Surface functionalization of coconut fibers by enzymatic biografting of syringaldehyde for the development of biocomposites

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In the present work, laccase from Trametes versicolor has been used for the biografting of natural phenol syringaldehyde (SA) on the surface of coconut fibers. Three parameters such as concentration of laccase, phenol and incubation period have been varied to optimize the reaction conditions for maximum biografting. Biografted coconut fibers were characterized with FTIR, SEM, and XRD techniques. Thermal, antibacterial and hydrophobic properties were analyzed by thermogravimetric analysis (TGA), colony forming unit (CFU) and moisture retention methods, respectively. An enhancement in the properties of coconut fibers was observed after biografting of SA. Modified coconut fibers were used as a reinforcement in the poly(butylene succinate) matrix to prepare biocomposites. Mechanical properties (tensile and flexural strength) of the biocomposites were evaluated by a universal testing machine. An increase in the mechanical strength of biocomposites was observed when reinforced with biografted fibers in comparison to unmodified coconut fibers. The fractured surface morphology of the composites indicated the better interlocking of the biografted fibers with the polymer matrix.

1. Introduction

Proper handling and disposal of the large amounts of hazardous chemicals used for chemical treatments of natural fibers is a major problem and leads to an additional cost to the final product. Therefore, surface functionalization of natural fibers by environmentally friendly methods such as enzyme-catalyzed reactions are more interesting keeping in mind the concept of green chemistry. Laccase-assisted biografting of natural fibers is an environment friendly method to impart the antibacterial and hydrophobic properties to the substrate. Use of modified natural fibers has increased in textiles, household materials, automobiles, packaging and composite materials. Natural fibers are hydrophilic in nature because of the presence of hydroxyl groups and other polar functionalities in various constituents of natural fibers. Hydrophilic nature decreases the wettability of natural fibers with the hydrophobic polymer matrix. Surface modification of natural fibers, therefore, becomes necessary to enhance the interphase interaction between natural fibers and resin. Surface modifications of natural fibers can be attained by chemical and biological methods. Biological methods are the best in addition to other environmentally friendly approaches such as physical treatments and use of environmentally friendly coupling agents. Laccase catalyzed surface functionalization improves the physical, chemical and mechanical properties of lignocellulosic materials. Laccase biografting is defined as laccase induced coupling of phenolic compounds or certain other types of low molecular weight compounds on the surface of lignocellulose fibers to impart novel, improved and desirable properties.

Laccase-catalyzed biografting of phenolic and other low molecular weight compounds was carried out to develop antibacterial and hydrophobic properties. Fillat et al. have carried out laccase assisted grafting of natural phenols on flax fibers to develop antimicrobial properties in fibers and handsheets with antimicrobial activity. Enzymatic grafting resulted in covalently bonding of natural phenols to the flax fibers. Antimicrobial packaging materials were developed through laccase-catalyzed biografting of phenolic compounds on unbleached kraft liner fibers. Synthesized handsheet papers showed a greater efficacy against Gram positive and Gram negative bacteria. Similarly laccase assisted coating of polyphenols on the lignocellulosic surface was performed to get the desired properties such as coloration and antimicrobial performance. Improved lignocellulosic performance depends upon the nature of the monomer used such as methoxyphenols showed different coloration and ferulic acid & hydroquinone reduced the growth of Bacillus subtilis and Staphylococcus aureus. Surface functionalization of wood veneer and pulp with tannins was reported to improve the antibacterial properties. Surface functionalization improved the antibacterial resistance of lignocellulosic material against S. aureus and E. coli. Antimicrobial activity of unbleached kraft
pulp fibers was improved by laccase assisted treatment with different phenolic compounds. Handsheets made from modified pulp showed a greater efficacy against Gram positive and Gram negative bacteria.\textsuperscript{10} Laccase-catalyzed grafting of simple phenols was performed on sisal and flax pulp fibers to impart novel and improved properties.\textsuperscript{11} Biografting of amines, fluorophenol, wood preservatives, non-polar chains and alkylamines on lignocellulosic materials results in the development of hydrophobicity.\textsuperscript{12–15} Enzymatically modified natural jute fibers were used as reinforcement to synthesize biocomposite. Synthesized biocomposites with improved mechanical properties were obtained due to enhanced cross linking between fibers and matrix.\textsuperscript{16}

