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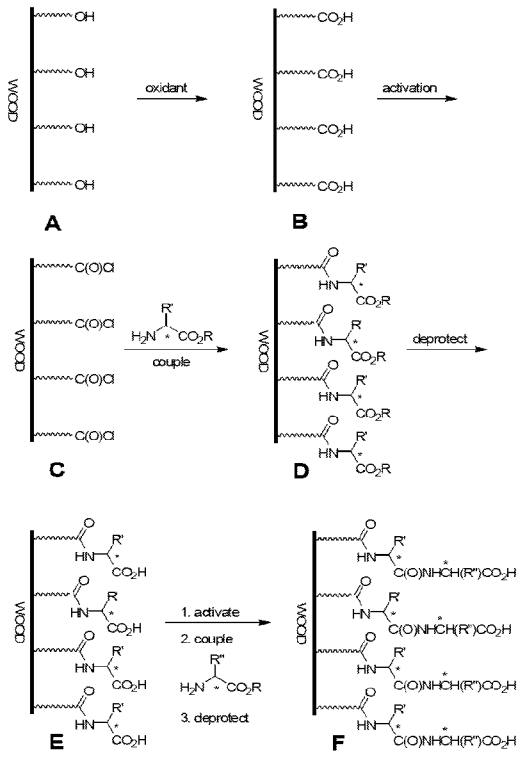
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(54) Title: TREATING LIGNOCELLULOSIC MATERIALS

FIG. 1



(57) Abstract: A process of covalently modifying a lignocellulosic material is provided. The process includes oxidizing a lignocelinlosic material having hydroxy, groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups, optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups, and reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from amino acids, peptides, or protected derivatives thereof to provide a treated lignocellulosic material. The treated lignocellulosic materials thus prepared displays resistance to degradation.

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TREATING LIGNOCELLULOSIC MATERIALS

FIELD

[0001] The present technology is generally related to the treatment of lignocellulosic materials.

BACKGROUND

[0002] The polymeric structure of lignocellulosic cell walls consists primarily of cellulose, hemicellulose, and lignin. Each of these components possesses hydroxyl functional groups which moderate the interaction of water with the lignocellulosic material. For example, lignocellulosic materials such as wood may swell under moist conditions, in large part due to hydrogen bonding between water and the hydroxyl groups on the cell wall components. Many chemical-based wood treatment methods rely on covalently modifying the hydroxyl groups of cell walls, to improve a variety of wood properties such as hardness, dimensional stability, resistance to UV light, and resistance to decay. For example, in acetylation, hydroxyl groups are reacted with acetic anhydride to incorporate acetyl groups on to the cell walls of the wood. Both through reduction of free hydroxyl functionality and through incorporation of less polar groups, the acetylated wood exhibits a marked decrease in its ability to absorb water. Incorporation of large acetyl groups also serves to bulk the cell walls of the material, further blocking water absorption pathways. As a result, in comparison to untreated wood, acetylated wood demonstrates much better ability to resist attack by wood-decaying organisms such as brown, white, and soft rot fungi.

[0003] Despite the aforementioned advantages of acetylation as a wood preservation technique, the method suffers from drawbacks. In particular, acetylation requires the use of a difficult-to-handle chemical reagent (acetic anhydride) which produces a stench byproduct (acetic acid) that must either be recycled or disposed. Furthermore, since acetylation processes are typically tailored to chemically modify most or all of the hydroxyl functionality of wood, large volumes of acetic anhydride are necessary.

SUMMARY

[0004] In accordance with one aspect, a process of preparing a treated lignocellulosic material is provided, the process including oxidizing a lignocellulosic material having hydroxyl groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups, optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups, and reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from amino acids, peptides, or protected derivatives thereof to provide the treated lignocellulosic material. In some embodiments, the lignocellulosic material is wood. In some embodiments, the amino acid, the peptide, or protected derivative thereof is a biocidal agent, such as a pesticide, a microbicide, a fungicide, an herbicide, an insecticide, an algicide, a rodenticide, and the like. In some embodiments, biocidal agent imparts similar biocidal activity to the treated lignocellulosic material; thus the treated lignocellulosic material is a pesticide, a microbicide, a fungicide, an herbicide, an insecticide, an algicide, a rodenticide, and the like.

[0005] In another aspect, a treated lignocellulosic material is provided according to a process including oxidizing a lignocellulosic material having hydroxyl groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups, optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups, and reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof to provide the treated lignocellulosic material.

[0006] In another aspect, a method of inhibiting fungal growth on a lignocellulosic material is described, the method including oxidizing a lignocellulosic material having hydroxyl groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups, optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups, and reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof to provide a treated lignocellulosic material. In some embodiments, fungal growth is prevented.

[0007] In a further aspect, a composition is provided which includes an amide-bound amino acid or an amide-bound peptide on a surface of a lignocellulosic material where the composition is a biocidal agent. In some embodiments, the amide-bound amino acid is (S)-canavanine.

[0008] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments and features described above, further aspects, embodiments and features will become apparent by reference to the following drawings and the detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a general illustration of a lignocellulosic treatment process, according to one embodiment.

[0010] FIG. 2 is a general illustration of a wooden cube, functionalized with (S)-canavanine residues, according to one embodiment.

DETAILED DESCRIPTION

[0011] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here.

[0012] The technology is described herein using several definitions, as set forth throughout the specification.

[0013] As used herein, unless otherwise stated, the singular forms "a," "an," and "the" include plural reference. Thus, for example, a reference to "a cell" includes a plurality of cells, and a reference to "a molecule" is a reference to one or more molecules.

[0014] As used herein, "about" will be understood by persons of ordinary skill in the art and will vary to some extent depending upon the context in which it is used. If there are uses of the term which are not clear to persons of ordinary skill in the art, given the context in which it is used, "about" will mean up to plus or minus 10% of the particular term.

