine,  
 1-amino-4-sulfonato-benzene,  
 1-N-methylsulfonato-4-aminobenzene,  
 1-methyl-2-hydroxy-4-amino-benzene (3-amino o-cresol),  
 1-methyl-2-hydroxy-4-b-hydroxyethylamino-benzene (2-hydroxy-4-b-hydroxyethylamino-toluene),  
 1-hydroxy-4-methylamino-benzene (p-methylaminophenol),  
 1-methoxy-2,4-diamino-benzene (2,4-diaminoanisole),  
 1-ethoxy-2,3-diamino-benzene (2,4-diaminophenetole),  
 1-b-hydroxyethyloxy-2,4-diamino-benzene (2,4-diaminophenoxyethanol),  
 1,3-dihydroxy-2-methylbenzene (2-methyl resorcinol),  
 1,2,4-trihydroxybenzene,  
 1,2,4-trihydroxy-5-methylbenzene (2,4,5-trihydroxytoluene),  
 2,3,5-trihydroxytoluene,  
 4,8-disulfonato-1-naphtol,  
 3-sulfonato-6-amino-1-naphtol (J acid),  
 6,8-disulfonato-2-naphtol,  
 1,4-Phenylenediamine  
 2,5-Diaminotoluene  
 2-Chloro-1,4-phenylenediamine  
 2-Aminophenol  
 3-Aminophenol  
 4-Aminophenol  
 1,3-Phenylenediamine  
 1-Naphthol

2-Naphthol  
 4-Chlororesorcinol  
 1,2,3-benzenetriol (Pyrogallol)  
 1,3-Benzenediol (Resorcinol)  
 5 1,2-Benzenediol (Pyrocatechol)  
 2-Hydroxy-cinnamic acid  
 3-Hydroxy-cinnamic acid  
 4-Hydroxy-cinnamic acid  
 2,3-diaminobenzoic acid  
 10 2,4-diaminobenzoic acid  
 3,4-diaminobenzoic acid  
 3,5-diaminobenzoic acid  
 Methyl 2,3-diaminobenzoate  
 Ethyl 2,3-diaminobenzoate  
 15 Isopropyl 2,3-diaminobenzoate  
 Methyl 2,4-diaminobenzoate  
 Ethyl 2,4-diaminobenzoate  
 Isopropyl 2,4-diaminobenzoate  
 Methyl 3,4-diaminobenzoate  
 20 Ethyl 3,4-diaminobenzoate  
 Isopropyl 3,4-diaminobenzoate  
 Methyl 3,5-diaminobenzoate  
 Ethyl 3,5-diaminobenzoate  
 Isopropyl 3,5-diaminobenzoate  
 25 N,N-dimethyl-3,4-diaminobenzoic acid amide  
 N,N-diethyl-3,4-diaminobenzoic acid amide  
 N,N-dipropyl-3,4-diaminobenzoic acid amide  
 N,N-dibutyl-3,4-diaminobenzoic acid amide  
 4-Chloro-1-naphthol  
 30 N-Phenyl-p-phenylenediamine  
 3,4-Dihydroxybenzaldehyde  
 Pyrrole  
 Pyrrole-2-isoimidazole  
 1,2,3-Triazole  
 35 Benzotriazole  
 Benzimidazole  
 Imidazole  
 Indole  
 1-Amino-8-hydroxynaphthalene-4-sulfonic acid (S acid)  
 40 4,5-Dihydroxynaphthalene-2,7-disulfonic acid (Chromotropic acid)  
 Anthranilic acid  
 4-Aminobenzoic acid (PABA)  
 2-Amino-8-naphthol-6-sulfonic acid (Gamma acid)  
 5-Amino-1-naphthol-3-sulfonic acid (M acid)  
 45 2-Naphthol-3,6-disulfonic acid (R acid)  
 1-Amino-8-naphthol-2,4-disulfonic acid (Chicago acid)  
 1-Naphthol-4-sulfonic acid (Neville-winter acid)  
 Peri acid  
 N-Benzoyl J acid  
 50 N-Phenyl J acid  
 1,7-Cleves acid  
 1,6-Cleves acid  
 Bon acid  
 Naphthol AS  
 55 Disperse Black 9  
 Naphthol AS OL  
 Naphthol AS PH  
 Naphthol AS KB

Naphthol AS BS  
 Naphthol AS D  
 Naphthol AS B1  
 Mordant Black 3 CI 14640 (Eriochrome Blue Black B)  
 5 4-Amino-5-hydroxy-2,6-Naphthalene Disulphonic acid (H acid)  
 Fat Brown RR Solvent Brown 1 (CI 11285)  
 Hydroquinone  
 Mandelic Acid  
 Melamine  
 10 o-Nitrobenzaldehyde  
 1,5-Dihydroxynaphthalene  
 2,6-Dihydroxynaphthalene  
 2,3-Dihydroxynaphthalene  
 Benzylimidazole  
 15 2,3-Diaminonaphthalene  
 1,5-Diaminonaphthalene  
 1,8-Diaminonaphthalene  
 Salicylic acid  
 3-aminosalicylic acid  
 20 4-aminosalicylic acid  
 5-aminosalicylic acid  
 Methyl-3-aminosalicylate  
 Methyl-4-aminosalicylate  
 Methyl-5-aminosalicylate  
 25 Ethyl-3-aminosalicylate  
 Ethyl-4-aminosalicylate  
 Ethyl-5-aminosalicylate  
 Propyl-3-aminosalicylate  
 Propyl-4-aminosalicylate  
 30 Propyl-5-aminosalicylate  
 Salicylic amide  
 4-Aminothiophenol  
 4-Hydroxythiophenol  
 Aniline  
 35 4,4'-Diaminodiphenylamine sulfate  
 4-Phenylazoaniline  
 4-Nitroaniline  
 N,N-Dimethyl-1,4-phenylenediamine  
 N,N-Diethyl-1,4-phenylenediamine  
 40 Disperse Orange 3  
 Disperse Yellow 9  
 Disperse Blue 1  
 N-Phenyl-1,2-phenylenediamine  
 6-Amino-2-naphthol  
 45 3-Amino-2-naphthol  
 5-Amino-1-naphthol  
 1,2-Phenylenediamine  
 2-Aminopyrimidine  
 4-Aminoquinaldine  
 50 2-Nitroaniline  
 3-Nitroaniline  
 2-Chloroaniline  
 3-Chloroaniline  
 4-Chloroaniline  
 55 4-(phenylazo)resorcinol (Sudan Orange G, CI 11920)  
 Sudan Red B, CI 26110  
 Sudan Red 7B, CI 26050  
 4'-Aminoacetanilide

Alizarin  
 1-Anthramine (1-Aminoanthracene)  
 1-Aminoanthraquinone  
 Anthraquinone  
 5 2,6-Dihydroxyanthraquinone (Anthraflavic Acid)  
 1,5-Dihydroxyanthraquinone (Anthrarufin)  
 3-Amidopyridine (Nicotinamide)  
 Pyridine-3-carboxylic acid (Nicotinic Acid)  
 Mordant Yellow 1, Alizarin Yellow GG, CI 14025  
 10 Coomassie Grey, Acid Black 48, CI 65005  
 Palantine Fast Black WAN, Acid Black 52, CI 15711  
 Palantine Chrome Black 6BN, CI 15705, Eriochrome Blue Black R  
 Mordant Black 11, Eriochrome Black T  
 Naphthol Blue Black, Acid Black 1, CI 20470  
 15 1,4-Dihydroxyanthraquinone (Quinizarin)  
 4-Hydroxycoumarin  
 Umbelliferone, 7-Hydroxycoumarin  
 Esculetin 6,7-Dihydroxycoumarin  
 Coumarin  
 20 Chromotrope 2B Acid Red 176, CI 1657  
 Chromotrope 2R Acid Red 29, CI 16570  
 Chromotrope FB Acid Red 14, CI 14720  
 2,6-Dihydroxyisonicotinic acid, Citrazinic acid  
 2,5-Dichloroaniline  
 25 2-Amino-4-chlorotoluene  
 2-Nitro-4-chloroaniline  
 2-Methoxy-4-nitroaniline and  
 p-Bromophenol.

