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Review

Luffa cylindrica - an emerging cash crop

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Sponge-gourds, the fruit of *Luffa cylindrica*, are widely used throughout the world. It is an annual climbing crop which produces fruit containing fibrous vascular system. It is a summer season vegetable. At the moment, from the results of studies carried out on this wonder crop, it encourages the commercial cultivation of the crop because of its increasing economic importance. The objective of this review is to show the potentialities of this crop that is virtually found around the globe. Areas such as agriculture, medicine, science, engineering and biotechnology will be discussed. Recent major advances and discoveries will be considered.

Key words: *Luffa cylindrica*, cultivation, crop, commercial, agriculture.

INTRODUCTION

Loofa is derived from the cucumber and marrow family and originates from America (Mazali and Alves, 2005). Luffa [*Luffa cylindrica* (L.) Roem syn *L. aegyptiaca* Mill] commonly called sponge gourd, loofa, vegetable sponge, bath sponge or dish cloth gourd, is a member of cucurbi-taceous family. The number of species in the genus *Luffa* varies from 5 to 7. Only 2 species *L. cylindrica* and ribbed or ridge gourd [*L. acutangula* (L.) Roxb] are domesti-cated. 2 wild species are *L. graveolens* and *L. echinata*. *Luffa* is diploid species with 26 chromosomes (2n = 26) and a cross-pollinated crop (Bal et al., 2004). Loofa sponge is a lignocellulosic material composed mainly of cellulose, hemicelluloses and lignin (Rowell et al., 2002). The fibers are composed of 60% cellulose, 30% hemi-cellulose and 10% lignin (Mazali and Alves, 2005). The fruits of *L. cylindrica* are smooth and cylindrical shaped (Mazali and Alves, 2005) . 1 mature Luffa sponge will produce at least 30 seeds. Some will produce many more (Newton, 2006).

L. cylindrica has alternate and palmate leaves compris-ing petiole. The leaf is 13 and 30 cm in length and width respectively and has the acute-end lobe. It is hairless and has serrated edges. The flower of *L. cylindrica* is yellow and blooms on August-September. *L. cylindrica* is mono-ecious and the inflorescence of the male flower is a raceme and one female flower exists. Its fruit, a gourd, is green and has a large cylinder- like shape. The outside of the fruit has vertical lines and a reticulate develops inside of the flesh. *L. cylindrica* grows about 12 cm long. The stem is green and pentagonal and grows climbing other physical solid (Lee and Yoo, 2006). The loofa sponge is a highly complex macroscopic architectural template, an inexpensive and sustainable resource. The loofa sponge is cultivated, unlike the sponge produced with cellulose that is extracted from trees. The plant is cultivated in many countries, including Brazil, where its cultivation has an increasing economic importance (Mazali and Alves, 2005).

L. cylindrica is a sub-tropical plant, which requires warm summer temperatures and long frost- free growing season when grown in temperate regions. It is an annual climbing which produces fruit containing fibrous vascular system. It is a summer season vegetable. It is difficult to assign with accuracy the indigenous areas of *Luffa* spe-cies. They have a long history of cultivation in the tropical countries of Asia and Africa. Indo-Burma is reported to be the center of diversity for sponge gourd. The main commercial production countries are China, Korea, India, Japan and Central America (Bal et al., 2004).

Sponge gourd prefers pH of around 6 to 6.8. High level of K and P is recommended for growth. It also grows well in green house and will grow on many soil types but well drained sandy loams are preferred. Seeds need to be germinated at 25^{o}C and grown on and transplanted when the soil temperature is about 18^{o}C. Although *L. cylindrica*

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can be left to grow along the ground, best yields and fruit quality are obtained using a support structure or trellis system (Bal et al., 2004).

Any constriction will result in deformed fruit. Irrigation is essential for good growth during dry periods but excessive water can result in poor growth and root diseases. Generally there have been few pest and disease problems of sponge gourd reported in Nepal. Damping off can be a problem with young seedlings if grown in cool wet conditions and fruit rots may cause losses if the fruit are allowed to grow on the ground. Problems with aphids and subsequently viruses have been sometimes reported (Bal et al., 2004). Frost kills the plant and it needs 4 to 5 months of growth to produce sponges (Newton, 2006).

Applications

Generally, *L. cylindrica* can be used in virtually all areas. Factors such as high surface area per volume, strong and durable structure, low specific gravity (which makes it light) and reasonable cost are characteristics of loofa making it a suitable alternative for use as a packing medium in an attached growth system (Mazali and Alves, 2005). It (*L. cylindrica*), has been suggested as an immobilization matrix for plant, algal, bacterial and yeast cells (Iqbal and Zafar, 1993a, b; Iqbal and Zafar, 1994).