All the previous reported work is on modification of only cellulosic fibers or pulp for development of packaging materials. Moreover laccase-catalyzed biografting is mainly targeted on lignin and the majority of raw natural fibers with approximatel 10% lignin will remain unaffected by use of this technique. Lignin-rich coconut fibers can successfully be modified by this technique and can potentially be used as reinforcing material for the development of antibacterial composite materials. In the present work, laccase (from \textit{Trametes versicolor}) catalyzed biografting of syringaldehyde (natural phenol) was performed on coconut fibers. Antibacterial, moisture retention and thermal properties of biografted coconut fibers were analyzed. Modified fibers were then used as reinforcement in poly(butylenes succinate) (PBS) matrix to synthesize biocomposite materials.

2. Experimental

2.1 Materials and methods

Coconut fibers were extracted from surrounding the fruit of the coconut palm (\textit{Cocos nucifera}). Coconut palm was purchased from the local market of Solan (Himachal Pradesh), India. Extracted fibers were washed with mild detergent followed by distilled water to remove the water soluble impurities. Clean fibers were then extracted with acetone in a Soxhlet extractor for 24 h to remove the organic impurities. All chemicals were of analytical grade and used without further purification. Laccase from \textit{Trametes versicolor}, syringaldehyde (SA) (98% pure) and PBS poly(butylene succinate) were purchased from Sigma-\textit{Aldrich}. Citric acid (Himedia, extra pure), sodium citrate (Himedia, extra pure), nutrient broth (Himedia, M002) and nutrient agar (Himedia, M001) were used as received.

2.2 Laccase-catalyzed biografting

Laccase catalyzed biografting was carried out in a 250 mL Erlenmeyer flask containing 200 mg of coconut fibers at 1% consistency in 40 mM citrate buffer (pH 4), 3.5% (w/w) syringaldehyde and 40 U g\(^{-1}\) of laccase. The reaction mixture was incubated at 50 °C for 12 h with constant shaking (30 rpm). Control reaction was also used under identical conditions in the absence of laccase. Modified fibers were washed thoroughly with distilled water after biografting and then Soxhlet extracted with acetone for 12 h to remove the fraction of unreacted SA. Samples were then vacuum dried at 40 °C to a constant weight.\textsuperscript{15} Optimization of reaction conditions was carried out by varying three parameters, \textit{i.e.} laccase concentration, SA concentration and incubation period.

2.3 Quantitative analysis of biografting

Quantitative analysis of biografted coconut fibers was determined by weighing method. The percentage of biografting was calculated by using the following equation:

\[ \text{Biografting (\%)} = \frac{w_2 - w_1}{w_1} \times 100 \]

where \(w_2\) is the weight of biografted fibers and \(w_1\) is the final weight of control sample.\textsuperscript{16}

2.4 Characterization techniques

FTIR spectra of coconut fibers were taken on a Perkin Elmer RXI spectrophotometer averaged over 64 scans from 400–4000 cm\(^{-1}\). Surface morphologies of coconut fibers were examined by Jeol JSM-6610LV scanning electron microscope operating at 7−10 kV and magnification of 200 times. Thermal behavior of fibers was studied using a Perkin-Elmer TGA in an inert atmosphere from 50–800 °C at a heating rate of 10°C min\(^{-1}\). XRD studies were done on a Bruker D\(_8\) Advance X-ray diffractometer under ambient conditions. Crystalline and amorphous material in natural fibers is represented by peak intensities at 22° and 18° respectively. Percentage crystallinity (\% Cr) was calculated as follows:

\[ \% \ Cr = \frac{I_{22}}{I_{22} + I_{18}} \times 100 \]

where \(I_{22}\) and \(I_{18}\) are the crystalline and amorphous intensities at 2\(\theta\) scale close to 22° and 18°, respectively.\textsuperscript{17}