30 **[0017]** After soaking the material in an aqueous solution with the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds, the material is treated in an aqueous solution with a hydrogen peroxide source and an enzyme exhibiting peroxidase activity or an enzyme exhibiting oxidase activity on the one or more aromatic or heteroaromatic compounds. In a preferred embodiment, the same aqueous solution is used to soak and to dye the material. The aqueous solution, i.e., the dye liquor, used to dye the material in the methods of the present invention may have  
 35 a water/material ratio in the range of about 0.5:1 to about 200:1, preferably about 5:1 to about 20:1.

**[0018]** In the methods of the present invention, the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds may be oxidized by (a) a hydrogen peroxide source and an enzyme exhibiting peroxidase activity or (b) an enzyme exhibiting oxidase activity on the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds, e.g., phenols and related substances. Enzymes exhibiting peroxidase activity include, but are not limited to,  
 40 peroxidase (EC 1.11.1.7) and haloperoxidase, e.g., chloro- (EC 1.11.1.10), bromo- (EC 1.11.1) and iodoperoxidase (EC 1.11.1.8). Enzymes exhibiting oxidase activity include, but are not limited to, bilirubin oxidase (EC 1.3.3.5), catechol oxidase (EC 1.10.3.1), laccase (EC 1.10.3.2), o-aminophenol oxidase (EC 1.10.3.4), and polyphenol oxidase (EC 1.10.3.2). Assays for determining the activity of these enzymes are well known to persons of ordinary skill in the art.

**[0019]** Preferably, the enzyme is a laccase obtained from a genus selected from the group consisting of *Aspergillus*,  
 45 *Botrytis*, *Collybia*, *Fomes*, *Lentinus*, *Myceliophthora*, *Neurospora*, *Pleurotus*, *Podospora*, *Polyporus*, *Scytalidium*, *Trametes*, and *Rhizoctonia*. In a more preferred embodiment, the laccase is obtained from a species selected from the group consisting of *Humicola brevis* var. *thermoidea*, *Humicola brevispora*, *Humicola grisea* var. *thermoidea*, *Humicola insolens*, and *Humicola lanuginosa* (also known as *Thermomyces lanuginosus*), *Myceliophthora thermophila*, *Myceliophthora vellerea*, *Polyporus pinsitus*, *Scytalidium thermophila*, *Scytalidium indonesiacum*, and *Torula thermophila*. The  
 50 laccase may be obtained from other species of *Scytalidium*, such as *Scytalidium acidophilum*, *Scytalidium album*, *Scytalidium aurantiacum*, *Scytalidium circinatum*, *Scytalidium flaveobrunneum*, *Scytalidium hyalinum*, *Scytalidium lignicola*, and *Scytalidium uredinicolum*. The laccase may be obtained from a species of *Polyporus*, such as *Polyporus zonatus*, *Polyporus alveolaris*, *Polyporus arcularius*, *Polyporus australiensis*, *Polyporus badius*, *Polyporus biformis*, *Polyporus brumalis*, *Polyporus ciliatus*, *Polyporus colensoi*, *Polyporus eucalyptorum*, *Polyporus meridionalis*, *Polyporus varius*, *Polyporus palustris*, *Polyporus rhizophilus*, *Polyporus rugulosus*, *Polyporus squamosus*, *Polyporus tuberaster*, and *Polyporus tumulosus*. The laccase may also be obtained from a species of *Rhizoctonia*, e.g., *Rhizoctonia solani*. The laccase may also be a modified laccase by at least one amino acid residue in a Type I (T1) copper site, wherein the modified oxidase possesses an altered pH and/or specific activity relative to the wild-type oxidase. For example,

the modified laccase could be modified in segment (a) of the T1 copper site.

**[0020]** Peroxidases which may be employed for the present purpose may be isolated from and are producible by plants (e.g., horseradish peroxidase) or microorganisms such as fungi or bacteria. Some preferred fungi include strains belonging to the subdivision Deuteromycotina, class Hyphomycetes, e.g., *Fusarium*, *Humicola*, *Trichoderma*, *Myrothecium*, *Verticillium*, *Arthomyces*, *Caldariomyces*, *Ulocladium*, *Embellisia*, *Cladosporium* or *Dreschlera*, in particular *Fusarium oxysporum* (DSM 2672), *Humicola insolens*, *Trichoderma reesii*, *Myrothecium verrucana* (IFO 6113), *Verticillium alboatrum*, *Verticillium dahliae*, *Arthomyces ramosus* (FERM P-7754), *Caldariomyces fumago*, *Ulocladium chartarum*, *Embellisia alli* or *Dreschlera halodes*.

**[0021]** Other preferred fungi include strains belonging to the subdivision Basidiomycotina, class Basidiomycetes, e.g., *Coprinus*, *Phanerochaete*, *Coriolus* or *Trametes*, in particular *Coprinus cinereus* f. *microsporus* (IFO 8371), *Coprinus macrorhizus*, *Phanerochaete chrysosporium* (e.g., NA-12) or *Coriolus versicolor* (e.g., PR4 28-A).

**[0022]** Further preferred fungi include strains belonging to the subdivision Zygomycotina, class Mycoraceae, e.g., *Rhizopus* or *Mucor*, in particular *Mucor hiemalis*.

**[0023]** Some preferred bacteria include strains of the order Actinomycetales, e.g., *Streptomyces spheroides* (ATCC 23965), *Streptomyces thermoviolaceus* (IFO 12382) or *Streptoverticillum verticillium* ssp. *verticillium*.

**[0024]** Other preferred bacteria include *Bacillus pumillus* (ATCC 12905), *Bacillus stearothermophilus*, *Rhodobacter sphaeroides*, *Rhodomonas palustri*, *Streptococcus lactis*, *Pseudomonas purrocinia* (ATCC 15958) or *Pseudomonas fluorescens* (NRRL B-11).

**[0025]** Other potential sources of peroxidases are listed in B.C. Saunders et al., *op. cit.*, pp. 41-43.

**[0026]** Methods of producing enzymes to be used according to the invention are described in the art, e.g., FEBS Letters 1625, 173(1), Applied and Environmental Microbiology, Feb. 1985, pp. 273-278, Applied Microbiol. Biotechnol. 26, 1987, pp. 158-163, Biotechnology Letters 9(5), 1987, pp. 357-360, Nature 326, 2 April 1987, FEBS Letters 4270, 209(2), p. 321, EP 179 486, EP 200 565, GB 2 167 421, EP 171 074, and Agric. Biol. Chem. 50(1), 1986, p. 247.

**[0027]** Particularly preferred enzymes are those which are active at a pH in the range of about 2.5 to about 12.0, preferably in the range of about 4 to about 10, most preferably in the range of about 4.0 to about 7.0 and in the range of about 7.0 to about 10.0. Such enzymes may be isolated by screening for the relevant enzyme production by alkalophilic microorganisms, e.g., using the ABTS assay described in R.E. Childs and W.G. Bardsley, Biochem. J. 145, 1975, pp. 93-103.

**[0028]** Other preferred enzymes are those which exhibit a good thermostability as well as a good stability towards commonly used dyeing additives such as non-ionic, cationic, or anionic surfactants, chelating agents, salts, polymers, etc.