Young fruits are edible and matured fibers are generally used in washing ships and decks and manufacturing slippers or baskets and used as shoes mats, inner cloth of bonnet (Lee and Yoo, 2006). The fibrous vascular system inside the fruit after separating from the skin, flesh and seeds, can be used as a bathroom sponge, as a component of shock absorbers, as a sound proof linings, as a utensils cleaning sponge, as packing materials, for making crafts, as filters in factories and as a part of soles of shoes (Bal et al., 2004). They also can be used for cleaning floors or cars without scratching. The small ones are softer and good for washing the face and larger ones for the body. They can also be recycled into mats or pillows when they finally wear down (Newton, 2006). Other areas of application are treated below.

Agriculture

A number of plants of wide variety contain proteins that enzymatically inhibit protein synthesis on eukaryotic ribosomes (Olsnes and Pihl, 1973; Irvin et al., 1980; Stirpe and Barbieri, 1986). These proteins have conclusively been shown to inactivate the 60S ribosomal subunit by cleaving off a specific adenine residue (A_{4324}) from 28S rRNA (Endo et al., 1987, 1988). 2 isoforms of ribosome inactivating proteins, luffin-a and b, from the seeds of the sponge gourd (*L. cylindrica*) has been isolated and it was shown that they have similar molecular masses (28,000 Da) and isoelectric points (pl > 10), but differ in ribosome inactivating activity: inhibitory activity of luffin-b on protein synthesis in rabbit reticulocyte lysate was approximately 1/4 of that of luffin-a (Kamenosono et al., 1988). Moreover, when sequenced the amino acids of luffin-a was shown to be homologous to the ricin A-chain (Islam et al., 1990).

It has been discovered that the consumption of sponge gourds can supply some antioxidant constituents to human body. From a recent study carried out, hydrophilic antioxidant constituents in the fruits of the vegetable *L. cylindrica* were separated by an antioxidant-guided assay to yield 8 compounds:

i) *p*-coumaric acid.
ii) 1 -*O*-feruloyl- -D-glucose.
iii) 1 -*O*-*p*-coumaroyl- -D-glucose.
iv) 1 -*O*-caffeoyl- -D-glucose.
v) 1 -*O*-(4-hydroxybenzoyl) glucose.
vi) Diosmetin-7-*O*- -D-glucuronide methyl ester.
vii) Apigenin-7-*O*- -D-glucuronide methyl ester.
viii) Luteolin-7-*O*- -D-glucuronide methyl ester.

The 8 compounds were isolated by high-speed counter current chromatography and identified by electrospray ionization−mass spectrometry and NMR analysis and the antioxidant activity was evaluated by the radical scavenging effect on the 1, 1- diphenyl-2-picrylhydrazyl radical. High-performance liquid chromatography analysis showed that a total amount of the 8 compounds in the dried gourds without skin was about 1% (Qizhen et al., 2006).

Samples of *L. cylindrica* were analyzed for proximate composition and mineral contents (Mg, Ca, Na, K, Fe, Cu, Zn and Mn), Tannin, oxalate, phytin phosphorus and phytic acid. The results obtained indicated the potential in its use as a source of vegetable protein in animal and human nutrition (Dairo et al., 2007). When extracted and analysed the seed of *L. cylindrica* contained 40% oil which is used as oil sources and oil cake obtained is used as fertilizer and feed (Lee and Yoo, 2006).

Medicine

A wide variety of plants contain proteins that inhibit protein synthesis. The group of these inhibitors most extensively studied is that of the ribosome-inactivating proteins (RIP), having molecular masses of about 30 kDa (Stirpe and Barbieri, 1986). Besides the RIPs named luffins have so far been isolated and characterized (Kamenosono et al., 1988; Kishida et al.,1983), polypeptides of about 5 kDa molecular mass, such as thionins (Garcia-Olmedo et al., 1983), have been reported to inhibit cell-free protein synthesis, probably by a nonenzymatic mechanism. The physiological functions of these protein synthesis inhibitors (PSI) from plants are not known. However, they have been attracting much interest for their use to prepare immunotoxins by conjugation to monoclonal antibodies specific for cell-surface antigens (Vitetta et al., 1983).

The isolation and some properties of 3 new PSIs in *L. cylindrica* seeds have been reported. The results indicated that 3 new PSIs purified from *L. cylindrica* seeds structurally had no relation to luffin, a ribosome inactivating protein (RIP) which is a specific RNATV-glycosidase. 2 of them had unusual amino acid compositions and the other appears to be a nuclease. The physiological functions of these PSIs are not obvious, although it is an attractive hypothesis that these proteins may act in regulation of protein synthesis or in defense from some parasite (Keiichi et al., 1990).