[0015] Processes for preparing treated lignocellulosic materials, treated lignocellulosic materials themselves, and methods of inhibiting decay or decomposition of lignocellulosic materials are provided. In particular, a variety of avenues are presented for covalent modification of lignocellulosic materials with amino acids, peptides or combinations thereof. The amino acids, and/or peptides, are covalently bound *via* the N-terminus to the lignocellulosic material through amide bonds. Such a modification may serve to protect the lignocellulosic material from degradation by a variety of mechanisms. For example wood may be covalently modified to include amino acids or peptides which are not readily metabolized by wood-degrading microorganisms, thus making the wood resistant to decay. Alternatively, wood may be covalently modified to contain amino acids or peptides which display biological activity against wood-degrading microorganisms. In this regard, the amino acids or peptides behave as a microbicide. Alternatively, the biologically-active amino acids or peptides may behave as a pesticide, a fungicide, an herbicide, an insecticide, an algicide, a rodenticide, and the like. Furthermore, such biological activity may be imparted to the treated lignocellulosic material. Combinations of amino acids and/or peptides with varying wood-protecting properties may be employed.

[0016] Typically, any lignocellulosic material may be used, providing such lignocellulosic material has hydroxyl groups which can be chemically modified. Indeed, all lignocellulosic materials have hydroxyl groups as part of their cell walls in the form of cellulose, hemicellulose, and lignin. Cellulose is a polysaccharide comprised of hundreds to thousands of linked D-glucose units, with each glucose residue possessing three hydroxyl groups. Similarly, hemicellulose contains hydroxyl groups which may be modified. Lignin is a complex polymer derived from a phenylpropane repeating unit and contains numerous hydroxyl groups, both phenolic and non-phenolic. Phenolic hydroxyl groups are hydroxyl groups which are attached to an aromatic ring, such as found in phenol or β-naphthol. Thus,

there are generally ample hydroxyl groups susceptible to oxidation, regardless of the nature of the lignocellulosic material.

[0017] Lignocellulosic materials may be woody materials or non-woody materials. In the case of woody materials, the lignocellulosic material may be a softwood or a hardwood. Hardwoods and softwoods originate from a variety of tree species, including, but not limited to: oak, pine, fir (such as Douglas fir), pecan, ash, beech, birch, maple, walnut, teak, redwood, and the like. Non-woody plant materials such as cereal straw, bagasse, bamboo, reeds, cotton, or grass plants such as flax, kenaf, jute, hemp, sisal, abaca, and the like may also be employed. Indeed, the short growth cycles and moderate irrigation requirements make non-woody lignocellulosic attractive renewable resources for modification. Furthermore, mixtures of lignocellulosic materials may be used.

[0018] The physical form of the lignocellulosic material is generally inconsequential and the selection of a given form depends simply on the downstream application of the treated lignocellulosic material. In the case of wood-derived lignocellulosic materials, the wood may be in the form of lumber (typically solid planks, boards, sheets, and the like), wood fiber, wood particles, wood chips, ground wood, wood flour, wood flakes, wood veneers, wood laminates, saw dust and the like.

[0019] The process includes oxidizing at least a portion of the hydroxyl groups of the lignocellulosic material with an oxidant to carboxylic acid groups. In some embodiments, the hydroxyl groups which are oxidized by the oxidant are on, or are in, the cell walls of the lignocellulosic material. Hydroxyl groups of cellulose, hemicellulose, or lignin may be oxidized. In other embodiments, the hydroxyl groups which are oxidized are phenolic hydroxyl groups, such as those found in lignin. In other embodiments, oxidation of hydroxyl groups occurs at the surface of the lignocellulosic material, such as at the surface of a wooden board. There is no requirement that all of the hydroxyl groups in the lignocellulosic material be oxidized to carboxylic acid groups. It may well be the case that some hydroxyl groups, such as phenolic hydroxyl groups, are refractory towards oxidation, especially if a mild oxidant is employed. Furthermore, it may be desirable to oxidize only a portion of the hydroxyl groups of the lignocellulosic material in certain instances. For example, if a lignocellulosic material possessing hydroxyl groups is only partially oxidized, then both

carboxylic acid and hydroxyl groups (*i.e.*, unreacted hydroxyl groups) will be present. Thus, it would be possible to acetylate the hydroxyl groups and use the carboxylic acid groups for further modification as presented herein. In some embodiments, about 0.5% to about 100% of the hydroxyl groups are oxidized to carboxylic acid groups. In other embodiments, about 2% to about 70% of the hydroxyl groups are oxidized to carboxylic acid groups.

[0020] The oxidation of hydroxyl groups to carboxylic acid groups may be accomplished by any number of oxidants known to those of skill in the art. The only requirement of the oxidant is that it possess sufficient oxidizing strength to oxidize a portion of the hydroxyl groups of the lignocellulosic material to carboxylic acid groups. For commercial scale processes, inexpensive oxidants which are available in tonnage quantities may be desired. The oxidants may be stoichiometric (*e.g.*, bleach) or a catalytic (*e.g.*, 2,2,6,6-tetramethylpiperidin-1-yl)oxyl, "TEMPO") in nature. Multiple oxidants may be used in combination.

[0021] The oxidant may include a diatomic halogen of formula X_2, where X is a halogen. Thus, halogen oxidants include F_2, Cl_2, Br_2, I_2, and the like. The oxidant may include a hypohalite of formula XO^-, where X is a halogen in a +1 oxidation state. Hypohalites include metal hypohalite salts such as sodium hypochlorite and potassium hypobromite. As used herein, the term "metal" not only includes alkali metals (*e.g.*, Li, Na, K, Cs, *etc.*), but also alkaline earths (*e.g.*, Mg, Sr, Ca, *etc.*) and transition metals (*e.g.*, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ru, Rh, Pd, Ag, Re, *etc*). The oxidant may include a halite of formula XO_2^-, where X is a halogen in a +3 oxidation state. Halites include metal halite salts such as sodium chlorite and potassium bromite. The oxidant may include a halate of formula XO_3^-, where X is a halogen in a +5 oxidation state. Halates include metal halate salts such as sodium chlorate and potassium bromate. The oxidant may include a perhalate of formula XO_4^-, where X is a halogen in a +7 oxidation state. Perhalates include metal perhalate salts such as sodium perchlorate, sodium periodate, and potassium perbromate. The oxidant may include a hypohalous acid (*e.g.*, HOCl, HOBr, or HOI), a halous acid (*e.g.*, $HClO_2$, $HBrO_2$, or HIO_2), a halic acid (*e.g.*, $HClO_3$, $HBrO_3$, or HIO_3), or a perhalic acid (*e.g.*, $HClO_4$, $HBrO_4$, or HIO_4). The oxidant may include a chromate such as a metal chromate salt (*e.g.*, K_2CrO_4 and the like), a dichromate such as a metal chromate salt (*e.g.*, $K_2Cr_2O_7$ and the like), chromic

