Chapter

Comprehensive Review on Potential Applications of Natural *Luffa Cylindrica* Fibers

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Abstract

Luffa fibers are obtained from matured dried fruit of Luffa cylindrica (sponge-gourd), an annual climbing crop widely grown in sub-tropical countries. These fibers are easily available, cheap, light weight and biodegradable in nature. Due to these advantages, the fibres possess high economic significance and also enormous studies have been reported on these environmental friendly natural fibers. The current review focuses briefly on the characteristic properties and geographical sources of the fibers. Also, the different modification approaches in order to enhance the efficiency of luffa fibers in various fields have been discussed. The significant properties of luffa fibers like renewability, non-toxicity to microbes as well as environment, simple operation technique and high stability during long term storage and repeated use have made this matrix to be successfully used as an immobilization carrier. The comprehensive summary of the potential features of the fiber in various fields such as material science, textile industry, medical science, environmental and bioprocess engineering are highlighted in this article.

Keywords

Luffa Cylindrical; Sponge-Gourd; Composites; Immobilization Carrier

Key message: *Luffa cylindrica* a vegetable sponge possess many applications such as material science, textile industry, medical science, environmental and bioprocess engineering.

Introduction

Luffa cylindrica is a peculiar vegetable native to cucurbitacea family, commonly called as vegetable sponge, sponge-gourd, wash sponge, loofah gourd or dishcloth gourd. It is an annual climbing plant growing in sub-tropical regions that produces fruits containing fibrous vascular system. The plant has leaves as 7-20 cm long with three lobes, bright yellow flowers and young green fruit of about

60 cm length in oblong or cylindrical shape that may contain many seeds. The matured fruit is brown and dry, which develop as sponge-like structure. The unripe fruits are generally harvested at young stage as vegetable source, whereas the fully ripened fruit is non-edible and very fibrous in nature. The fibrous network of matured dried fruits of these plants is termed as luffa sponge or *Luffa cylindrica* fibers. Gianpietro *et al*. have characterized and reported that these fibres comprised of cellulose, hemicelluloses and lignin in an approximate ratio of 6:3:1[1] (Table 1&2).

Table 1: Composition of *Luffa cylindrica* fibers [2].

Components	**Amount (%)**
α-cellulose	62
hemicellulose	20
lignin	11.2
ash	0.4
extracts	3.1

Table 2: Taxonomy of Luffa cylindrical [3].

Kingdom	Plantae
Division	Mangoliophyta
Class	Mangoliosida
Order	Cucurbitales
Family	Cucurbitaceae
Genus	Luffa
Species	Cylindrica

The plant has been traditionally used for its medicinal properties [4] as acrimonious tonic, emetic, promotes diuresis, strongly laxative and also useful in treating chronic airway disease, graze diseases (skin) and spleen enlargement. It has been used orally for rheumatoid arthritis, back pain, internal bleeding, and pain at thorax as well as haemorrhoids and topically, it is used for varicella zoster virus infections (shingles) and skin abscesses (boils). The fruits are antihelminthics, flatulence relief, purgative, detoxicity, soothing skin, to treat cough and increases the secretion of mother's milk and are useful in high body temperature, bacterial infections (syphilis), abnormal cell growth, inflammation in bronchi, any infection of spleen, cancer [5] and Hansen's diseases. The fibres of dried fruit are used as scratchy scrubber for skin care, that removes skin cell (dead) and to normalise the blood flow of the skin.

Geographical Source and Properties

Luffa cylindrica is a vegetable plant commonly growing in summer seasons. The assigning of the indigenous areas of luffa species with accuracy is a challenging process. It keeps a wide history of plantation in the tropical areas of the world (Asia and Africa) [6,7]. Indo-Burma was known as the focal point of diversity for sponge gourd. China, Korea, India, Japan and Central America are reported as the main commercial production countries [8].

Attractive properties of these natural fibers include higher porosity and precise pore volume, constant somatic properties, non-toxic and biodegradability. These characteristics render it more suitable as a supporting matrix for the culturing of plant, algal, bacterial and yeast cells [9].