**[0029]** The enzymes may also be produced by a method comprising cultivating a host cell transformed with a recombinant DNA vector which carries a DNA sequence encoding said enzyme as well as DNA sequences encoding functions permitting the expression of the DNA sequence encoding the enzyme, in a culture medium under conditions permitting the expression of the enzyme and recovering the enzyme from the culture.

**[0030]** A DNA fragment encoding the enzyme may, for instance, be isolated by establishing a cDNA or genomic library of a microorganism producing the enzyme of interest, such as one of the organisms mentioned above, and screening for positive clones by conventional procedures such as by hybridization to oligonucleotide probes synthesized on the basis of the full or partial amino acid sequence of the enzyme, or by selecting for clones expressing the appropriate enzyme activity, or by selecting for clones producing a protein which is reactive with an antibody against the native enzyme.

**[0031]** Once selected, the DNA sequence may be inserted into a suitable replicable expression vector comprising appropriate promoter, operator and terminator sequences permitting the enzyme to be expressed in a particular host organism, as well as an origin of replication enabling the vector to replicate in the host organism in question.

**[0032]** The resulting expression vector may then be transformed into a suitable host cell, such as a fungal cell, preferred examples of which are a species of *Aspergillus*, most preferably *Aspergillus oryzae* or *Aspergillus niger*. Fungal cells may be transformed by a process involving protoplast formation and transformation of the protoplasts followed by regeneration of the cell wall in a manner known *per se*. The use of *Aspergillus* as a host microorganism is described in EP 238,023 (of Novo Industri A/S), the contents of which are hereby incorporated by reference.

**[0033]** Alternatively, the host organisms may be a bacterium, in particular strains of *Streptomyces*, *Bacillus*, or *E. coli*. The transformation of bacterial cells may be performed according to conventional methods, e.g., as described in T. Maniatis et al., Molecular Cloning: A Laboratory Manual, Cold Spring Harbor, 1982.

**[0034]** The screening of appropriate DNA sequences and construction of vectors may also be carried out by standard procedures, cf. T. Maniatis et al., *op. cit.*

**[0035]** The medium used to cultivate the transformed host cells may be any conventional medium suitable for growing the host cells in question. The expressed enzyme may conveniently be secreted into the culture medium and may be recovered therefrom by well-known procedures including separating the cells from the medium by centrifugation or filtration, precipitating proteinaceous components of the medium by means of a salt such as ammonium sulphate,

followed by chromatographic procedures such as ion exchange chromatography, affinity chromatography, or the like.

**[0036]** When the enzyme employed in the invention is a peroxidase, a hydrogen peroxide source, e.g., hydrogen peroxide itself, must be used. The hydrogen peroxide source may be added at the beginning or during the process, e.g., in an amount of 0.001-5 mM, particularly 0.01-1 mM.

**[0037]** One source of hydrogen peroxide includes precursors of hydrogen peroxide, e.g., a perborate or a percarbonate. Another source of hydrogen peroxide includes enzymes which are able to convert molecular oxygen and an organic or inorganic substrate into hydrogen peroxide and the oxidized substrate, respectively. These enzymes produce only low levels of hydrogen peroxide, but they may be employed to great advantage in the process of the invention as the presence of peroxidase ensures an efficient utilization of the hydrogen peroxide produced. Examples of enzymes which are capable of producing hydrogen peroxide include, but are not limited to, glucose oxidase, urate oxidase, galactose oxidase, alcohol oxidase, amine oxidase, amino acid oxidase and cholesterol oxidase.

**[0038]** In the methods of the present invention, the material is dyed at a temperature in the range of about 5 to about 120°C, preferably in the range of about 5 to about 80°C, and more preferably in the range of about 15 to about 70°C, and at a pH in the range of about 2.5 to about 12, preferably between about 4 and about 10, more preferably in the range of about 4.0 to about 7.0 or in the range of about 7.0 to about 10.0, can be used. More preferably, a pH below 6.5 (e.g., a pH in the range of 3-6, preferably in the range of 4-6 and most preferably in the range of 4.5-5.5) or above 8.0 (e.g., a pH in the range of 8-10, preferably in the range of 8.5-10 and most preferably in the range of 9-10), is used. Surprisingly, the colors of the materials dyed by the methods of the present invention at a pH below 6.5 and above 8.0 are different than the colors of the same materials dyed by methods at a pH in the range of 6.5-8.0. In a most preferred embodiment, a temperature and pH near the temperature and pH optima of the enzyme, respectively, are used.

**[0039]** In a preferred embodiment, the methods of the present invention further comprise adding to the aqueous solution a mono- or divalent ion which includes, but is not limited to, sodium, potassium, calcium and magnesium ions (0-3 M, preferably 25 mM - 1 M), a polymer which includes, but is not limited to, polyvinylpyrrolidone, polyvinylalcohol, polyaspartate, polyvinylamide, polyethylene oxide (0-50 g/l, preferably 1-500 mg/l) and a surfactant (10 mg-5 g/l).

**[0040]** Examples of such surfactants are anionic surfactants such as carboxylates, for example, a metal carboxylate of a long chain fatty acid; N-acylsarcosinates; mono or di-esters of phosphoric acid with fatty alcohol ethoxylates or salts of such esters; fatty alcohol sulphates such as sodium dodecyl sulphate, sodium octadecyl sulphate or sodium cetyl sulphate; ethoxylated fatty alcohol sulphates; ethoxylated alkylphenol sulphates; lignin sulphonates; petroleum sulphonates; alkyl aryl sulphonates such as alkyl-benzene sulphonates or lower alkylnaphthalene sulphonates, e.g., butyl-naphthalene sulphonate; salts or sulphonated naphthalene-formaldehyde condensates; salts of sulphonated phenol-formaldehyde condensates; or more complex sulphonates such as amide sulphonates, e.g., the sulphonated condensation product of oleic acid and N-methyl taurine or the dialkyl sulphosuccinates, e.g., the sodium sulphonate or dioctyl succinate. Further examples of such surfactants are non-ionic surfactants such as condensation products of fatty acid esters, fatty alcohols, fatty acid amides or fatty-alkyl- or alkenyl-substituted phenols with ethylene oxide, block copolymers of ethylene oxide and propylene oxide, acetylenic glycols such as 2,4,7,9-tetraethyl-5-decyn-4,7-diol, or ethoxylated acetylenic glycols. Further examples of such surfactants are cationic surfactants such as aliphatic mono-, di-, or polyamines such as acetates, naphthenates or oleates; oxygen-containing amines such as an amine oxide of polyoxyethylene alkylamine; amide-linked amines prepared by the condensation of a carboxylic acid with a di- or polyamine; or quaternary ammonium salts.

**[0041]** In another preferred embodiment, the methods of the present invention further comprise adding to the aqueous solution an agent which enhances the activity of the enzyme exhibiting peroxidase activity or the enzyme exhibiting oxidase activity. Enhancing agents are well known in the art. For example, the organic chemical compounds disclosed in WO 95/01426 are known to enhance the activity of a laccase. Furthermore, the chemical compounds disclosed in WO 94/12619 and WO 94/12621 are known to enhance the activity of a peroxidase.

**[0042]** The invention is further illustrated by the following non-limiting examples.

## EXAMPLES

### Example 1

#### DETERMINATION OF LACCASE ACTIVITY

**[0043]** Laccase activity was determined from the oxidation of syringaldazin under aerobic conditions. The violet color produced was measured by spectrophotometry at 530 nm. The analytical conditions were 19 μM syringaldazin, 23.2 mM acetate buffer, pH 5.5, 30°C, and 1 minute reaction time. One laccase unit (LACU) is the amount of laccase that catalyzes the conversion of 1 μmole syringaldazin per minute at these conditions.