acid (H_2CrO_4), a permanganate such as a metal permanganate salt (*e.g.*, $KMnO_4$ and the like), an oxide such as a metal oxide (*e.g.*, Ag_2O, OsO_4, RuO_4, TPAP, and the like), a peroxide such as a metal peroxide salt (*e.g.*, Li_2O_2 and the like), a superoxide such as a metal superoxide salt (*e.g.*, NaO_2 and the like), hydrogen peroxide (H_2O_2), an oxygen-containing gas (*e.g.*, oxygen, air, ozone, chlorine dioxide, nitrogen dioxide, and the like), a nitrate such as metal nitrate salt (*e.g.*, KNO_3 and the like), nitric acid (HNO_3), and nitrobenzene ($C_6H_5NO_2$). The oxidant may also be an organic oxidant, such as an organic nitroxide or an organic oxoammonium salt. Organic nitroxides are free radical species of the general formula R_1R_2NO where R_1 and R_2 are independently selected from substituted or unsubsituted alkyl, alkenyl, and aryl groups. R_1 and R_2 may further be taken together to form a heterocyclic, N-containing ring. Examples of heterocyclic nitroxides include TEMPO, 4-hydroxy-TEMPO, 4-acetamido-TEMPO, 4-oxo-TEMPO, and the like. Similarly, oxoammonium salts may be employed as the oxidant. N-Oxoammonium salts have the general formula $[R_1R_2NO]^+ Y^-$, where R_1 and R_2 are defined as above and Y is a stabilizing anion. An example of a heterocyclic oxoammonium salt is 4-acetamido-2,2,6,6-tetramethylpiperidine oxoammonium tetrafluoroborate. Any of the above oxidants may be used in combination with each other when oxidizing the hydroxyl groups of the lignocellulosic material.

[0022] The process optionally includes activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups. As used herein, the term "activated carboxylic acid groups" refers to derivatives of carboxylic acid groups which are more reactive towards nucleophilic acyl substitution than carboxylic acid groups. Activated carboxylic acid groups have a formula of –C(O)Z, where Z is a leaving group. In some embodiments, the activated carboxylic acid groups are acid halides (*i.e.*, Z is a halogen). Acid halides include acid fluorides, acid chlorides, acid bromides, and the like. The activated carboxylic acid groups may be ester groups, where Z has the formula of –OR, where R is a C_1-C_{10} alkyl, C_1-C_{10} alkenyl, C_1-C_{10} alkynyl, C_3-C_6 aryl, or a substituted derivative thereof. In some embodiments, the activated carboxylic acid groups are alkyl esters or aryl esters. In some embodiments, the activated carboxylic acid groups are methyl esters, ethyl esters, tert-butyl esters, and the like. While it may be possible to isolate the lignocellulosic material possessing such activated carboxylic acid groups, there may be instances where it is neither

desirable nor possible to isolate the lignocellulosic material having such groups. For example, acid halides are generally understood by those of skill in the art be highly reactive, particularly towards adventitious moisture. Thus, if the lignocellulosic material includes activated carboxylic acid groups which are acid halide groups, it may be desirable to use the acid halide-functionalized lignocellulosic material directly in a subsequent reaction, without any substantial purification and/or isolation. Furthermore, the activated carboxylic acid groups may be so reactive as to preclude the possibility of isolating the lignocellulosic material which possesses such reactive groups. As will be appreciated by those of the skill in the art, many of the activating agents in the following paragraph generate activated carboxylic acid species which are used *in situ* (*e.g.*, intermediates generated upon the reaction of a carboxylic acid with a carbodiimide, a guandinium salt, a uronium salt, *etc*).

[0023] A variety of activating agents may be employed to prepare activated carboxylic acid groups. In some embodiments, the activating agent includes, a chlorinating reagent, a brominating reagent, a fluorinating reagent, a carbodiimide, an alcohol, an amine, a pyridine, an N-hydroxy reagent, an uronium salt, a guandinium salt, a phosphonium salt, a phosphorus reagent or mixtures thereof. The activating agent may include N-hydroxysuccinimide, DMAP (4-dimethylaminopyridine), pentafluorophenylphenol, N-hydroxyphthalimide, phosgene, thionyl chloride, cyanuric chloride, phosphoryl chloride, phosphorus trichloride, phosphorus pentachloride, CDMT (2-chloro-4,6-dimethoxy-1 ,3,5-triazine), BTC (bis(trichloromethyl) carbonate), oxalyl chloride, phosphorus tribromide, phosphorus pentabromide, cyanuric fluoride, TFFH (tetramethylfluoroformamidinium hexafluorophosphate), BTFFH (bis(tetramethylene) fluoroformamidinium hexafluorophosphate), DFIH (2-fluoro-1,3-dimethylimidazolium hexafluorophospate, DAST ((dimethylamino)sulfur trifluoride), EDC N-(3-dimethylaminopropyl)-N′-ethylcarbodiimide or the hydrochloride salt thereof), DCC (N,N′-dicyclohexylcarbodiimide), DIC (N,N′-diisopropylcarbodiimide), CIC (cyclohexyl isopropyl carbodiimide), BMC (tert-butyl methyl carbodiimide), BEC (tert-butyl ethyl carbodiimide), BDDC (bis((4-(2,2-dimethyl-l,3-dioxolyl))methyl carbodiimide), N,N-dicyclopentylcarbodiimide, HOAT (1-hydroxy-7-azabenzotriazole), HOBT (1-hydroxybenzotriazole), Cl-HOBT (1-hydroxy-6-chlorobenzotriazole), HODhbt (3-hydroxy-1,2,3-benzotriazin-4(3H)-one), HOCt, PTF (benzyltriphenylphosphonium dihydrogen trifluoride), HATU (N-[(dimethylamino)-1H-

