Industrial Crops & Products 112 (2018) 556–560

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Curcuma longa L. plant residue as a source for natural cellulose fibers with antimicrobial activity

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ARTICLE INFO

Keywords:
Curcumin longa
Natural cellulose fibers
Antibacterial properties
Valorization

ABSTRACT

Natural cellulose fibers extracted from stems of *Curcuma longa* L. have properties similar to fibers from lignocellulosic crop residues and also inherit antimicrobial properties. Turmeric contains curcumin, the natural compound known to have many medicinal benefits including anti-cancer activity. Turmeric plants are mainly cultivated for its rhizome (tuber) but the plant generates considerable amounts of stem and leaves as residues. Leaves and stems of turmeric plants have been reported to contain oil and other extractives having antimicrobial and anti-insecticidal activities. Such extracts are of limited quantity and hence it is difficult to justify the economic feasibility of using the residues for large scale applications. Natural fibers have a large market and offer higher value addition and options to develop various products. However, fibers obtained from lignocellulosic sources do not have inherent antimicrobial properties. Turmeric stems were treated with alkali solution to obtain natural cellulose fiber bundles. These fibers had cellulose content of about 50%, lignin content of 12% and about 10% ash. Alkali treatment removed surface substances resulting in smooth fiber bundles. Cellulose in the fibers showed typical diffraction peak at 22.7° belonging to the 002 plane. Tensile strength of the fibers at 2.5 g/den (325 MPa) was similar to jute. Fibers showed antimicrobial activity against both gram positive and gram negative bacteria. Turmeric fibers could be useful for wound dressings, textiles, composites and other applications.

1. Introduction

Multipurpose agricultural crops that yield more than one produce/processed products are limited. Most of the major crops such as wheat, corn, rice, sugarcane etc are grown primarily for their produce. Unfortunately, the amount of produce generated from these crops is considerably low compared to the waste or residues they generate. For instance, the corn collected is much low in quantity compared to the stalks, leaves, husks and cobs generated as byproducts or residue. Generally, these residues are either burnt or buried in the ground. This means that the natural resources and energy used to grow the crop are not utilized efficiently. Owing to the large amounts available at low cost and in a sustainable route, considerable efforts are being made to utilize the agricultural residues for industrial applications (Reddy and Yang, 2009a,b,c). Similar to the agricultural residues, high yield and low resource intensive biomass such as switchgrass and water hyacinth are also considered for various industrial applications (Guna et al. 2016, 2017).

Agricultural residues such as stalks, leaves and husks have been used to develop fibers, composites, filters, sorbents for waste water etc. Among the various uses, fibrous applications are most promising due to the high value addition possible. Fibers have been extracted from cornhusks, stalks, wheat and rice straw, cotton stalks and other agricultural residues with properties similar to that of the fibers in current use (Anandamurthy et al., 2017; Reddy, 2015). Properties of textiles and composites made from fibers extracted from agricultural residues have been found to be suitable for automotive composites and other areas (Vinayaka et al., 2017; Bhuvaneswari et al., 2017).

Curcumin longa, commonly referred to as turmeric is an herb used for its medicinal properties. India is the largest producer of turmeric with annual production of about 25 M tonnes. Turmeric is grown in about 180,000 ha in India and the yield is about 39 t per hectare. It typically takes about 225 days for the plants to be mature. Although considerable quantity of turmeric is produced, the most valuable

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https://doi.org/10.1016/j.indcrop.2017.12.042
Received 7 September 2017; Accepted 17 December 2017
Available online 04 January 2018
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component curcumin yield from turmeric is about 6–7% depending up on the variety and the conditions during growth (Hossain and Yukio, 2005). Since turmeric is a rhizome, the stem and leaves above the ground are not considered useful and are generally disposed as waste. Unfortunately, the amount of residues generated is considerably higher than the turmeric harvested.

Several attempts have been made to utilize parts of the turmeric plant in addition to the rhizome and curcumin extracted from the turmeric. About 40% oil is extracted when turmeric is processed to obtain the yellow pigment curcumin (Negi et al., 1999). Four different fractions were separated from the oil. Ar-Turmerone, turmerone and curlone were found to be the major compounds in the oil with one of the fractions having considerably higher antimicrobial activity (Negi et al., 1999). Curcumin was also reported to correct cystic fibrosis (Egan et al., 2004). Fractionation of curcumin yields three curcuminoids having enzyme inhibition activity. Other compounds extracted from curcumin have exhibited antifungal and mosquitocidal activity (Roth et al., 1998). Given such unique and distinct applications, it is reasonable that curcumin is considered a novel and highly valuable biocompound. Since curcumin only forms a minor part of the crop, it is highly practical to use other parts of the plant for value added applications. Such efforts will not only add value to the crops but will also decrease the amount of waste generated.