2.5 Antimicrobial studies

Colonial forming unit (CFU) method was used to study the antimicrobial behavior of coconut fibers. The developed colonies on the agar plates were counted in this method and by comparing colony count with the control, it was determined whether the sample is able to inhibit the growth of bacteria or not. Coconut fibers (0.05 g) were added to nutrient broth (10 mL) followed by addition of inoculated culture (1 mL) of \textit{S. aureus} and \textit{E. coli} and incubated at 37 °C. Colonies were counted after 24–48 h by seeding the aliquot of incubated sample on nutrient agar plates. The number of microorganisms grown in the plate was multiplied by dilution factor and divided by volume used to seed the plate in order to determine the CFU mL\(^{-1}\) as follows.\textsuperscript{18}

\[ \text{CFU mL}^{-1} = \frac{\text{colony count on plate} \times \text{dilution factor}}{\text{sample poured on plate}} \]

2.6 Moisture retention studies

Humidity chamber was used to study the moisture retention of original and modified coconut fibers. Coconut fibers were dried
at 80 °C for 4 h in order to attain the equal moisture level. Fibers were then exposed to 55% and 75% RH at 23 °C in a humidity chamber. Fibers were quickly removed from the chamber after every hour and weighed. This procedure was repeated till a constant weight was obtained. The percentage weight gain was calculated as follows.\(^{19}\)

\[
\text{Weight gain} \% = \frac{W_f - W_i}{W_i} \times 100
\]

where \(W_i\) and \(W_f\) are the initial and final weight of coconut fibers, respectively.

### 2.7 Synthesis of biocomposites reinforced with original and biografted fibers

Poly(butylene succinate) (PBS) based biocomposites were prepared by crushing the PBS to powder form. PBS and fiber samples were then dried overnight at 60 °C for the removal of all moisture content. 0.5% and 1% coconut fibers (3 cm long) were used to prepare the biocomposites. Coconut fibers and PBS were weighted in required composition and transferred to the mold cavity of hot press. Three different heating cycles were chosen for complete soaking, mixing and adhesion of fibers with resin. The mold was heated initially from room temperature to 70 °C and maintained there for 15 minutes. The temperature was then raised to 100 °C and kept there for 30 minutes and finally temperatures was raised to 125 °C and maintained there for 20 minutes. Mold was then allowed to cool to room temperature. Constant pressure (100 MPa) was maintained during thermal and cooling treatments to avoid any structural disorder. A schematic representation of preparation of biocomposites reinforced with biografted fibers is shown in Fig. 1. The synthesized composite sheet was removed from the mold and cut into the required dimensions for further mechanical testing.\(^{20}\)

### 2.8 Tensile and flexural testing

Tensile and flexural tests of synthesized composites were performed in 5 kN universal testing machine (Tinius Olsen, H5KT). Tensile and flexural tests were performed at room temperature with a crosshead speed of 5 mm min\(^{-1}\). The results were taken as average value of three samples. All samples were in the form of a rectangular strip with 100 × 10 × 3 mm dimensions.

### 3. Results and discussion

#### 3.1 Mechanism of laccase catalyzed biografting

Fig. 2 shows the schematic representation of laccase catalyzed biografting of SA on the coconut fibers. In the first step, laccase oxidized the lignin part of coconut fiber to form a lignin radical. In the second rate determining step, laccase assisted oxidation of phenolic compound occurred to generate phenoxy radical. Loss of an electron from the SA molecule gives rise to a radical cation species, which depends upon the substitutions on the molecule. There is an electron releasing group \((-OCH_3)\) present on both \textit{ortho} positions of SA. Electron releasing effect eases the formation of a radical cation. Radical cation formation quickly followed by the removal of hydrogen atom and resulted in the generation of a phenoxy radical. The bond dissociation energy of the O–H bond decreases because of the presence of electron donating groups at \textit{ortho} position.\(^{21}\) Presence of methoxy groups at \textit{ortho} positions in SA facilitates the formation of phenoxy radical easily. The last step is grafting of SA on the coconut fibers by covalent bonding of phenoxy and lignin radicals.\(^{22}\)

#### 3.2 Optimization of reaction parameters

Three different reaction parameters such as phenol concentration, enzyme concentration and incubation period were optimized to get the maximum biografting. Four different concentrations of SA, \textit{i.e.} 2.5%, 3.5%, 4.5% and 5.5% (w/w) were used to get the maximum biografted coconut fibers \textit{i.e.} CF\textsubscript{g}-SA(1). Maximum biografting (15.6%) was obtained at 4.5% (w/w) of SA (Fig. 3a). Percentage biografting was found to increase with the increase in SA concentration due to the increased reactivity of laccase towards the phenolic structure of SA. Phenoxy radicals are easily formed because of the electron

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**Fig. 1** Schematic representation of preparation of biocomposites reinforced with biografted fibers.