In oriental medicine, *L. cylindrica* has effect on the treatment of fever, enteritis and swell etc. The extracts from vines alive are used as an ingredient in cosmetics and medicine (Lee and Yoo, 2006). They are used for bathing, removing toxins and regenerating the skin. They help varicose veins and cellulite by stimulating circulation. Immature fruit is used as vegetables, which is good for diabetes (Bal et al., 2004).

Environmental engineering

The study of engineering applications of natural fibers in resin matrix composite materials is at its early stages in respect to the number of fibers studied. Many fibers with very promising properties like sponge gourd (*L. cylindrica*), among many others, have not yet had their potentialities fully explored. Of particular interest when studying the development of a new natural fiber reinforced resin matrix composite is its behavior against weathering since natural fibers readily absorb humidity. Result and the values obtained from mechanical tests show that, without any surface treatment, Luffa already has a high potential use as a core material in hybrid composites (Boynard and D'Almeida, 1999). The absorbent capacity of the fibers for deionized water is 13.6 g/g (Bal et al., 2004).

Using natural *L. cylindrica* fibers as adsorbent removal of methylene blue dye from aqueous solutions at different temperatures and dye concentrations and also the thermodynamics and kinetics of adsorption has been investigated. The thermodynamic parameters of methylene blue (MB) adsorption indicated that the adsorption is exothermic and spontaneous. The average MB adsorption capacity was found out as 49 mg/g and average BET surface area of fibers was calculated as 123 m (2) /g (Demir et al., 2008).

Biotechnology

A novel circulating loop bioreactor with cells immobilized in loofa (*L. cylindrica*) sponge has been used for the bioconversion of raw cassava starch to ethanol (Roble et al., 2002).

Loofa sponge has been used as a medium for the culture of human hepatocyte cell line (Chen et al., 2003). Sponge-gourds biocomposites are a novel use of these fibers, but a better understanding of their surface characteristics is necessary to maximize their potential use (Tanobe et al., 2005). *L. cylindrica* showed a very good performance as a solid substrate for the development of the biofilm aggregating microorganisms capable of metabolizing both organic and inorganic compounds adsorbed on it, particularly those responsible for nitrification (Tavares et al., 2008).

Loofa sponge is a suitable natural matrix for immobilization of *P. chrysosporium*. Immobilized *P. chrysosporium* has been successfully used as biosorbing agent for removal of Cd (II) and Pb (II).

Science

A study on *L. cylindrica* was carried out where different chemical treatments were conducted on the fibers (*L. cylindrica*) with aqueous solutions of NaOH 2%, or methacrylamide (1 - 3%) at distinct treatment times. *L. cylindrica* was characterized via chemical analysis and analytic techniques such as FTIR, XPS/ESCA, X-Ray, TGA and SEM. Methacrylamide 3% treatment for all times (60, 120 or 180 min) severely damaged the fibers. NaOH, on the other hand, showed the same beneficial effect regarding enhancement of surface area and thermal stability together with similar levels of lignin and hemicellulose extraction, without causing exaggerated harm to fiber integrity (Tanobe et al., 2005).

It has been reported that preparative separations of the phenolic compounds in two pre-purified sponge gourd extracts Fr30 and Fr50 from macro-porous resin AB- 8, using slow rotary countercurrent chromatography (SRCCC) with 2 solvent systems, respectively. The separation of 3 g of Fr30 using solvent system $CHCl_3$-MeOH-2-propanol -H_2O (5:6:1:4, v/v) yielded 5 compounds: *p*-coumaric acid (i, 65 mg), 1-*O*-feruloyl-ß-D-glucose (ii, 189 mg), 1-*O*-*p*-coumaroyl-ß-D-glucose (iii, 96 mg), 1-*O*-caffeoyl-ß-D-glucose (iv, 130 mg) and 1-*O*-(4-hydroxybenzoyl)-glucose (v, 90 mg) and the separation of 3 g of Fr50 using solvent system $CHCl_3$-MeOH-H_2O (13:7:8, v/v) afforded 3 compounds: diosmetin-7-*O*-ß-D-glucuronide methyl ester (vi, 125 mg), apigenin-7-*O*-ß-D-glucuronide methyl ester (vii, 164 mg) and luteolin-7-*O*-ß-D-glucuronide methyl ester (viii, 98 mg) (Qizhen and Wang, 2007).