In addition to the tuber, other parts of the turmeric plant have also been reported to have medicinal and other properties. Arutselvi et.al, studied the photochemical content and potential antimicrobial activity of the extractants from turmeric leaves (Arutselvi et al., 2012). Leaf extractants were composed of flavanoids, cardiac glycosides and phenols and showed antimicrobial activity against *S.pyrogens*, *B.subtilis* and *C. albicans* (Arutselvi et al., 2012). In another study, hexane extracts from turmeric leaves contained labda-8(17),12-diene-15,16 dial. These compounds were found to effectively inhibit growth of *Candida albicans, Candida kruseii* and *Candida parapsilosis*. One of the extract (12-diene-15,16 dial) was also found to act as mosquitocide against *A. aegyptii* larvae when used at a concentration of 10 μg mL^{-1} and also acted against three different types of beetle (*R. dominica, S. oryzae* and *T. castaneum*) (Roth et al., 1998). Similar to the rhizome, oil extracted from the leaf contained about 60 compounds, prominent among them being alpha-phellandrene (18.2%), 1,8-cineole 04.6%) and p-cymene (13.3%) (Sharma et al., 1997).

Although some efforts have been made to identify and utilize parts of turmeric plant other than the rhizome, to the best of our knowledge, turmeric residues have not been studied to understand their potential as sources for natural cellulose fibers. In this research, we have extracted natural cellulose fibers from the stalks of the turmeric plant and characterized the structure and properties of the fibers. In addition, we have studied the potential antimicrobial properties of the fibers.

2. Materials and methods

2.1. Raw material

Turmeric plants were collected from a field on campus after the rhizome was harvested. Leaves and stalks were dry and used directly without any treatment. Laboratory grade sodium hydroxide, acetic acid and other chemicals required for fiber extraction were purchased from local vendors.

2.2. Extraction of fibers

Turmeric plants were treated with 1 M sodium hydroxide solution for 30 min at 90 °C. Material to the alkali solution ratio was maintained at 1:10. After treatment, the liquid that contained dissolved hemicellulose, lignin and other extractives was decanted and disposed. Fibers extracted were thoroughly washed several times until the pH of the fibers in water was about 7. Later, the fibers were immersed in 10% acetic acid solution for about 10 min, rinsed and dried.

2.3. Composition

Composition of the untreated turmeric stems and the fibers extracted were determined in terms of cellulose, hemicellulose, solubles, lignin and ash. The compositional analysis was done using standard test methods. Cellulose and hemicellulose were determined using the acid and neutral detergent procedure. Neutral detergent was added into the biomass at 1:100 ratio along with decalin and anhydrous sodium sulfite. Beaker was boiled for 5–10 min and continued to heat for 60 min. Similar procedure was also followed to determine the acid detergent fiber. Residue obtained after treatment was called Acid Detergent Fiber (ADF) and neutral detergent fiber (NDF) which represent cellulose and hemicellulose, hemicellulose and lignin, respectively. ADF and NDF values were used to determine the% cellulose and hemicellulose. About 2 g of sample was placed in a crucible and heated in a muffle furnace for 5 h at 550 °C to determine the ash content. Weight of the sample after burning was recorded and the difference in weight was used to calculate the% ash content. Klason lignin was determined using the sulfuric acid hydrolysis approach. Samples were treated with 72% sulfuric acid (1:5 ratio) and allowed to stay at room temperature for about 2 h under constant stirring. Later, the solution was diluted with water at 1:540 ratio and boiled for 6 h under reflux. After the thorough boiling, the residue in the flask was washed several times until the pH was neutral. Weight of the residue was determined after drying and used to calculate the% lignin. The flavonoid and phenolic contents in the turmeric plant and extracted fibers were determined using qualitative and quantitative methods based on established protocols (Sadasivam and Manickam, 1997; Nagananda et al., 1986; Tripathi et al., 2002).

2.4. Tensile properties

Tensile strength, elongation and modulus of the fibers were determined using a universal tensile tester (MTS Mechatronics, Ichalakarnji, India). Samples were tested using a gauge length of 1 inch and crosshead speed of 18 mm/min according to ASTM standard D 3822-14. A 500 N load cell was used for testing. All tests were done at room temperature and about 30 fibers each from three different extractions were tested. The average and ± one standard deviation of the values has been reported.

2.5. Morphology

A Hitachi (Model SU 3500) scanning electron microscope was used to observe the morphology of the turmeric stems before extraction and the fibers obtained after extraction. Changes in the surface and cross-sections were studied. Samples were sputter coated in an Ion beam coater for 60 s before observation. Images were collected using the secondary electron detector operating at 15 kV.

2.6. X-ray diffraction studies

Turmeric stems and fibers were powdered in a Wiley mill for the X-ray powder diffraction studies. Samples were powdered and placed in a Teflon holder. Readings were taken on a Bruker D8 Advanced Eco X-ray diffractometer having Bragg-Brentano Focusing geometry. A Cu-K_α radiation at a wavelength ($\lambda = 1.54$ Å) was used for the measurement. A SSD 160 recorded the diffraction intensities for 2θ angles varying from 5 to 40°. Readings obtained were analyzed using Origin and the peak positions were identified.

2.7. Thermogravimetric analysis

Thermal degradation of the turmeric stalk and fibers were determined using a Shimadzu DTG 60 thermogravimetric analyzer. About

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