DETERMINATION OF PEROXIDASE ACTIVITY

[0044] One peroxidase unit (POXU) is the amount of enzyme that catalyzes the conversion of 1  $\mu$ mol hydrogen peroxide per minute at the following analytical conditions: 0.88 mM hydrogen peroxide, 1.67 mM 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonate), 0.1 M phosphate buffer (containing Triton X405 (1.5 g/1000 ml)), pH 7.0, incubated at 30°C, photometrically followed at 418 nm (extinction coefficient of ABTS is set to 3.6 l/mmol\*mm).

DYEING OF FABRICS

[0045] Five mg of a first compound (p-phenylenediamine ("A"), p-tolulenediamine ("B"), or o-aminophenol ("C")) and 5 mg of a second compound (m-phenylenediamine ("D"),  $\alpha$ -naphthol ("E"), or 4-chlororesorcinol ("F")) (or 10 mg of the first compound in experiments without the second compound) were dissolved in 10 ml of 0.1 M  $K_2HPO_4$ , pH 7.0, buffer. A *Polyporus pinsitus* laccase ("PpL") with an activity of 71.7 LACU/ml (deposited with the Centraal Bureau voor Schimmelcultures and given accession number CBS 678.70) or a *Myceliophthora thermophila* laccase ("MtL") with an activity of 690 LACU/ml (deposited with the Centraal Bureau voor Schimmelcultures and given accession number CBS 117.65) was diluted in the same buffer to an activity of 10 LACU/ml.

[0046] Multifiber swatches Style 10A (4x10 cm) obtained from Test Fabrics Inc. (Middlesex, New Jersey) were rolled up and placed in a test tube. The swatches contained a strip of a fiber made of wool. 4.5 ml of the precursor/coupler solution and 1 ml of the laccase solution were added to the test tube. The test tube was closed, mixed and mounted in a test tube shaker and incubated for 60 minutes in a dark cabinet. After incubation the swatches were rinsed in running hot tap water for about 30 seconds.

[0047] The results of the experiment are provided in the following tables:

Table 1

FABRIC	A alone	A + D	A + E	A + F
wool	gray brown	dark blue	dark purple	brown

Table 2

FABRIC	B alone	B + D	B + E	B + F
wool	brown	dark blue	blue brown	yellow/brown

Table 3

FABRIC	C alone	C + D	C + E	C + F
wool	orange/red	strong orange/red	strong orange	strong orange

[0048] The results demonstrate that color is formed on wool in the presence of precursor and *Polyporus pinsitus* laccase. Similar results were obtained with the *Myceliophthora thermophila* laccase.

Example 2

[0049] Various materials were dyed in an Atlas Launder-O-Meter ("LOM") at 30°C for 1 hour at a pH in the range of 4-10. The materials dyed (all obtained from Test Fabrics Inc.) were worsted wool (Style 526, 7 cm x 7 cm) and chlorinated worsted wool (Style 530, 7 cm x 7 cm).

[0050] A 0.1 M Britten-Robinson buffer solution was prepared at the appropriate pH by mixing solution A (0.1 M  $H_3PO_4$ , 0.1 M  $CH_3COOH$ , 0.1 M  $H_3BO_3$ ) and B (0.5 M NaOH). In order to produce buffer solutions at pH's 4, 5, 6, 7, 8, 9 and 10, 806 ml, 742 ml, 706 ml, 656 ml, 624 ml, 596 ml and 562 ml of solution A, respectively, were diluted to one liter with solution B.

[0051] To 75 ml of each buffer solution was added 0.5 mg/ml of a compound selected from p-phenylenediamine, o-aminophenol and m-phenylenediamine. The pH was checked and adjusted if necessary. The 75 ml buffer/compound solutions were combined to form 150 ml of each buffer/compound combination solution which was added to a LOM beaker.

[0052] Swatches of the materials were then soaked in each buffer/compound combination solution. A volume corresponding to the volume of laccase to be added was then withdrawn. A *Myceliophthora thermophila* laccase ("MtL")

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with an activity of 690 LACU/ml was diluted in the buffer solution to an activity of 300 LACU/ml. 2 LACU/ml was added for each pH, except pH 7.0. At pH 7.0, 0, 1, 2, and 4 LACU/ml was added for the dosing profile. The LOM beakers were then mounted on the LOM. After 1 hour at 42 RPM and 30°C, the LOM was stopped. The liquid was poured off and the swatches were rinsed in the beaker in running deionized water for about 15 minutes. The swatches were dried and the CIELAB values measured using a ColorEye 7000 instrument. The CIELAB results are given in Tables 4-7.

Table 4

Dyeing with precursors p-phenylenediamine and m-phenylenediamine (pH-profile, 2 LACU/ml)								
		pH 4	pH 5	pH 6	pH 7	pH 8	pH 9	pH 10
Worsted	L*	41.57	28.21	20.25	14.73	18.94	35.06	13.52
Wool	a*	2.71	1.24	0.43	1.63	3.56	-1.92	1.79
	b*	-0.75	-2.09	-5.76	-5.84	-17.52	-14.05	-4.28
Chlorinated	L*	18.46	16.05	15.04	14.19	15.47	31.44	13.84
Wool	a*	2.32	1.01	0.88	1.83	2.78	-3.05	2.97
	b*	0.09	0.87	1.03	1.53	-11.43	-13.27	2.06

Table 5

Dyeing with precursors p-phenylenediamine and m-phenylenediamine (Dosing profile - pH 7)				
		0 LACU	1 LACU	4 LACU
Worsted	L*	54.97	14.52	14.27
Wool	a*	1.48	1.55	1.49
	b*	1.26	-6.09	-5.6
Chlorinated	L*	43.2	14.42	14.33
Wool	a*	1.79	1.75	1.69
	b*	1.61	1.5	1.65

Table 6

Dyeing with precursors o-aminophenol and m-phenylenediamine (pH-profile, 2 LACU/ml)								
		pH 4	pH 5	pH 6	pH 7	pH 8	pH 9	pH 10
Worsted	L*	33.68	33.05	35.96	37.42	42.55	59.24	49.65
Wool	a*	3.77	5.35	8.56	10.07	8.75	10.53	8.63
	b*	8.26	11.03	18.83	22.33	22.82	37.2	34.81
Chlorinated	L*	21.07	19.11	21.01	24.7	34.42	59.9	48.74
Wool	a*	3.14	2.77	4.82	7.22	6.88	10.08	10.4
	b*	4.23	4.31	8.04	12.64	18.08	36.78	34.76

Table 7

Dyeing with precursors o-aminophenol and m-phenylenediamine (Dosing profile - pH 7)				
		0 LACU	1 LACU	4 LACU
Worsted	L*	80.23	38.57	36.18
Wool	a*	1.1	9.21	10.8
	b*	20.09	21.33	22.76
Chlorinated	L*	77.36	27.1	26.33
Wool	a*	0.86	7.92	6.92
	b*	19.53	14.8	13.5

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[0053] The parameters "L\*\*", "a\*\*" and "b\*\*" used in the tables are used to quantify color and are well known to persons of ordinary skill in the art of color science. See for example, Billmeyer & Saltzman, *Principles of Color Technology*, Second Edition, John Wiley & Sons, New York, 1981, p. 59.

[0054] The results show that worsted wool and chlorinated worsted wool were dyed at all pH's, with strong shades ranging from gray at low pH to marine blue and black at high pH with the combination of p-phenylenediamine and m-phenylenediamine and shades from brown at low pH to orange/yellow at high pH with the combination of o-aminophenol and m-phenylenediamine.

[0055] In all dosing experiments, no notable difference was seen from dosing 1, 2 or 4 LACU/ml. The control experiment with 0 LACU/ml clearly demonstrates that dyeing is catalyzed by the laccase.