**Fig. 2** Mechanism of laccase-catalyzed biografting of eugenol on coconut fibers.
releasing group at ortho-position. Moreover, SA itself acts as a natural redox mediator, so it enhances the biografting process on the lignin part of coconut fibers.\textsuperscript{21} Phenoxy radicals form covalent bond with lignin radicals to attain the stabilization. Enzyme concentration was varied from 20 U g\textsuperscript{-1} to 80 U g\textsuperscript{-1}. Extent of biografting was maximum (13.0\%) at 40 U g\textsuperscript{-1} of laccase to get the optimized sample, \textit{i.e.} CF-g-SA(2) (Fig. 3b). This was due to the availability of more phenoxy radicals generated by an initial increase in laccase concentration. Decreased percentage biografting with further increase in laccase concentration was due to the generation of different products in the reaction media and degradation of lignin on higher laccase concentration.\textsuperscript{4} The effect of incubation period was analyzed by using different time period \textit{i.e.} 12 h, 24 h and 36 h. Optimized sample, \textit{i.e.} CF-g-SA(3) with maximum biografting (14.8\%) was obtained at incubation period of 24 h (Fig. 3c). Further increase in reaction time results in decreased biografting, which was be due to the inactivation of the laccase enzyme at so prolonged incubation time. Initial increase in percentage biografting is consistent with literature.\textsuperscript{8,24} Optimized samples were used for further studies such as antibacterial, humidity retention and preparation of biocomposites.

3.3 Characterization of raw and biografted coconut fibers

3.3.1 FTIR spectra. FTIR spectra of raw and biographed coconut fiber is depicted in Fig. 4. Bands at 3400 cm\textsuperscript{-1} in coconut fiber and 3398 cm\textsuperscript{-1} in biographed coconut fiber is due to the O–H stretching.\textsuperscript{25} Bands at the frequencies 2923 cm\textsuperscript{-1} and 2924 cm\textsuperscript{-1} are due to the C–H stretching, respectively.\textsuperscript{26} Characteristics bands at 1737 cm\textsuperscript{-1} and 1736 cm\textsuperscript{-1} arise due the C=O stretching in coconut fiber and biographed coconut fibers. Additional band at 1670 cm\textsuperscript{-1} in case of biographed coconut fiber is due to C=O aldehyde stretching.\textsuperscript{26} While bands at 1611 cm\textsuperscript{-1} and 1605 cm\textsuperscript{-1} in coconut fibers and biographed coconut fibers are due to the C–C=C stretching.\textsuperscript{27} Characteristics bands at 1463 cm\textsuperscript{-1}, 1331 cm\textsuperscript{-1} and 1111 cm\textsuperscript{-1} due to the ether stretching (–OCH\textsubscript{3}), which is absent in the coconut fibers.\textsuperscript{26} Bands at 835 cm\textsuperscript{-1} and 617 cm\textsuperscript{-1} are due to out-of-plane C–H stretching (Table 1).\textsuperscript{27} This interpretation completely supports the biografting of SA on lignin part of coconut fibers.

3.3.2 X-ray diffraction. X-ray diffraction pattern of original and biographed coconut fiber is represented in Fig. 5. The relative intensities and % crystallinity of raw and modified fibers are given in Table 2. Biografting of SA mainly targeted at lignin and can’t be applied to all other major constituents of the lignocellulose material such as cellulose and hemicellulose, thereby leaving this part of lignocellulosic surface unaffected. A negligible change in the crystallinity is due to the grafting of SA, which has changed the functionalities of coconut fiber.\textsuperscript{28}
3.3.3 Surface morphology. Morphological changes in coconut fiber after biografting of SA are depicted in Fig. 6. Coconut fiber is free from any kind of deposition and coating (Fig. 6a), whereas biographed coconut fibers were coated with SA layer as a result of biografting (Fig. 6b-d). The surface morphology of coconut fibers was changed and become rough due to the polymerization reactions in biografting. Availability of more and more phenoxy radicals in the reaction mixture results in self-polymerization and changed the surface morphology. These attachments of phenolic units on the surface of the fiber is due to the covalent bonding during the process of biografting.10,24