The decolourisation of Reactive Black 5 (RB5) by immobilised *Funalia trogii* has also been investigated. Cultures of *F. trogii* immobilised on *L. cylindrica* sponge could effectively decolourise the dye (Mazmanci and Ünyayar, 2005).

Recent major advances and discoveries

Cell immobilization techniques using biological materials are ecofriendly and have many advantages over suspended cell systems. Many studies have shown that the adsorption method for immobilization of microorganisms has many advantages over the entrapment method using gel beads (Fujii et al., 2001; Ogbonna et al., 1994) . It has been reported that loofa (*L. cylindrica*) sponge is an excellent carrier for immobilization of microorganisms and plants and animal cells (Roble et al., 2002; Chen et al., 2003; Ogbonna et al., 2001; Liu et al., 1999).

There have been recent advances in the method for preparing a transformed *L. cylindrica* Roem, which comprises the steps of:

(i) Inoculating an intact cotyledon from *L. cylindrica* Roem with *Agrobacterium tumefaciens* harboring a vector, in which the vector is capable of inserting into a genome of a cell from *L. cylindrica* Roem and contains the following sequences:

(a) A replication origin operable in the cell from *L. cylindrica* Roem.
(b) A promoter capable of promoting a transcription in the cell from *L. cylin*drica Roem.
(c) A structural gene operably linked to the promoter.
(d) A polyadenylation signal sequence.

(ii) Placing the inoculated cotyledon on a medium containing 1.0 - 2.5 mg/1 of BAP (6 - benzylaminopurine) by insert and culturing the inoculated cotyledon to obtain regenerated shoots.
(iii) Culturing the regenerated shoots to obtain the transformed *L. cylindrica* on a rooting medium containing 0.005 - 0.03 mg/1 of NAA (Lee and Yoo, 2006).

Recently, production of renewable energy from biomass materials has been emphasized as a means of solving current environmental problems such as global warming. In this regard, production of ethanol from lignocellulosic materials has a great potential because such materials are the cheapest and the most abundant biomass materials on earth. Among the systems for ethanol production from lignocellulose, the simultaneous saccharification and fermentation (SSF) process seemed to be one of the promising options (Ye et al., 2002; Itoh et al., 2003). In this process, cellulase, cellulase enzymes or cellulase- producing microorganisms are used for saccha-rification. The use of immobilized cells for this SSF pro-cess requires that the carrier used for immobilization of both cellulase-producing strain and the ethanol pro-ducing strain must be resistant to cellulase because both of them are in constant contact with the enzymes (Akihiro et al., 2007).

Furthermore, in order to use loofa sponge as an immobilization carrier in systems containing/producing cellulase enzymes, a method of protecting the loofa from cellulase by acetylation has been developed (Akihiro et al., 2007). Biofilm systems are efficient in the removal of organic matter and ammonium from wastewaters. It has been reported that loofa sponge, a natural product, was used as a supporting medium in an aerated submerged fixed-film reactor (Ramin et al., 2008).

Loofa sponge immobilized fungal biosorbent have been used extensively for the biosorption of heavy metals from olive oil mill wastewater and other wastewaters (Iqbal and Edyvean, 2004, 2005; Ahmadi et al., 2006a, b). Traditionally, it is used for bathing and dish washing and, recently, the fibers were used for environmental reclamation (Iqbal and Edyvean, 2004).

Future directions

There is lack of scientific data concerning thermal, mechanical and chemical properties of these fibers. Sponge gourd (*L. cylindrica*), among many others, have not yet had their potentialities fully explored. With regard to industrial and technological development, the cost of fuel is on the increase. Oil is extracted from seeds for industrial use (Bal et al., 2004). The seed of *L. cylindrica* is used as oil sources (Lee and Yoo, 2006). The oil extracted from *L. cylindrica* is finding increasing use in the production of biodiesel which is now gaining wide acceptance because of low CO_2 emission and other considerations (Ajiwe et al., 2005).

Conclusion

Loofa sponge is fast becoming an indispensible crop because of its very wide industrial applications. In the context of the morphosynthesis, the capability of replication of the loofa sponge opens the possibility of the use of biodiversity in obtaining new materials. Effort is being made towards the possibility of harnessing, converting and recycling waste seeds from edible fruits and those regarded as weeds (non- edible ones), like *L cylindrica* into industrial, domestic or technological resources. Loofa sponge is a suitable natural matrix for immobilization of microorganisms and has been successful in the process of biosorption of heavy metals from wastewater. This emerging cash crop will improve the economies of many nations in the nearest future because of its numerous potentials.

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