Example 3

[0056] The time profile for dyeing was determined using the procedure described in Example 2 except the experiments were conducted only at pH 5.0 and 8.0 over time intervals of 0, 5, 15, 35 and 55 minutes. In each experiment, 2 LACU/ml of the *Myceliophthora thermophila* laccase was added. The results are shown in Tables 8-11.

Table 8

Dyeing with precursors p-phenylenediamine and m-phenylenediamine Time profile, 2 LACU/ml, pH 5						
		0 min	5 min	15 min	35 min	55 min
Worsted Wool	L*	76.48	52.08	36.3	27.02	26.56
	a*	0.02	1.35	1.96	1.3	1.18
	b*	8	-0.02	-1.39	-1.68	-2.03
Chlorinated Wool	L*	63.73	19.23	16.81	16.48	16.75
	a*	0.1	1.86	1.28	0.77	1.11
	b*	10.3	-0.68	0.49	1.04	1.03

Table 9

Dyeing with precursors p-phenylenediamine and m-phenylenediamine Time profile, 2 LACU/ml, pH 8						
		0 min	5 min	15 min	35 min	55 min
Worsted Wool	L*	64.43	23.66	14.57	13.11	13.06
	a*	-3.03	1.05	2.14	1.49	1.2
	b*	-3.32	-15.45	-8.72	-4.52	-3.68
Chlorinated Wool	L*	58.96	17.36	14.09	13.89	13.66
	a*	-1.66	0.57	1.9	2.71	2.64
	b*	2.68	-3.98	0.14	2.21	1.99

Table 10

Dyeing with precursors o-aminophenol and m-phenylenediamine Time profile, 2 LACU/ml, pH 5						
		0 min	5 min	15 min	35 min	55 min
Worsted Wool	L*	79.4	50.67	35.94	32.4	32.89
	a*	1.54	6.47	7.11	6.08	5.98
	b*	16.02	20.88	18.43	14.28	12.52
Chlorinated Wool	L*	76.72	39.53	22.12	18.82	19.58
	a*	2.33	6.81	4.21	2.88	3.1
	b*	18.26	16.48	8.23	4.89	4.77

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Table 11

Dyeing with precursors o-aminophenol and m-phenylenediamine Time profile, 2 LACU/ml, pH 8						
		0 min	5 min	15 min	35 min	55 min
Worsted Wool	L*	80.06	63.03	49.37	42.51	41.24
	a*	1.63	15.71	17.1	12.32	9.97
	b*	25.87	43.37	38.69	30.26	25.78
Chlorinated Wool	L*	79.6	62.87	47.88	36.72	33.62
	a*	0.57	13.17	14.46	10.26	7.88
	b*	24.63	41.64	34.34	24.47	19.7

[0057] The results show that most of the color forms within the first 15 minutes. Worsted wool and chlorinated worsted wool were dyed at both pH's.

Example 4

[0058] Wool was dyed in an Atlas Launder-O-Meter ("LOM") at 30°C for one hour at pH 5.5. The material dyed (obtained from Test Fabrics, Inc.) was worsted wool (style 526, 8 cm x 8 cm).

[0059] A 0.5 mg/ml solution of a first compound (p-phenylenediamine, "A") and a 0.5 mg/ml solution of a second compound (1-naphthol, "B") was prepared by dissolving the compound in the appropriate amount of 0.1 M CH<sub>3</sub>COONa, pH 5.5, buffer. A total volume of 100 ml was used in each LOM beaker. 100 ml "A" was added to one beaker and 50 ml "A" and 50 ml "B" were combined to form 100 ml in a second beaker. Swatches of the materials listed above were wetted in DI water and soaked in the precursor solutions. A *Myceliophthora thermophila* laccase ("MtL") with an activity of 690 LACU/ml (80 LACU/mg) was added to each beaker at a concentration of 12.5 mg/l. The LOM beakers were sealed and mounted in the LOM. After 1 hour at 42 RPM and 30°C, the LOM was stopped. The spent liquor was poured off and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature and CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 12 and 13.

Table 12 -

Dyeing with precursor p-phenylenediamine (pH 5.5, 12.5 mg/l MtL)			
	L*	a*	b*
Wool	30.93	61.66	10.10

Table 13 -

Dyeing with precursors p-phenylenediamine and 1-naphthol (pH 5.5, 12.5 mg/l MtL)			
	L*	a*	b*
Wool	30.70	61.12	-4.28

[0060] The results show that wool can be dyed (brown using A, purple using A/B) using precursor and *Myceliophthora thermophila* laccase.

Example 5

[0061] Wool was dyed in an Atlas Launder-O-Meter ("LOM") at 30°C for one hour at pH 5.5. The material dyed (obtained from Test Fabrics, Inc.) was worsted wool (style 526, 8 cm x 8 cm).

[0062] A 0.5 mg/ml solution of a first compound (p-phenylenediamine, "A") and a 0.5 mg/ml solution of a second compound (1-naphthol, "B") was prepared by dissolving the compound in the appropriate amount of 0.1 M CH<sub>3</sub>COONa, pH 5.5, buffer. A total volume of 100 ml was used in each LOM beaker. 100 ml "A" was added to one beaker and 50 ml "A" and 50 ml "B" were combined to form 100 ml in a second beaker. Swatches of the materials listed above were

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wetted in DI water and soaked in the precursor solutions. A *Polyporus pinsitus* laccase ("PpL") with an activity of 70 LACU/ml (100 LACU/mg) was added to each beaker at a concentration of 12.5 mg/l. The LOM beakers were sealed and mounted in the LOM. After 1 hour at 42 RPM and 30°C, the LOM was stopped. The spent liquor was poured off and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 14 and 15.

Table 14 -

Dyeing with precursor p-phenylenediamine (pH 5.5, 12.5 mg/l PpL)			
	L*	a*	b*
Wool	36.06	70.46	8.49

Table 15 -

Dyeing with precursors p-phenylenediamine and 1-naphthol (pH 5.5, 12.5 mg/l PpL)			
	L*	a*	b*
Wool	37.92	58.71	-2.23

[0063] The results show that wool can be dyed (brown using A, purple using A/B) using precursor and *Polyporus pinsitus* laccase.

Example 6

[0064] Wool was dyed in an Atlas Launder-O-Meter ("LOM") at 30°C for one hour at pH 5.5. The material dyed (obtained from Test Fabrics, Inc.) was worsted wool (style 526, 8 cm x 8 cm).

[0065] A 0.5 mg/ml solution of a first compound (p-phenylenediamine, "A") and a 0.5 mg/ml solution of a second compound (1-naphthol, "B") was prepared by dissolving the compound in the appropriate amount of 0.1 M CH<sub>3</sub>COONa, pH 5.5, buffer. A total volume of 100 ml was used in each LOM beaker. 100 ml "A" was added to one beaker and 50 ml "A" and 50 ml "B" were combined to form 100 ml in a second beaker. Swatches of the materials listed above were wetted in DI water and soaked in the precursor solutions. A *Myrothecium verrucaria* bilirubin oxidase ("BiO") with an activity of 0.04 LACU/mg (1 mg/ml) was added to each beaker at a concentration of 12.5 mg/l. The LOM beakers were sealed and mounted in the LOM. After 1 hour at 42 RPM and 30°C, the LOM was stopped. The spent liquor was poured off and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature and CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 16 and 17.

Table 16 -

Dyeing with precursor p-phenylenediamine			
	L*	a*	b*
Wool	27.54	80.84	-2.13

Table 17 -

Dyeing with precursors p-phenylenediamine and 1-naphthol			
	L*	a*	b*
Wool	40.21	87.73	-13.47

[0066] The results show that wool can be dyed (brown using A, purple using A/B) using precursor and bilirubin oxidase.