4. Properties of raw and biographed coconut fibers

4.1 Thermogravimetric analysis

Fig. 7 shows thermogravimetric analysis of the raw and biographed coconut fibers. Thermal behavior of coconut fibers has changed a lot due to the biografting of SA. Raw and biographed coconut fibers have depicted with two stage decomposition. First decomposition stage of CF-g-SA(1), CF-g-SA(2) and CF-g-SA(3) was observed up to 200 °C (3.8% weight loss), 216 °C (3.5% weight loss), 251 °C (4.7% weight loss) and 246 °C (5.0% weight loss), respectively. First stage decomposition attributed towards the dehydration process, i.e. loss of water by evaporation. Maximum weight loss was observed in second decomposition stage of both raw and biographed coconut fibers. Second decomposition stage of CF-g-SA(1), CF-g-SA(2) and CF-g-SA(3) occurred in the range of 220–338 °C (61.3% weight loss), 216–431 °C (66.6% weight loss), 251–436 °C (62.3% weight loss) and 246–439 °C (65.5% weight loss), respectively. Second stage decomposition represents the degradation of lignin and breaking of covalent bonding between lignin and SA. The increased final decomposition temperature in biographed fibers confirms the strengthen of fiber due to biografting. It can be analyzed from Table 3 that biographed coconut fibers are thermally more stable than raw coconut fibers. Thermal stability

### Table 2  Crystallinity of raw and biographed coconut fibers

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Fibers</th>
<th>At 2(\theta) scale</th>
<th>(I_{22})</th>
<th>(I_{18})</th>
<th>% Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coconut fibers (CF)</td>
<td>1177</td>
<td>1953</td>
<td>62.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CF-g-SA(1)</td>
<td>1445</td>
<td>914</td>
<td>61.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CF-g-SA(2)</td>
<td>1906</td>
<td>1131</td>
<td>62.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CF-g-SA(3)</td>
<td>1745</td>
<td>2794</td>
<td>62.4</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 6  SEM of raw and biographed coconut fibers: (a) coconut fiber (b) CF-g-SA(1) (c) CF-g-SA(2) (d) CF-g-SA(3).

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Fig. 7  TGA of raw and biographed fibers.
was enhanced due to the biografting of SA on the lignin part of coconut fibers through covalent bonding.29–34

### 4.2 Antibacterial studies

Syringaldehyde is known to have antioxidant, antibacterial and other medicinal properties.35 Biografting of SA onto coconut fibers have developed the antibacterial activity, which is depicted in Fig. 8 and 9. Antibacterial activities of the SA grafted coconut fibers has been analyzed against the Gram negative (*E. coli*) and Gram positive (*S. aureus*) bacteria. Biografted coconut fibers results in decreased microbial viable count against the *E. coli* in comparison to *S. aureus*. Thick peptidoglycan layer of Gram positive bacteria creates obstacles in the killing mechanism of the bacteria by phenolic groups. The CFU mL⁻¹ was 56 × 10⁹ for *E. coli* (Fig. 8c) and 280 × 10⁹ for *S. aureus* (Fig. 9c). The best antibacterial activity of biografted fibers is due to the presence of hydroxyl group and delocalized electron system. SA in biografted fibers permits the exchange of proton across the cell membrane and decrease the gradient. Energy and nutrition flow were stopped and resulted in the death of the cell.36 Presence of –OH (proton donor) and –OCH₃ (proton acceptor) groups at para and ortho positions of SA increases the antibacterial activity of biografted fibers.37

### 4.3 Moisture retention studies

Moisture retention capacity of coconut fibers was found to be decreased after biografting with SA (Fig. 10). There was the diffusion of moisture from the outer atmosphere to the surface of coconut fibers followed by diffusion from the surface to the individual fiber surface. Finally, diffusion to the interior of fibers took place.38 Phenoxy radicals generated by an enzymatic reaction undergo coupling reactions, which results in the grafting and polymerization on the surface of coconut fibers. Various moisture vulnerable sites of coconut