Modifications on *Luffa Cylindrica* Fibers

Different scientists have tried to modify the surface nature of the *Luffa cylindrica* fibers to increase its potential in various fields. In order to make the luffa fibers more useful as composites, the somatic characteristics of luffa fibres have been improved by chemical or physical modifications. The studies have investigated the influence of different chemical treatments on the structure of fibers. The two treatments reported are: i) alkali treatment using sodium hydroxide as delignification agent and ii) mixed treatment using sodium hydroxide along with hydrogen peroxide as bleaching agent, at different concentrations and treatment conditions of temperature and pressure [10]. It was also reported that the structure conservation and high crystalline index of fibers after processing has acceptable interests in their technical applicability. A fine structure of the fibre could be attained by other conditions of mixed method by destructing the fiber crystalline structure [10].

An on-going study on luffa fibers has focused to enhance its stability properties by the removal of lignin through surface modification. These modified fibers could have an impeccable impact in the field of drug delivery. The modification of luffa fibers could be performed by using different chemical treatments such as alkali like sodium hydroxide and potassium hydroxide [11]. The results of on-going studies on *Luffa cylindrica* fibers and the literature on other natural fibers showed that the removal of lignin from the surface of the fibers could be done with lower concentration of alkali at a higher temperature and pressure, however higher concentration of alkali may be required at room temperature. From the literature of natural fiber modification approaches, an alternative method for fiber modification by acid treatment has been identified. This method could completely remove the lignin and partially remove hemicelluloses (figure 1, 2), and hence the integrity of the fiber would be lost since the hemicelluloses provided the structural integrity to the fiber. The resulted chemically modified fibers could play a major role in the field of sustained and controlled delivery of drugs [12].

Figure 1: SEM images of untreated luffa fibers [12].

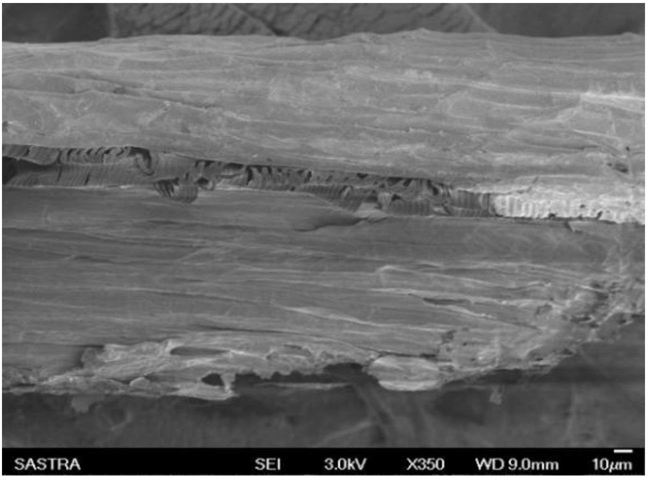

Figure 2: SEM images of acid and alkali treated luffa fibers [12].

Composites of Luffa Fibers

Composites are the materials which are made by the combination of two or more components with different physical and chemical properties. The composites which are re-inforced with natural fibers contributes worthable ecologically and economically important properties since they posses many beneficial characters such as renewability, biodegradability, comparatively less weight with reasonable strength and stiffness [13].

Because of several environmental issues, 21st century has noticed impressive attainments in green technology through the development of bio composites. There is an increase in demand for bio-degradable products made from renewable resources for the development of natural fiber composites (NFC), which have wide applications in various fields. During the last two decades, the nano composite materials have grown rapidly by replacing traditional micro composites, to rid over the drawbacks of the micro scale materials. The nano composites aids by constructing new structures and materials with peculiar adaptability and remodelled physical properties. Recently, the studies on fibers extracted from *Luffa cylindrica* have revealed it as one of the new potential sources of micro fibrillated cellulose and cellulose nanocrystals, [14] which could strongly affect the properties of bio nano composites. It has been reported that cellulose nano crystals prepared by the acid hydrolysis of luffa fibers are used as reinforcing material for the dealing of bio nano composites [10]. One of the main advantages of these nanocrystals in the development of bio nano composites is due to the possible promotion of the interfacial filler/matrix interactions by the chemical modification on the surface of the cellulose nano crystals with some chemical agents such as N-octadecyl isocyanate ($C_{18}H_{37}NCO$). Both unmodified and chemically modified nanocrystals are desirable in the preparation of nano composites [15]. It has also been investigated that the contribution of the nano filler content of the poly (e-caprolactone) (PCL) based nano composite film has been reinforced by these cellulose nanocrystals on the transport properties through water sorption and water permeation processes [16].