Example 7

[0067] Wool was dyed in an Atlas Launder-O-Meter ("LOM") at 30°C for one hour at pH 5.5. The material dyed (obtained from Test Fabrics, Inc.) was worsted wool (style 526, 8 cm x 8 cm).

[0068] A 0.5 mg/ml solution of a first compound (p-phenylenediamine, "A") and a 0.5 mg/ml solution of a second compound (1-naphthol, "B") was prepared by dissolving the compound in the appropriate amount of 0.1 M CH<sub>3</sub>COONa, pH 5.5, buffer. A total volume of 100 ml was used in each LOM beaker. 100 ml "A" was added to one beaker and 50 ml "A" and 50 ml "B" were combined to form 100 ml in a second beaker. Swatches of the materials listed above were wetted in DI water and soaked in the precursor solutions. A *Rhizoctonia solani* laccase ("RsL") with an activity of 5.2 LACU/ml (2 mg/ml) was added to each beaker at a concentration of 12.5 mg/l. The LOM beakers were sealed and mounted in the LOM. After 1 hour at 42 RPM and 30°C, the LOM was stopped. The spent liquor was poured off and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature and CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 18 and 19.

Table 18 -

Dyeing with precursor p-phenylenediamine (pH 5.5, 12.5 mg/l RsL)			
	L*	a*	b*
Wool	27.89	58.97	1.59

Table 19 -

Dyeing with precursors p-phenylenediamine and 1-naphthol (pH 5.5, 12.5 mg/l RsL)			
	L*	a*	b*
Wool	29.03	63.94	-3.65

[0069] The results show that wool can be dyed (brown using A, purple using A/B) using precursor and *Rhizoctonia solani* laccase.

Example 8

[0070] The material dyed (obtained from Test Fabrics Inc.) was Wool (Style 526, 8 cm x 8 cm) in an Atlas Launder-O-Meter ("LOM") at 60°C and pH 5.5.

[0071] A 0.25 mg/ml solution of a first compound (p-phenylenediamine, "A") and a 0.25 mg/ml solution of a second compound (2-aminophenol, "B") were prepared by dissolving the compound in the appropriate amount of a 2 g/L CH<sub>3</sub>COONa, pH 5.5, buffer. A total volume of 100 ml was used in each LOM beaker. 50 ml "A" and 50 ml "B" were combined to form 100 ml in an LOM beaker. Swatches of the material listed above were wetted in DI water and soaked in the precursor solutions. The LOM beakers were sealed and mounted in the LOM. After a 10, 15, or 30 minute incubation time in the LOM (42 RPM), the LOM was stopped and a *Myceliophthora thermophila* laccase ("MtL") with an activity of 690 LACU/ml (80 LACU/mg) was added to each beaker at a concentration of 1 LACU/ml. After 50, 45 or 30 minutes at 42 RPM and 60°C, the LOM was stopped and the sample was removed. Two controls without preincubation were made by adding the precursor solution, swatches, and enzyme to LOM beakers. The beakers were mounted in the LOM. After 30 minutes at 42 RPM and 60°C, one beaker was removed. The other control was run for a total of 60 minutes at 42 RPM and 60°C and then removed. The spent liquor was poured off the samples and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature and CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 20-24.

Table 20 -

Control Dyeing with precursors A and B, 0 min./30 min.			
	L*	a*	b*
Wool	36.26	2.01	7.28

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Table 21 -

Control Dyeing with precursors A and B, 0 min./60 min.			
	L*	a*	b*
Wool	36.49	2.28	7.42

Table 22 -

Dyeing with precursors A and B, 10 min./50 min.			
	L*	a*	b*
Wool	32.95	2.41	10.16

Table 23 -

Dyeing with precursors A and B, 15 min./45 min.			
	L*	a*	b*
Wool	33.20	2.65	10.80

Table 24 -

Dyeing with precursors A and B, 30 min./30 min.			
	L*	a*	b*
Wool	33.45	2.87	11.59

**[0072]** The colorfastness to laundering (washfastness) for these swatches was evaluated using the American Association of Textile Chemist and Colorist (AATCC) Test Method 61-1989, 2A. The Launder-O-Meter was preheated to 49°C and 200 ml 0.2% AATCC Standard Reference Detergent WOB (without optical brightener) and 50 steel balls were placed in each LOM beaker. The beakers were sealed and mounted in the LOM and run at 42 RPM for 2 minutes to preheat the beakers to the test temperature. The rotor was stopped and the beakers were unclamped. The swatches were added to the beakers and the LOM was run for 45 minutes. The beakers were removed and the swatches rinsed in hot tap water for 5 minutes, with occasional squeezing. The swatches were then dried at room temperature and evaluated by the Macbeth ColorEye 7000. A gray scale rating (1-5) was assigned to each swatch using the AATCC Evaluation Procedure 1, Gray Scale for Color Change. The results are given in Tables 25-29.

Table 25 -

Washfastness Results for A and B, 0 min./30 min.				
	L*	a*	b	Gray Scale Rating
Wool	40.10	2.06	3.53	3

Table 26 -

Washfastness Results for A and B, 0 min./60 min.				
	L*	a*	b*	Gray Scale Rating
Wool	39.93	2.27	4.25	3

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Table 27 -

Washfastness Results for A and B, 15 min./45 min.				
	L	a*	b*	Gray Scale Rating
Wool	36.02	2.70	4.93	3-4

Table 28 -

Washfastness Results for A and B, 10 min./50 min.				
	L*	a*	b*	Gray Scale Rating
Wool	35.09	2.62	4.45	4

Table 29 -

Washfastness Results for A and B, 30 min./30 min.				
	L*	a*	b*	Gray Scale Rating
Wool	35.86	2.89	5.38	4

**[0073]** The results show that wool can be dyed using precursor and *Myceliophthora thermophila* laccase. Both from the L\* and the gray scale rating, it is evident that color intensity and washfastness are improved by incubating the swatches in the precursor solution before adding the enzyme.

Example 9

**[0074]** The materials dyed (all obtained from Test Fabrics Inc.) were worsted wool (Style 526, 7 cm x 7 cm) and chlorinated worsted wool (Style 530, 7 cm x 7 cm) in an Atlas Launder-O-Meter ("LOM") at 40°C for one hour at a pH 5.5.

**[0075]** Two mediators were evaluated in this experiment and each was dissolved in a buffer solution. Three buffer solutions were made: a 2 g/L CH<sub>3</sub>COONa, pH 5.5, buffer ("1"), a 2 g/L CH<sub>3</sub>COONa, pH 5.5, buffer containing 100 μM 10-propionic acid-phenothiazine (PPT) ("2"), and a 2 g/L CH<sub>3</sub>COONa, pH 5.5, buffer containing 100 μM methyl syringate ("3").

**[0076]** Three 0.25 mg/ml solutions of a first compound (p-phenylenediamine, "A") and three 0.25 mg/ml solutions of a second compound (m-phenylenediamine, "B") were prepared by dissolving the compound in the appropriate amount of buffer (1, 2 or 3). A total volume of 120 ml was used in each LOM beaker. 60 ml of A and 60 ml of B were combined to form 120 ml (for each buffer: 1, 2, or 3). Swatches of the materials listed above were wetted in DI water and soaked in the precursor solutions. The LOM beakers were sealed and mounted in the LOM. After 10 minutes at 42 RPM and 40°C, the LOM was stopped. A *Myceliophthora thermophila* laccase ("MtL") with an activity of 690 LACU/ml (80 LACU/mg) was added to each beaker at an activity of 0.174 LACU/ml. The beakers were once again sealed and mounted in LOM and run (42 RPM) for 50 minutes at 40°C. The beakers were removed and the spent liquor was poured off and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature and CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 30, 31 and 32.