1,2,3-triazolo-[4,5-b]pyridin-1-yl-methylene]-N-methylmethanaminium hexafluorophosphate N-oxide), HBTU (O-(benzotriazol-1-yl)-N,N,N′,N′-tetramethyluronium hexafluorophosphate), TBTU (O-(benzotriazol-1-yl)-N,N,N′,N′-tetramethyluronium tetrafluoroborate), COMU ((1-cyano-2-ethoxy-2-oxoethylidenaminooxy)dimethylamino-morpholino-carbenium hexafluorophosphate), Oxyma (ethyl cyano(hydroxyimino)acetate), HCTU ((2-(6-chloro-1H-benzotriazole-1-yl)-1,1,3,3-tetramethylaminium hexafluorophosphate)), TSTU (N,N,N′,N′-tetramethyl-O-(N-succinimidyl)uronium tetrafluoroborate), TNTU (O-(5-norbornene-2,3-dicarboximido)-N,N,N′,N′-tetramethyluronium tetrafluoroborate), HAMDU (O-(7-azabenzotriazol-1-yl)-1,3-dimethyleneuronium hexafluorophosphate), HAPyU (1-(1-pyrrolidinyl-1H-1,2,3-triazolo[4,5-b]pyridin-1-ylmethylene) pyrrolidinium hexafluorophosphate N-oxide), HDTU (2-(3,4-dihydro- 4-oxo-1,2,3-benzotriazin-3-yl)-1,1,3,3-tetramethyluronium hexafluorophosphate), CloP (chlorotris(dimethylamino)phosphonium hexafluorophosphate), BroP (bromotris(dimethylamino)phosphonium hexafluorophosphate), BOP (benzotriazol-1-yloxytris(dimethyl-amino)phosphonium hexafluorophosphate), AOP ((7-azabenzotriazol-1-yl)oxytris-(dimethylamino)phosphonium hexafluorophosphate), PyCloP (chlorotri(pyrrolidino)phosphonium hexafluorophosphate), PyBroP (bromotri(pyrrolidino)phosphonium hexafluorophosphate), PyBOP (benzotriazol-1-yloxytri(pyrrolidino)phosphonium hexafluorophosphate), PyAOP ([(7-azabenzotriazol-1-yl)oxy]tris(pyrrolidino)phosphonium hexafluorophosphate), DPPA (diphenylphosphoryl azide), MPTA (dimethylphosphinothioyl azide), DECP (diethylcyanophosphonate), BBC (benzotriazolyloxybis(pyrrolidino)carbonium hexafluorophosphate), BOP-Cl (N,N-bis(2-oxo-3-oxazolidinyl)phosphinic chloride), and the like.

[0024] According to another aspect, the process further includes reacting the carboxylic acid groups or the activated carboxylic acid groups of the lignocellulosic material with a first nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof to provide the treated lignocellulosic material. As used herein, the phrase "protected derivatives" means that the amino functional groups and/or the carboxylic acid functional groups of the amino acids or peptides are protected with protecting groups commonly known in the art. Non-limiting examples of protecting groups for amino groups include, Cbz (carbobenzyloxy), Phth (phthalimide), Fmoc (9-

fluorenylmethyloxycarbonyl), Boc (tert-butoxycarbonyl), Tr (trityl), Bn (benzyl), Bz (benzoyl), Ts (tosyl), Ac (acetyl), PMB (p-methoxybenzyl), DMPM (dimethoxybenzyl), PMP (p-methoxyphenyl), Nosyl (nitrobenzenesulfonyl), Nps (nitrophenylsulfenyl), and trifluoroacetyl groups. Carboxylic acids are commonly protected as esters such as alkyl esters (*e.g.*, methyl, ethyl, tert-butyl, and benzyl esters, *etc.*) or orthoesters. The amino acid (or peptide) may be protected at both the amino group and the carboxylic acid group. Of course, such protecting groups should not prevent reaction between the carboxylic acid groups or activated carboxylic acid groups with the first nitrogen-containing reagent.

[0025] As will be readily appreciated by those of skill in the art, reaction of the first nitrogen-containing reagent with the carboxylic acid groups or the activated carboxylic acid groups of the lignocellulosic material will cause the first nitrogen-containing reagent to be covalently bound to the lignocellulosic material through an amide bond (*i.e.*, the reaction is an amidation reaction). More specifically, the N-terminus of the amino acid, peptide, or protected derivative thereof will be covalently bound to the lignocellulosic material *via* an amide bond. Thus, in one aspect a process for the covalent modification of lignocellulosic materials possessing carboxylic acid groups or activated carboxylic acid groups.

[0026] The first nitrogen-containing reagent can include amino acids, peptides or protected derivatives thereof. In some embodiments, the first nitrogen-containing reagent includes α-amino acids, β-amino acids, γ-amino acids, δ-amino acids, or protected derivatives thereof, or mixtures thereof. In other embodiments, the first nitrogen-containing reagent includes proteinogenic amino acids, non-proteinogenic amino acids, protected derivatives thereof, or mixtures thereof. As used herein, the phrase "proteinogenic amino acids" refers to those amino acids that can be found in proteins and requires the cellular machinery associated with the genetic code for their isolated production. Thus, the phrase "proteinogenic amino acids" includes, but is not limited to, glycine and the L-isomers of the 20 amino acids that are directly encoded for protein synthesis by the standard genetic code: arginine, histidine, lysine, aspartic acid, glutamic acid, serine, threonine, asparagine, glutamine, cysteine, proline, alanine, isoleucine, leucine, methionine, phenylalanine, tryptophan, tyrosine, and valine. The term further includes selenocysteine and pyrrolysine. As used herein, the term "non-proteinogenic amino acid" refers to amino acids which are not proteinogenic amino acids.