Applications of Luffa Cylindrical

Luffa cylindrica finds wide applications in various fields such as material science, medical science, pharmaceutical industry, biotechnology and bioprocess engineering etc., due to its stable properties as one of the commercial edible vegetable. They have been used as hygienic scouring materials during bathing, packing medium, car filters, etc. [17] It is also utilized for the manufacture of hats, table mats, pot-holders, doors, flip-flops and scarfs. The fibre has also been well adopted for properties like capability in absorbing sound and shock, for instance in hats and armoured automobiles. The dry fibre of luffa is used to purify water and wine in some countries (Ghana) and to clean wearables in other countries (Central Africa). Another potential use is in the strengthening of gum background amalgamated constituents, but in this case a barricade film, for example of glass characters, is essential to evade liquid preoccupation from the atmosphere.

Luffa was discovered as an industrial plant in Japan between 1890 and 1895, as the fibers were used in the filter manufacturing for steam and diesel motors. It has been demonstrated and confirmed the feasibility of using luffa fibers for industrial effluent treatment due to the advantageous characteristic as a natural fiber [18]. It has also been reported for its high performance in the clearing of heavy metals ($Cu2+$) from effluents by adsorption [19] and in the removal of organic / inorganic solvents such as synthetic phenols [20]. Fungal bio sorbents immobilized on *Luffa cylindrica* sponges have been used for the bio sorption of heavy metals from wastewaters, especially from olive oil mill effluents.

Recent studies on *Luffa cylindrica* have reported the use of its fibers in the discolouration process of certain solutions and water dyeing as a supporting material for immobilization [21-23]. Akhtar et al.

have investigated the higher potential of the luffa sponge for its use as supporting materials to bring out a new sorption system for the removal of some metals such as chromium III, cadmium and nickel II ions from the contaminated aqueous mediums. It has been reported that *Luffa cylindrica* fibers exhibited the potential to remove methylene blue dye from aqueous solutions as an adsorbent. At different temperatures and different dye concentrations, the average methylene blue absorption capacity and average BET surface area of fiber was evaluated to be 49 mg/g and 123 m^2/g, respectively [22].

The significant properties of luffa fibers like renewability, availability, low-cost, non toxicity to microbes as well as environment, [23] simple operation technique and high stability during long period of repeated use, [25] have made this matrix to be successfully used as an immobilization carrier. Certain researchers have adopted this immobilization characteristic to the surfaces as on luffa fibers as great potential for industrial applications. It has reported that, in the production of gibberellic acid by mutant *Fusarium monoliforme* cells, the immobilized luffa sponge showed 2.8 times greater production than the free cells [24]. Another study reported in literature had shown 3 times higher production of ethanol by *Luffa cylindrica* fibers immobilized with *Candida brassicae* cells than that of a suspension culture. These fibers offer many advantages for technical and industrial use in Brazil even though luffa sponge is widely produced in tropical and sub-tropical countries [24].

The morphological studies on *Luffa cylindrica* fibers have revealed that the micro spongy structure of fibrous strands of luffa contains a number of micro-cell fibers (m-CF) in the range of 200 to 500, which enable the higher accessible volume and increased capacity of absorption. This feature might play a significant application as micro-reservoirs in the case of the delivery of metals and other active substances. For instance, the micro sized *Luffa cylindrica* fibers spread with silver (Ag) particle could be used in wound dressing and as a material for controlled drug release. It is also been identified that, it is possible to enhance the silver incorporation in to the micro spongy structure of *Luffa cylindrica* fibers by using a biopolymer chitosan, which has useful and important properties in wound healing due to the presence of metal chelating groups like amine [26]. Thus, the micro spongy structure covered with chitosan membrane could offer an efficient platform for the growth of silver nano particles, [27] whereas *Luffa cylindrica* fibers could prevent the infections by fostering the absorption of fluids [28,29].

Roble et al. have introduced a novel bioreactor with circulating loops by immobilizing the cells in luffa sponge, which has been used in the production of ethanol by the bioconversion of cassava starch. The sponge has been used as a medium for culturing the human hepatocyte cell lines and also for hepato-protective medicine [30]. These fibers showed its potential in the development of bio film aggregating microbes, which were capable to metabolize both organic and inorganic compounds adsorbed on it, especially those involved in nitrification process [31].