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Fibers</th>
<th>Transition temp. range (°C)</th>
<th>Weight loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Coconut fiber</td>
<td>0–200</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200–338</td>
<td>61.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>338–455</td>
<td>8.1</td>
</tr>
<tr>
<td>2.</td>
<td>CF-g-SA(1)</td>
<td>0–216</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>216–431</td>
<td>66.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>431–608</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>608–713</td>
<td>3.1</td>
</tr>
<tr>
<td>3.</td>
<td>CF-g-SA(2)</td>
<td>0–251</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>251–436</td>
<td>62.3</td>
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<td>436–580</td>
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<td></td>
<td></td>
<td>580–700</td>
<td>2.8</td>
</tr>
<tr>
<td>4.</td>
<td>CF-g-SA(3)</td>
<td>0–246</td>
<td>5.0</td>
</tr>
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<td></td>
<td></td>
<td>246–439</td>
<td>65.5</td>
</tr>
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<td>439–572</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>572–700</td>
<td>3.8</td>
</tr>
</tbody>
</table>
fibers were blocked as a result of polymerization and grafting of SA.16

5. Mechanical properties and fractured surface morphology of biocomposites

Tensile load-strain curves and tensile strength (MPa) of composites are depicted in Fig. 11. Tensile and flexural testing of neat PBS and fiber reinforced composites were carried out to explore the effect of biografting on the mechanical strength of biocomposites. It has been observed from Fig. 11a and b that more tensile force was required to break the composites reinforced with CF-g-SA in comparison to neat PBS (7.3 MPa) and raw coconut fiber reinforced composites. Fiber content also plays an important aspect in the mechanical properties of composites (Fig. 11c). Tensile strength was found to increase with the increase in fiber content from 0.5 to 1%. Maximum tensile strength (22.5 MPa) was observed in case of composites reinforced with CF-g-SA (1%) followed by composites reinforced with CF-g-SA (0.5%) (18.04 MPa). Tensile strength was found to be 10.48 MPa and 13.64 MPa with 0.5% and 1% raw coconut fibers, respectively. Stress–strain curves and flexural strength (MPa) of composites are depicted in Fig. 12. Flexural strength of biocomposites reinforced with CF-g-SA was found to increase in comparison to neat PBS (6.8 MPa) and coconut fibers reinforced PBS. Flexural strength was also increased with the increase in concentration of fibers. Biocomposites reinforced with CF-g-SA (1%) showed maximum flexural strength (13.5 MPa) followed by composites reinforced with CF-g-SA (0.5%) i.e. 9.38 MPa. In case of raw coconut fibers, flexural strength was found to be 7.68 MPa (0.5% fiber content) and 8.9 MPa (1% fiber content). An improvement in mechanical strength of composites was observed even with the small amount of biografted fibers.

Better compatibility and even stress distribution between biografted fibers and PBS matrix contributes towards the improved tensile and flexural strength of composites.19 The enhancement in interface compatibility between biografted fibers and PBS matrix was due to the increased hydrophobicity of coconut fibers. The surface of the biografted coconut fiber was coated by irregularly arranged flakes or particulates, which results in better interlocking with PBS matrix. An increase in the compatibility between matrix and biografted fibers results in composites with improved mechanical strength. Proper wetting of fibers during various thermal treatments also contributed towards improved adhesion between fiber and matrix and resulted in a strong interphase and improved mechanical properties of composites.

Fractured surface morphology of coconut fiber/PBS and CF-g-SA/PBS biocomposites is depicted in Fig. 13a and b, respectively. Biografted fibers are more compatible with PBS in comparison to the unmodified coconut fibers. The nature of fibers and PBS matrix forming the interface results in strong interfacial adhesion. Polarities of above two materials become more similar after the biografting of SA on coconut fibers. After biografting, coconut fibers become hydrophobic in nature and showed better wetting with hydrophobic PBS matrix.16,40
6. Conclusions

Biografting is an eco-friendly approach to modify the surface of natural fibers and endow fibers with novel and improved properties. Syringaldehyde was successfully grafted on the lignin part of coconut fibers by laccase catalyzed surface functionalization. A strong interaction between hydrophobic biografted fibers and hydrophobic microbes endows the biocomposites with improved mechanical properties. The developed antibacterial material will have potential applications, especially in food industries or where the growth of microbes is a serious problem.

References

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