Non-proteinogenic amino acids include those amino acids which are either not found in proteins or are not produced directly and in isolation by standard cellular machinery. For example, carnitine, GABA (γ-aminobutyric acid), L-DOPA (L-3,4-dihydroxyphenylalanine), hydroxyproline, homoserine, and selenomethionine, are non-proteinogenic amino acids. The phrase "non-proteinogenic amino acids" further includes unnatural stereoisomers of proteinogenic amino acids. In other embodiments, the first nitrogen-containing reagent includes D-amino acids, L-amino acids, protected derivatives thereof, or mixtures thereof. In other embodiments, the first nitrogen-containing reagent includes amino acids or protected derivatives thereof, and the amino acids or protected derivatives are a racemic mixture. In an illustrative embodiment, the first nitrogen-containing reagent includes (S)-canavanine or a protected derivative thereof.

[0027] The first nitrogen-containing reagent may also be a peptide of the aforementioned amino acids or amino acid derivatives. As used herein, the term "peptides" includes dipeptides, tripeptides, polypeptides and protected derivatives thereof. For example, the first nitrogen-containing reagent may be a tripeptide of the amino acid L-tryptophan. In some embodiments, the dipeptide, the tripeptide, the polypeptide, or the protected derivative thereof has a molecular weight of about 100 g/mol to about 10,000 g/mol or has a molecular weight of about 130 g/mol to about 2,500 g/mol.

[0028] According to another aspect, the process may optionally include a deprotecting step after the reacting step. Such a step may be desired to remove protecting groups after protected amino acids, protected peptides, or protected derivatives thereof have been covalently attached to the lignocellulosic material. In this regard, it is also possible to perform peptide synthesis on or in a lignocellulosic material in an iterative fashion. For example, wood which has been covalently modified to contain methyl glycinate residues bound through the N-terminus of methyl glycinate may be treated with aqueous acid to deprotect the methyl ester groups and liberate carboxylic acid groups. The carboxylic acid groups of the amide-bound glycine residue may be reacted with a second nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof.

[0029] The selection of a given first nitrogen-containing reagent will depend on the desired application of the treated lignocellulosic material. For example, non-polar amino acids such as alanine, valine, or phenylalanine may be covalently bound to a wood surface to impart water resistance (*e.g.*, lumber for building materials) or to increase compatibility of the surface with a polymeric coating. As previously indicated, the amino acid, peptide, or protected derivative thereof may display biological activity against microbes, fungi, rodents, plants, and insects, thereby protecting the lignocellulosic material from degradation. For example, the non-proteinogenic α-amino acid (S)-canavanine displays strong insecticidal properties which may be imparted to a lignocellulosic material through covalent attachment. Alternatively, the amino acids, peptides, or protected derivatives may be tailored as to not be readily metabolized by any of these organisms, thus also protecting the lignocellulosic material from degradation or decay.

[0030] Acetylation processes used to chemically modify lignocellulosic materials are fully compatible with the present processes. For example, the lignocellulosic material possessing hydroxyl groups may be partially acetylated, such that there remains non-acetylated hydroxyl groups for modification. Alternatively, the lignocellulosic material possessing hydroxyl groups may be subjected to oxidizing conditions where only a portion of the hydroxyl groups are oxidized to carboxylic acid groups which are further modified in the manner described. In such a case, the treated lignocellulosic material may possess "unreacted" hydroxyl groups which may be acetylated.

[0031] Thus, in some embodiments, the lignocellulosic material possessing hydroxyl groups also possesses acylated hydroxyl groups. In some embodiments the acylated hydroxyl groups are acetylated hydroxyl groups. In some embodiments, the process described further includes an acylation step. In some embodiments, the acylation step is an acetylating step. In some embodiments, the acetylating step is performed by reaction of either a lignocellulosic material possessing hydroxyl groups or a treated lignocellulosic material possessing hydroxyl groups with acetic anhydride.

[0032] As will be appreciated by those skilled in the art, any of the oxidizing, activating, or reacting steps of the present process described herein may include a solvent or combinations of solvents. For example, the oxidation of a lignocellulosic material possessing

hydroxyl group may be performed in the presence of a solvent which is compatible with the oxidant. Solvents or combinations thereof may also be used to wash the lignocellulosic material after completion of any or all of the oxidizing, activating, or reacting steps. Additional heating or drying steps may also be employed before, or after any of the steps of the processes described herein. The additional heating or drying steps may be performed at or below atmospheric pressure. For example, where a step involves the use of a moisture sensitive reagent, it would be advantageous to dry the lignocellulosic material, potentially with heating, prior to contacting it with the moisture sensitive reagent, as to not reduce the effectiveness of the reagent (*e.g.,* it would be desirable to dry a lignocellulosic material including carboxylic acid groups prior to exposing such lignocellulosic material to a moisture sensitive activating reagent such as thionyl chloride in the activating step). Similarly, any of the steps of the present process may further include heating at a temperature, and for a time period, sufficient to cause oxidation, activation, or reaction in the oxidizing, activating, or reacting steps.

[0033] In another aspect, the process detailed herein provides a method for inhibiting fungal growth on a lignocellulosic material, the method including oxidizing a lignocellulosic material having hydroxyl groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups, optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups and reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof to provide a treated lignocellulosic material. In some embodiments, the fungal growth on the treated lignocellulosic material is reduced by about 10% to about 100% in comparison to an untreated lignocellulosic material. As used herein, the phrase "untreated lignocellulosic material" means the same lignocellulosic material including hydroxyl groups which has not been subjected to the steps of the present process or method. Reduction in fungal growth on a treated lignocellulosic material in comparison to an untreated lignocellulosic material may be measured over a time period of about one day, about one week, about one month, about 3-6 months, about one year, or about 1-5 years. In some embodiments, fungal growth is prevented. In this regard, fungal growth may be prevented for at least one month, one year, five years, or longer than five years.

[0034] The present technology, thus generally described, will be understood more readily by reference to the following examples, which is provided by way of illustration and is not intended to be limiting of the present technology.