In the bioprocess industries luffa sponge has been used as an immobilization carrier for various techniques involving cellulase enzyme. But, the main demerit was the degradation of cellulose in *Luffa cylindrica* by the cellulase enzyme. It has been demonstrated that acetylation of luffa sponge with acetic anhydride has a good ability to protect the sponge from cellulose degradation [32] and this increased the possibility of its application in bioprocesses involving cellulose enzymes. These acetylated luffa sponge has greater potential than other cellulose carriers since it was a natural cheap fiber and also the acetylation process was simple and economic, when an autoclave was used for acetylation. The characterization studies evaluated the acetylated luffa sponges in terms of tolerance to cellulase, immobilization efficiency, toxicity to immobilized cells and stability for long-term operation, which proved that the acetylated luffa sponge was very good carrier for the immobilization. Moreover, in case of Saccharomyces cerevisiae IR-2, both the cell growth rate and percentage of cells immobilized on the acetylated luffa sponge were as high as those obtained using the non-acetylated luffa sponge. Also, the ethanol production by the cells immobilized on the acetylated luffa sponge was the same as that obtained using suspended cells and cells immobilized on the non-acetylated luffa sponge.

The studies on luffa has been demonstrated that the potential of luffa sponge as a plant cell immobilization carrier and as a microbial cell supporting matrix because of their excellent characters [27]. The effect caused by the size of aggregate and the luffa parts needed for immobilization has examined using the suspension cultured plant cells of *Angelica sinensis, Carthamus tinctorius* and *C. arabicu*. The studies reported that the *C. arabicu* cells with large aggregate size were effectively immobilized on luffa matrix by entrapment with the random lattice of network configuration.

The studies on luffa sponge have reported its potential as an excellent immobilization carrier for flocculating cells. Henceforth, luffa fibers received wider applications in bioprocessing industries as it improved the productivity of fermentation processes as a cheaper carrier and it also ensured that the immobilization can be performed with the minimal effect in the total production cost. Furthermore, it was identified as suitable for application in industries of fermented food and beverages. This is because, the use of immobilized cells in these industries is limited to those immobilization carders which do not feel necessity to use chemical additives, since even the non-toxic chemicals may lead to noxious flavours and aromas to the fermented beverages.

Research experiments have showed that usage of chitosan as flocculant had increased the potential of luffa fibers as an immobilization carrier for non-flocculating cells. The efficacy of luffa fibers with chitosan polymer in the immobilization of *C. brassicae* was also demonstrated by researchers, which concluded that the effectiveness of the flocculants may depend on the cell characteristics. Since the construction of luffa sponge fixed beds in production scale reactors is very simple, it has great potential for this industrial applications.

A comparative study on luffa sponge, luffa sponge with chitosan, luffa sponge with alginate and synthetic sponge was performed by scientists, for the immobilization of *Bacillus firmus* strain cells for β-cyclodextrin (β-CD) production from dextrin. Similar results were observed for all the carrier matrices studied, however the researchers selected luffa fibers for the further studies due to its renewable nature and simple method of immobilization. The inventive use of luffa sponges as an environmentally favourable matrix for β-CD production have contributed an excellent performance at an reasonable cost, thus making the process potentially relevant for the industrial scale-up [33].

Conclusion

Luffa cylindrica fibers are effectively used as a reinforcement material as well as an immobilization carrier in various industrial and technological applications beyond its traditional usage as scrubbers, mats, carpets, etc. As luffa fibers are cheap and environmental friendly matrix, they are gaining high popularity among sustainable natural fibers. The role of these fibers as composites is inevitable. From the studies reviewed in this paper, it is clear that luffa fibers can be used as immobilization carriers for microbes for the production of organic solvents such as ethanol and gibberellic acid. In addition to this, they have high potential for adsorption of heavy metals and other toxic substances from the effluents. Since treatment of luffa fibers require no chemical additives that results in noxious flavours and aromas, it can be used in the fermented food and beverage industries. The main disadvantage of the material is that the fibres are highly hydrophilic so that they lose their mechanical properties after aqueous uptake. Further studies and modification techniques may be adopted to combine or enhance the compatibility of other hydrophobic polymers in luffa fibers.

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