Table 30 -

Dyeing with precursors A and B (2 g/L CH <sub>3</sub> COONa, pH 5.5, MtL)			
	L*	a*	b*
Wool	47.93	0.45	-0.05
Chlorinated Wool	27.80	2.94	-0.06

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Table 31 -

Dyeing with precursors A and B (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM PPT, MtL)			
	L*	a*	b*
Wool	42.11	1.52	-5.95
Chlorinated Wool	24.48	2.76	-2.15

Table 32 -

Dyeing with precursors A and B (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM methyl syringate, MtL)			
	L*	a*	b*
Wool	47.83	0.99	-0.14
Chlorinated Wool	25.77	3.37	-0.99

**[0077]** The colorfastness to laundering (washfastness) for these swatches was evaluated using the American Association of Textile Chemist and Colorist (AATCC) Test Method 61-1989, 2A. The Launder-O-Meter was preheated to 49°C and 200 ml 0.2% AATCC Standard Reference Detergent WOB (without optical brightener) and 50 steel balls were placed in each LOM beaker. The beakers were sealed and mounted in the LOM and run at 42 RPM for 2 minutes to preheat the beakers to the test temperature. The rotor was stopped and the beakers were unclamped. The swatches were added to the beakers and the LOM was run for 45 minutes. The beakers were removed and the swatches rinsed in hot tap water for 5 minutes, with occasional squeezing. The swatches were then dried at room temperature and evaluated by the Macbeth ColorEye 7000. A gray scale rating (1-5) was assigned to each swatch using the AATCC Evaluation Procedure 1, Gray Scale for Color Change. The results are given in Tables 33-35.

Table 33 -

Washfastness Results for precursors A and B (2 g/L CH <sub>3</sub> COONa, pH 5.5, MtL)				
	L*	a*	b*	Gray Scale Rating
Wool	50.59	1.11	7.07	3-4
Chlorinated Wool	31.74	2.83	7.09	3

Table 34 -

Washfastness results for precursors A and B (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM PPT, MtL)				
	L*	a*	b*	Gray Scale Rating
Wool	48.38	-0.48	4.61	2-3
Chlorinated Wool	31.56	1.06	4.86	2

Table 35 -

Washfastness Results for precursors A and B (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM methyl syringate, MtL)				
	L*	a*	b*	Gray Scale Rating
Wool	52.02	0.06	6.59	3
Chlorinated Wool	32.17	2.02	6.08	2-3

**[0078]** The same experiment was repeated, except that a third compound (2-aminophenol, "C") and a fourth com-

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pound (m-phenylenediamine, "D") were used. The temperature used was 50°C. The results are given in Tables 36-41.

Table 36 -

Dyeing with precursors C and D (2 g/L CH <sub>3</sub> COONa, pH 5.5, MtL)			
	L*	a*	b*
Wool	53.52	5.92	18.19
Chlorinated Wool	47.79	4.73	17.08

Table 37 -

Dyeing with precursors C and D (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM PPT, MtL)			
	L*	a*	b*
Wool	52.38	6.70	21.84
Chlorinated Wool	46.86	5.55	17.87

Table 38 -

Dyeing with precursors C and D (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM methyl syringate, MtL)			
	L*	a*	b*
Wool	57.09	8.10	24.44
Chlorinated Wool	48.69	7.82	19.40

Table 39 -

Washfastness Results for precursors C and D (2 g/L CH <sub>3</sub> COONa, pH 5.5, MtL)				
	L*	a*	b*	Gray Scale Rating
Wool	57.38	7.23	10.97	3
Chlorinated Wool	51.35	7.04	13.16	3

Table 40 -

Washfastness results for precursors C and D (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM PPT, MtL)				
	L*	a*	b*	Gray Scale Rating
Wool	51.37	8.18	12.33	5
Chlorinated Wool	46.86	5.55	17.87	2

Table 41 -

Washfastness Results for precursor C (2 g/L CH <sub>3</sub> COONa, pH 5.5, 100 μM methyl syringate, MtL)				
	L*	a*	b*	Gray Scale Rating
Wool	59.61	7.24	11.89	4
Chlorinated Wool	50.01	7.94	14.38	4-5

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**[0079]** The results from these two sets of experiments show that a mediator may be used for dyeing and for obtaining improved washfastness. In both experiments, worsted wool and chlorinated worsted wool were dyed at pH 5.5 in a CH<sub>3</sub>COONa buffer, in a CH<sub>3</sub>COONa buffer containing PPT, and in a CH<sub>3</sub>COONa buffer containing methyl syringate. However, a mediator resulted in improved washfastness only in the second experiment.

### Example 10

**[0080]** Wool was dyed in an Atlas Launder-O-Meter ("LOM") at 30°C for one hour at pH 5.5. The material dyed (obtained from Test Fabrics, Inc.) was worsted wool (Style 526, 8 cm x 8 cm).

**[0081]** A 0.5 mg/ml solution of a first compound (p-phenylenediamine, "A") and a 0.5 mg/ml solution of a second compound (1-naphthol, "B") was prepared by dissolving the compound in the appropriate amount of 0.1 M CH<sub>3</sub>COONa, pH 5.5, buffer. A total volume of 100 ml was used in each LOM beaker. 100 ml "A" was added to one beaker and 50 ml "A" and 50 ml "B" were combined to form 100 ml in a second beaker. Swatches of the material listed above were then wetted in DI water and soaked in the precursor solutions. A *Coprinus cinereus* peroxidase (CiP) with an activity of 180,000 POXU/ml was added to each beaker at a concentration of 0.05 POXU/ml. Either 200 or 500 μM hydrogen peroxide was added to each LOM beaker. The LOM beakers were sealed and mounted in the LOM. After 1 hour at 42 RPM and 30°C, the LOM was stopped. The spent liquor was poured off and the swatches were rinsed in cold tap water for about 15 minutes. The swatches were dried at room temperature and CIELAB values were measured for all of the swatches using the Macbeth ColorEye 7000. The results are given in Tables 42-45.

Table 42 -

Dyeing with precursor A, 200 μM H <sub>2</sub> O <sub>2</sub>			
	L*	a*	b*
Wool	54.84	1.70	-2.18

Table 43 -

Dyeing with precursor A, 500 μM H <sub>2</sub> O <sub>2</sub>			
	L*	a*	b*
Wool	43.58	2.50	-4.62

Table 44 -

Dyeing with precursors A and B, 200 μM H <sub>2</sub> O <sub>2</sub>			
	L*	a*	b*
Wool	56.19	2.60	-9.44

Table 45 -

Dyeing with precursors A and B, 500 μM H <sub>2</sub> O <sub>2</sub>			
	L*	a*	b*
Wool	50.48	4.14	-11.68

**[0082]** The results show that wool can be dyed (purple shades with A and A/B) using precursor, peroxide and *Coprinus cinereus* (CiP) peroxidase.

### Example 11

**[0083]** Chromed blue stock leather (Prime Tanning Corp., St. Joseph, MO) was dyed in a test tube at room temperature for 16 hours at pH 5, 7 and 9.

**[0084]** Three 0.5 mg/ml solutions of first compound (p-phenylenediamine, "A"), (pH 5, 7, and 9), three 0.5 mg/ml solutions of a second compound (1-naphthol, "B"), and three 0.5 mg/ml solutions of a third compound (4-hydroxycin-

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amic acid, "C") were prepared by dissolving each compound in the appropriate amount of 0.1 M Britten-Robinson Buffer (B-R buffer).

[0085] The leather substrate (1.5 cm x 4 cm) was rolled up and placed in a four inch test tube. A total volume of 7 ml was used in each test tube. 6 ml of A (or 6 ml of C) was added to one test tube and 3 ml of A and 3 ml of B (or 3 ml of A and 3 ml of C) were combined to form 6 ml in a second test tube. A *Myceliophthora thermophila* laccase ("MtL") with an activity of 690 LACU/ml (80 LACU/mg) was added to each beaker at a concentration of 2 LACU/ml (1 ml enzyme solution added to each test tube to give a total of 7 ml per test tube). The test tubes were closed, mixed and mounted on a test tube rotator. The test tubes were incubated for 16 hours in a dark cabinet at room temperature. After incubation, the swatches were rinsed in running cold tap water for 1 minute and dried at room temperature.

[0086] The results of the experiments are provided in Table 46:

Table 46

FABRIC	PRECURSOR	pH 5	pH 7	pH 9
Leather	A	Purple	Brown	Brown
Leather	A/B	Dark Purple	Purple	Purple
Leather	C	Light Green	Green	Green
Leather	A/C	Light Brown	Light Brown	Light Brown

[0087] These results demonstrate that colorant forms on leather in the presence of *Myceliophthora thermophila* laccase and different types of precursors over a range of pH conditions.

Example 12

[0088] Silk was dyed in a test tube at ambient temperature for 16 hours at pH 5, 7 and 9. The material dyed (obtained from Test Fabrics, Inc.) was silk crepe de chine (Style 601, 1.5 cm x 4 cm).

[0089] Three 0.5 mg/ml solutions of first compound (p-phenylenediamine, "A") (pH 5, 7, and 9) and three 0.5 mg/ml solutions of a second compound (1-naphthol, "B") were prepared by dissolving each compound in the appropriate amount of 0.1 M Britton-Robinson Buffer (B-R buffer).

[0090] The silk substrate was rolled up and placed in a four inch test tube. A total volume of 7 ml was used in each test tube. 6 ml of A was added to one test tube and 3 ml of A and 3 ml of B were combined to form 6 ml in a second test tube. A *Myceliophthora thermophila* laccase ("MtL") with an activity of 690 LACU/ml (80 LACU/mg) was added to each beaker at a concentration of 2 LACU/ml (1 ml enzyme solution added to each test tube to give a total of 7 ml per test tube). The test tubes were closed, mixed and mounted on a test tube rotator. The test tubes were incubated for 16 hours in a dark cabinet at room temperature. After incubation, the swatches were rinsed in running cold tap water for 1 minute and dried at room temperature.

[0091] The results of the experiments are provided in Table 47.

Table 47

FABRIC	PRECURSOR	pH 5	pH 7	pH 9
Silk	A	Dark Brown	Dark Brown	Dark Purple
Silk	A/B	Dark Brown	Dark Brown	Dark Brown

[0092] These results demonstrate that colorant forms on silk in the presence of *Myceliophthora thermophila* laccase and different types of precursors over a range of pH conditions.

Example 13

[0093] A print paste is made by dissolving 5 mg/ml of paraphenylenediamine in 0.1 M sodium phosphate, pH 5.5, buffer and adding 2.5% gum arabic. The print paste is manually transferred to a wool fabric using a printing screen and a scraper. The portions of the fabric which are not to be printed are covered by a mask.

[0094] The fabric is then steamed for 10 minutes in a steam chamber and allowed to dry.

[0095] Color is developed by dipping the fabric into a 2 LACU/ml laccase solution followed by a one hour incubation.

Example 14

**[0096]** A mono-, di- or polycyclic aromatic or heteroaromatic compound may be applied to the material by padding. For example, 0.5 mg/ml of p-phenylenediamine is dissolved in 500 ml of 0.1 M K<sub>2</sub>PO<sub>4</sub>, pH 7, buffer. A laccase is diluted in the same buffer. The p-phenylenediamine solution is padded on the material using a standard laboratory pad at 60°C. The fabric is steamed for 10 minutes. The steamed material may then be padded a second time with the enzyme solution. The dye is allowed to develop by incubating the swatches at 40°C. After incubation, the swatches are rinsed in running hot tap water for about 30 seconds.

**Claims**

1. A method of dyeing a material, comprising

(a) soaking the material in an aqueous solution which comprises one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds, each of which is optionally substituted with one or more functional groups or substituents, wherein each functional group or substituent is selected from the group consisting of halogen; sulfo; sulfonato; sulfamino; sulfanyl; amino; amido; nitro; azo; imino; carboxy; cyano; formyl; hydroxy; halo-carbonyl; carbamoyl; carbamidoyl; phosphonato; phosphonyl; C<sub>1-18</sub>-alkyl; C<sub>1-18</sub>-alkenyl; C<sub>1-18</sub>-alkynyl; C<sub>1-18</sub>-alkoxy; C<sub>1-18</sub>-oxycarbonyl; C<sub>1-18</sub>-oxoalkyl; C<sub>1-18</sub>-alkyl sulfanyl; C<sub>1-18</sub>-alkyl sulfonyl; C<sub>1-18</sub>-alkyl imino or amino which is substituted with one, two or three C<sub>1-18</sub>-alkyl groups; wherein each C<sub>1-18</sub>-alkyl, C<sub>1-18</sub>-alkenyl and C<sub>1-18</sub>-alkynyl group may be mono-, di or poly-substituted by any of the preceding functional groups or substituents; and

(b) treating the soaked material in an aqueous solution with (i) a hydrogen peroxide source and an enzyme exhibiting peroxidase activity or (ii) an enzyme exhibiting oxidase activity on the one or more aromatic or heteroaromatic compounds;

wherein the material is a fabric, yarn, fiber, garment or film made of fur, hide, leather, silk or wool.

2. The method according to claim 1, wherein the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds is a naphthol.

3. The method according to claim 1, wherein the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds is an aromatic diamine.

4. The method according to claim 1, wherein the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds is an aminophenol.

5. The method according to claim 1, wherein the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds is a phenol.

6. The method according to claim 1, wherein the material is made of fur.

7. The method according to claim 1, wherein the material is made of hide.

8. The method according to claim 1, wherein the material is made of leather.

9. The method according to claim 1, wherein the material is made of silk.

10. The method according to claim 1, wherein the material is made of wool.

11. The method according to claim 1, wherein the soaked material is treated with an enzyme exhibiting peroxidase activity on the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds and a hydrogen peroxide source.

12. The method according to claim 11, wherein the enzyme is a peroxidase or haloperoxidase.

13. The method according to claim 1, wherein the soaked material is treated with an enzyme exhibiting oxidase activity

on the one or more mono-, di- or polycyclic aromatic or heteroaromatic compounds.

5 **14.** The method according to claim 13, wherein the enzyme is selected from the group consisting of bilirubin oxidase, catechol oxidase, laccase, o-aminophenol oxidase, and polyphenol oxidase.

**15.** The method according to claim 1, wherein the material is dyed at a temperature in the range of about 5 to about 120°C.

10 **16.** The method according to claim 1, further comprising adding to the aqueous solution in step (b) a mono or divalent ion selected from the group consisting of sodium, potassium, calcium and magnesium ions.

**17.** The method according to claim 1, further comprising adding to the aqueous solution in step (b) a polymer selected from the group consisting of polyvinylpyrrolidone, polyvinylalcohol, polyaspartate, polyvinylamide, and polyethylene oxide.

15 **18.** The method according to claim 1, further comprising adding to the aqueous solution in step (b) an anionic, nonionic or cationic surfactant.

**19.** The method according to claim 1, wherein the material is dyed at a pH in the range of 2.5-12.

20 **20.** The method according to claim 1, further comprising adding to the aqueous solution in step (b) an agent which enhances the activity of the enzyme.

25 **21.** The method according to claim 1, wherein the aqueous solutions used in steps (a) and (b) are the same.

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