EXAMPLES

Example 1. Covalent modification of a wood surface with amino acids or peptides

[0035] FIG. 1 is a general illustration of a covalent modification process. In particular, FIG. 1A illustrates a wood substrate including hydroxyl groups on a surface. Oxidation of the hydroxyl groups provides a wood material including carboxylic acid groups on the surface (FIG. 1B). The carboxylic acid groups are activated to acid chloride groups (FIG. 1C). Reaction of the acid chloride groups with a protected and non-racemic amino acid derivative (*e.g.*, an ester of an α-amino acid) provides wood covalently modified with a protected and non-racemic amino acid derivative (*i.e.*, an amino ester), where the derivative is covalently bound to the wood material through amide bonds (FIG. 1D). The ester protecting groups on the amino ester residues are deprotected (such as through hydrolysis) to provide non-racemic amino acid modified wood (FIG. 1E). The treated wood material may be further modified through additional activation, coupling, and deprotection sequences to provide a wood material which includes peptide residues at the surface, as shown in FIG. 1F (*i.e.*, a dipeptide of an α-amino acid). In this example, it is also possible to prepare the amino acid-functionalized wood illustrated in FIG. 1E by direct reaction of the wood shown in FIG. 1C with an unprotected amino acid (process not shown). Likewise, it is also possible to prepare the peptide-functionalized wood shown in FIG. 1F by coupling a dipeptide or protected derivative with the wood indicated in FIG. 1C (process not shown).

Example 2. Covalent modification of a wood surface with (S)-canavanine

[0036] A. Wood oxidation. The oxidation of wood may be performed in a modification to that described in U.S. Patent 6,919,447, which employs 2,2,6,6-tetramethylpiperidine to form the primary oxidation catalyst. An aqueous solution of ClO_2 (7.1 g/L) is prepared. This solution (~5 mL) is reacted with 2,2,6,6-tetramethylpiperidine (~80 mg) to form the corresponding oxoammonium salt as a catalyst solution. Separately, a cube (1 in^3) of a Douglass fir is added to a solution containing aqueous ClO_2 (7.1 g/L, 85-90

mL), $NaHCO_3$ (3 g), and aqueous H_2O_2 (3.3%, 0.08 g). The catalyst solution is then added to solution containing the wood cube and the whole is contained in a sealed polyethylene bag. The polyethylene bag is immersed in a 70 °C water bath for at least 5-60 min. The pH is then adjusted below 3 with 1M H_2SO_4. Aqueous H_2O_2 (3.3%, 3 g) and aqueous ClO_2 (7.1 g/L, 30 mL) is then added and the mixture is again placed in the 70 °C water bath for at least 60 min. The wooden cube is washed with water, kiln dried, and the carboxyl content of the carboxylic acid-functionalized cube measured using standard analytical techniques.

[0037] B. Carboxylic acid activation. The carboxylic acid-functionalized wooden cube obtained from Example 2A above is added to a solution of thionyl chloride in chloroform (10M). The thionyl chloride solution is used in a sufficient amount to ensure complete conversion of carboxylic acid groups on the wooden cube. Dimethylformamide (several drops) is added and the reaction mixture is heated to reflux in a nitrogen atmosphere for several hours. The mixture is cooled to room temperature and the wooden cube is removed from the solution under a blanket of nitrogen and washed with dry chloroform. The acid chloride-functionalized wooden cube is used directly in the next reaction.

[0038] C. Amide-bond formation. A 1.5 M solution of (S)-canavanine methyl ester in chloroform is prepared. To this solution is slowly added at least 1 equivalent of triethylamine. The acid chloride-functionalized wooden cube from Example 2B is then added to an excess of the amino ester. The mixture is stirred initially at room temperature, and is heated as necessary until the amidation reaction is complete. The wooden cube is removed from the reaction mixture and washed with chloroform.

[0039] D. Deprotection. The wooden cube prepared in Example 2C is heated in the presence of aqueous HCl (3M) to hydrolyze the ester functional groups. The wooden cube is removed from the reaction mixture, rinsed with water and dried to provide a treated wooden cube which has been functionalized with S-canavanine, through the N-terminus of the amino acid, as illustrated in FIG. 2. The degree of functionalization is determined *via* standard analytical techniques.

[0040] E. Insect resistance testing. The S-canavanine-treated wooden cube from Example 2D is studied for its resistance to attack by insects such as moths (e.g., the

Nantucket Pine Tip moth) and beetles. The treated wood sample, along with an untreated control sample, is incubated with the study insect. The wood samples are inspected for decomposition every three days (both visually and by monitoring for mass loss of treated wood samples). After 6 months, the mass of the treated wood sample is expected to remain unchanged (no wood decomposition is observed). In contrast, the untreated control is expected to show a mass decrease of greater than 5%. The time period of insect resistance testing may be increased beyond a year. In general, it is expected to be found that the treated wood samples resist decay by insects over long periods (6 months, 1 year, 5 years, 10 years, 20 years, 30 years, and beyond). The testing procedure may be modified to use various shapes and types of wood materials, and may further include structural testing of the wood samples (e.g., modulus of elasticity (MOE), stiffness, tensile strength, compression, shear, etc.). In general, it is expected that the structural characteristics of the treated wood samples exposed to the study insect will remain unchanged over long periods (e.g., 6 months, 1 year, 5 years, 10 years, 20 years, 30 years, and beyond) in comparison to an untreated wood sample which has been exposed to the study insect.

Example 3. Covalent modification of a wood surface with other amino acids.

[0041] In an analogous fashion to Example 2, separate wood samples are modified with the following amino acids: L-canaline (an α-amino acid found in the jack bean with potent insecticidal properties against the tobacco hornworm and various moths), (1R,2S)-2-amino-4-methylenecyclopentane-1-carboxylic acid ("BAY 10-8888" or "PLD-118," a cyclic β-amino acid with antifungal properties), and (S)-amino-4-oxo-5-hydroxypentanoic acid ("RI-331," an α-amino acid which preferentially inhibits protein biosynthesis in fungi). These previously reported amino acids may be protected as methyl esters and may be attached wood in the manner described in Example 2C, followed by deprotection as set forth in Example 2D. Wood treated with L-canaline is expected to be up to 100% resistant to various insects including moths for long periods (e.g., 6 months, 1 year, 5 years, 10 years, 20 years, 30 years, and beyond). Wood treated with BAY 10-8888 or RI-331 is expected to exhibit up to 100% resistance to rot and/or general hardwood decay by various fungi species and yeast strains (e.g., 6 months, 1 year, 5 years, 10 years, 20 years, 30 years, and beyond). In all cases, the structural integrity of the treated wood samples exposed to insects, fungi, or

yeast is expected to be completely preserved in comparison to untreated controls exposed to the same insects, fungi, or yeast.

EQUIVALENTS

[0042] The embodiments, illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms 'comprising,' 'including,' 'containing,' *etc.* shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the claimed technology. Additionally, the phrase 'consisting essentially of' will be understood to include those elements specifically recited and those additional elements that do not materially affect the basic and novel characteristics of the claimed technology. The phrase 'consisting of' excludes any element not specified.

[0043] The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent compositions, apparatuses, and methods within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0044] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0045] As will be understood by one skilled in the art, for any and all purposes, particularly in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, *etc.* As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, *etc.* As will also be understood by one skilled in the art all language such as 'up to,' 'at least,' 'greater than,' 'less than,' and the like, include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member.

[0046] While certain embodiments have been illustrated and described, it should be understood that changes and modifications can be made therein in accordance with ordinary skill in the art without departing from the technology in its broader aspects as defined in the following claims.

WHAT IS CLAIMED IS:

1. A process of preparing a treated lignocellulosic material, the process comprising:

oxidizing a lignocellulosic material comprising hydroxyl groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups;

optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups; and

reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof to provide the treated lignocellulosic material.

2. The process of claim 1, wherein the lignocellulosic material comprises wood, plant-derived material, kenaf, grasses, bagasse, cotton, jute, hemp, flax, bamboo, sisal, abaca, and mixtures of any two or more thereof.

3. The process of claim 1, wherein the lignocellulosic material is wood lumber, wood fiber, wood particles, wood chips, ground wood, wood flour, wood flakes, wood veneers, wood laminates, or saw dust.

4. The process of claim 1, wherein the hydroxyl groups are on the cell walls of the lignocellulosic material.

5. The process of claim 1 wherein a ratio of hydroxyl groups to carboxylic acid groups is about 0.5% to about 100%.

6. The process of claim 1, wherein the activated carboxylic acid group comprises an acid halide or an ester.

7. The process of claim 1, wherein the first nitrogen-containing reagent comprises an α-amino acid, a β-amino acid, a γ-amino acid, a δ-amino acid, a protected derivative thereof, or mixtures thereof.

8. The process of claim 1, wherein the first nitrogen-containing reagent comprises a proteinogenic amino acid, a non-proteinogenic amino acid, a protected derivative thereof, or mixtures thereof.

9. The process of claim 1, wherein the first nitrogen-containing reagent comprises a D-amino acid, an L-amino acid, a protected derivative thereof, or mixtures thereof.

10 The process of claim 1, the first nitrogen-containing reagent comprises (S)-canavanine.

11. The process of claim 1, wherein the amino acid, the peptide, or protected derivative thereof is a microbicide, a fungicide, a rodenticide, an herbicide, or an insecticide.

12. The treated lignocellulosic material prepared according to the process of claim 1.

13. A method of inhibiting fungal growth on a lignocellulosic material, the method comprising:

oxidizing a lignocellulosic material comprising hydroxyl groups with an oxidant to oxidize at least a portion of the hydroxyl groups to carboxylic acid groups;

optionally activating the carboxylic acid groups with an activating agent to form activated carboxylic acid groups; and

reacting the carboxylic acid groups or the activated carboxylic acid groups with a first nitrogen-containing reagent selected from the group consisting of amino acids, peptides, or protected derivatives thereof to provide a treated lignocellulosic material.

14. The method of claim 13 wherein fungal growth on the treated lignocellulosic material is reduced by about 10% to about 100% in comparison to an untreated lignocellulosic material.

15. A composition comprising:

an amide-bound amino acid, or an amide-bound peptide on a surface of a lignocellulosic material;

wherein the composition is a biocidal agent.

16. The composition of claim 15, wherein the lignocellulosic material comprises wood, plant-derived material, kenaf, grasses, bagasse, cotton, jute, hemp, flax, bamboo, sisal, abaca, and mixtures of any two or more thereof.

17. The composition of claim 15, wherein the lignocellulosic material is wood lumber, wood fiber, wood particles, wood chips, ground wood, wood flour, wood flakes, wood veneers, wood laminates, or saw dust.

18. The composition of claim 15, wherein the biocidal agent is a microbicide, a fungicide, a rodenticide, an herbicide, or an insecticide.

19. The composition of claim 15, wherein the amide-bound amino acid is (S)-canavanine.

20. The composition of claim 15, wherein fungal growth on the treated lignocellulosic material is reduced by about 10% to about 100% in comparison to an untreated lignocellulosic material.

FIG. 1

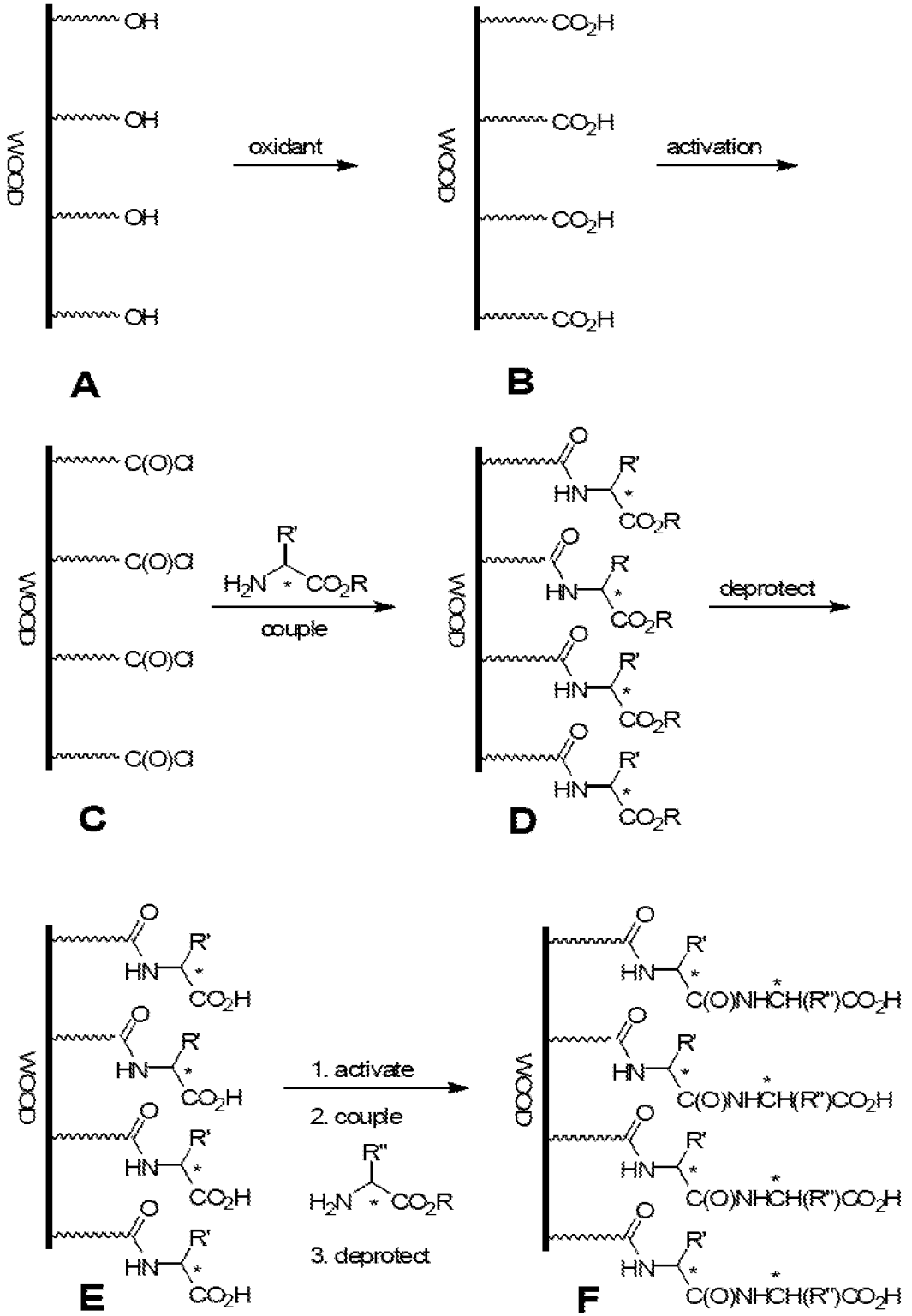
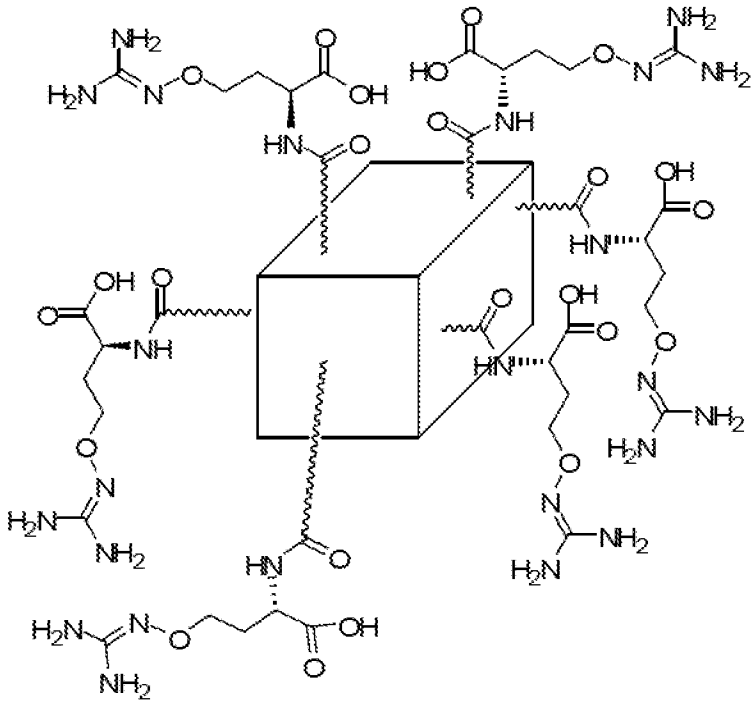

oxidant
activation
couple
deprotect
1. activate
2. couple
3. deprotect
A
B
C
D
E
F

FIG. 2


NH2
H2N
N
O
OH
HN
O
HO
NH
NH2
O
N
NH2
OH
O
HN
O
OH
O
NH
O
N
NH2
H2N
O
N
NH2
H2N
O
OH
HN
O
O
N
NH2
H2N
HN
O
H2N
N
O
OH
NH2
O

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/037930

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. ***C08H 8/00*** (2010.01) ***A01N 37/44*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO, WPI, CAplus: wood, lignocellulose, oxidation, amidation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BARAZZOUK, S. et al. "Spectroscopic characterization of oxidized nanocellulose grafted with fluorescent amino acids", Cellulose, 3 February 2011, Vol. 18, pages 643-653 Page 645; Scheme 1	1-9, 12
A	US 2007/0131362 A1 (BUCHERT et al.) 14 June 2007 Example 3	1-20
A	US 6830784 B2 (GUTOWSKI et al.) 14 December 2004 Columns 23-24	1-20

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 July 2011	14/07/2011
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/037930

C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4952684 A (YALPANI et al.) 28 August 1990 Table 3	1-20
A	HARRISON, S. et al. "Hybrid Rigid/Soft and Biologic/Synthetic Materials: Polymers Grafted onto Cellulosic Microcrystals", Biomacromolecules, 7 March 2011, Vol. 12, pages 1214-1223 Scheme 1	1-20

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/US2011/037930**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	2007131362	BR	PI0418046	BR	PI0418145	CA	2549471
		CA	2549519	EP	1702107	EP	1704281
		FI	20031903	US	2007151679	WO	2005060332
		WO	2005061790				
US	6830784	AU	29884/01	CA	2398973	EP	1253999
		JP	2003521395	NZ	520290	US	2003157268
		US	2005048207	US	7459185	WO	0156756
US	4952684	US	4959461	US	4963664		

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX