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The Coconut Tree – A Source of Sustainable Polymeric Materials

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1. Abstract

Coconut is a versatile tree belonging to the palm family (Botanic term *Arecaceae*, coconut palms, *Cocos nucifera*) in which each part is used for numerous applications. It is grown in the tropic and subtropic regions of the world. There is a tradition and culture associated with the coconut tree due to its enormous value as a food commodity, the use of its branches and wood for daily needs. Coconut is typically cultivated in the coastal regions of the countries due to its preferred moistened soil and salty nature. As well as a source of food, coconut fibres are widely used due to its high strength material properties for many domestic applications. It is clear that the coconut tree can contribute materials without compromising on the supply of food in contrast to other sources of sustainable materials.

2. Introduction to Coconut Trees

Coconut trees are known for their versatility as evidenced by many traditional products, ranging from food to engineering technologies and more recently coconut fibres have been explored as a potential material for value added applications. The principal products of the coconut tree are its fruits as a food commodity such as milk, oil and the husk which contains strong fibres is used for manufacturing domestic goods such as weaving ropes, mats, broomsticks and bowls. The tree bears fruit all around the year and they can be harvested every 3 to 4 months for consumption. The yield may depend on the climatic conditions such as humidity, rainfall and the amount of sunlight. Coconut forms a regular part of the diets of many people in the tropics and subtropics, in particular Sri Lanka, India, Philippine, Indonesia and Thailand. The coconut meat or the kernel is used as food and the dried meat is used for extracting oil. The coconut tree is an example of a non-food crop plant which is not in competition with the primary role as a food crop. Additionally, the wood obtained from old farmed coconut trees are used commercially in the construction industry. This review paper explores the coconut tree as a food commodity, its challenges to growth, development and a source for obtaining fibrous materials for industrial applications.

Figure 1 shows the lifecycle of a coconut tree from flowering, fruiting to seedling.

Figure 1: Lifecycle of a coconut tree (reproduced with permission [1].

2.1: Coconut history and biodiversity

The history of coconuts starts before the existence of human kind. According to [1,2] wild coconuts evolved naturally and were dispersed by floating. In Sri Lanka there is an established Coconut Research Institute conducting research on crop protection, genetics, plant breeding, tissue culture and the technology transfer [3] as well as expanding the coconut awareness among agriculturists, farmers and the general public.

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2.2 Coconut products, manufacture and nutrient content

There is a food industry related to the coconut-based products in several tropical and subtropical regions of the world, for an example milk, oil, vinegar and alcohol.

3. Coconut Milk

Industrially coconut milk is produced by filtering the finely ground coconut meat or the kernels without the addition of water which is then thermally processed appropriately and sealed in a container to prevent the decomposition [4].

4. Coconut Oil

Coconut oil is extracted from its dried meat or the kernel known as copra [5]. The drying process is achieved by the use of sunlight or the use of an oven. In this way the moisture content is reduced from 45 to 46%. Around 600 to 4000 coconuts are used to obtain a tonne of copra. The oil content ranges from 64% to 65% [6] and is obtained by crushing or pressing the copra. The world demand of coconut oil has increased and in 2018 it is estimated at 3.44 Tonnes/annum [7,8] and this amounts for 3% of the world vegetable oil production. The standard of the coconut oil depends on how the copra is dried, stored and transported. The primary oil of the coconut belongs to the group of 'lauric' oils (palm kernel oil, babassu kernel oil and cuphea oil) also known as lauric acid **(Figure 2)** because of its high level of medium chain fatty acids and low content of unsaturated fatty acids.

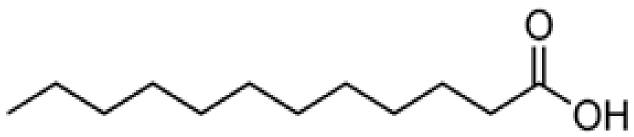

Figure 2: The chemical structure of lauric acid (IUPAC dodecanoic acid).

5. Coconut Alcohol and Vinegar Production

Coconut water or its kernel does not contain alcohol or vinegar. Coconut-based alcohol and vinegar **(Figure 3)** [9] are manufactured in small scale in the south Asian region. The following scheme 1, shows how it is achieved.

Figure 3: Coconut vinegar (reproduced with permission [9].

5. 1: Coconut derivatives in cosmetic and medical industry

The coconut oil is rich in lauric acid and myristic acid **(Figure 4)**. These fatty acids are 63% of the total composition and have been reported to be good for the skin when applied as a pure product [10].

Coconut oil studies have found positive impact in the medical field due to its antimicrobial effects [11] based on high content of lauric acids [12]. Moreover, it has already been reported that virgin coconut oil has a potential to reduce the development of hypertension and renal injury, possibly via its antioxidant protective effects on the kidneys [13].

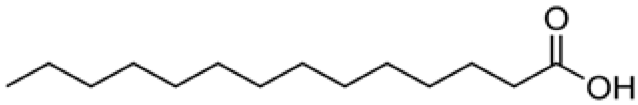

Figure 4: Myristic acid (IUPAC tetradecanoic acid).

5. 2: Current challenges in coconut cultivation and development

The ambient temperature required for the optimum growth of coconuts is 27±5^{o}C with a relative humidity of more than 60%. It can withstand a heavy rainfall distribution. However, a well-distributed rainfall of about 200 cm per year is the best and ideal for the proper growth of the palm and higher yield of nuts [14]. Factors such as soil depth, drainage, soil fertility and layout of the land have an impact on the overall growth of the tree. Soils commonly planted in coconut have adequate amounts of sodium, calcium, magnesium, iron, manganese and zinc but most inland soils are severely deficient (very low in sodium, chlorine and inadequate potassium, phosphorus, sulphur and boron) Table 1[15]. Coconut trees prosper in areas with abundant sunlight and regular rainfall [16] which makes colonizing shorelines of the tropics relatively straightforward.

Table 1: Fatty Acid Composition of Coconut Oil as determined by Gas Chromatography [8].

Fatty Acid	% Composition
Caproic	<1
Caprylic	2.4
Capric	4.4
Lauric	44.5
Myristic	18.6
Palmitic	12.0
Stearic	4.8
Oleic	11.0
Linoleic	2.2

5.3: Propagation

Generally, 9-12 month old seedlings are used for planting. Since the productivity of the tree depends on the quality of the seedlings, importance should be given during the selection of the best coconuts [17]. The seedlings should be grown from the fruits selected from high yield trees of 20-40 years of age.

5.4: Plantation

The method of land preparation before planting depends upon the topography of the land, soil type, and other environmental factors. Adoption of an improper system can result in overlapping of plant parts, competition for water, light, nutrient and unequal distribution of water etc., and ultimately leading to poor tree growth [14].

5.5: Challenges of coconut cultivation

The principal issues of coconut cultivation are, pest attacks and diseases, nutritional deficiency, unfavourable soil and climatic conditions, defective pollination and fertilisation, and formation of separate layers between the dead leaves and ripen fruit known as the abscission layers as compared to the other crops [16-18].

6. Coconut Leaf Miner (Promecotheca Cumingii)

Coconut leaf miner are a type of beetle which are reddish brown and 7 - 8 mm long. They can damage the palm leaves in two ways. The larvae feed by mining the tissues of the leaflets, whereas the adults feed by making narrow grooves in the lower surface of the leaflets. In general, the beetles are more damaging to the mature palms. Promecotheca cumingii and its effect on the leaves is shown in **Figure 5**.

Figure 5: Leaves affected by Promecotheca cumingii (reproduced with permission [17].

7. Black-Headed Caterpillar (Opisina Arenosella)

The black-headed caterpillar in the larval form is greenish brown with dark brown head and prothorax and a reddish mesothorax. The caterpillar feeds on the leaf tissues from the undersurface. The attack of this pest results in the death of leaf. The black-headed caterpillar's effects on the leaves are shown in **Figure 6**.

Figure 6: Leaves affected by Opisina arenosella (reproduced with permission [18].

8. Coconut Rhinoceros Beetle (Oryctes Rhinoceros)

This beetle is one of the most damaging insects to palms as the adult beetles eat the leaves and burrow into the crown, cutting across young fronds and flowers thereby stunting plant development. The beetle attack results in loss of leaf area, dying of the flowers, early nut fall and ultimately lowers the yields **(Figure 7)**.

Figure 7: Palm attacked by Oryctes rhinoceros (reproduced with permission [19].

9. Red Weevil (Rhynchophorus Ferrugineus)

It is a dark brown weevil (about 3 cm) which is a large devastating pest. It usually infests palms younger than twenty years. The infestation of the pest can result in yellowing and wilting of palms, leading to the death of the affected plant **(Figure 8)**.

Figure 8: leaves affected by Rhynchophorus ferrugineus (reproduced with permission.

10. Coconut Scale

Coconut scale can be found at high densities on the undersurface of coconut leaves, as well as on the frond stalks, flower clusters and young fruit. It causes yellow spots on leaves developed beneath the insects, due to the toxicity of saliva injected in to plant tissues while feeding. Entire leaves may turn yellow to brown and fall. The fruits may be discoloured, stunted or may fall down prematurely. The yellow spots caused and leaves affected by the coconut scale are respectively shown in **Figure 9**.

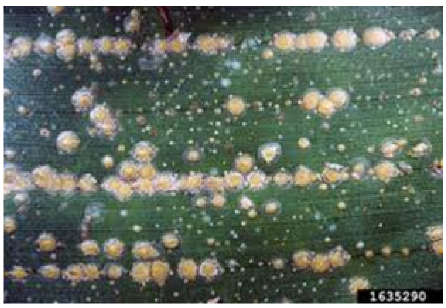

Figure 9: Yellow spots caused by coconut scale (reproduced with permission.

11. Termites

Termites feed on the husk portion of nuts and the collar region of seedlings and this results in wilting of the central shoot. The yield of young trees may also be reduced, and they may die before they bear coconuts. A dead coconut palm following a termite attack is presented in **Figure 10.**

There is a great scope for enhancing the productivity of coconut trees through the adoption of scientific cultivation technologies including individually selection of climate and soil, and protection of palms from pests and diseases.

Figure 10: Termite attack on Coconut palm (reproduced with permission.

11.1: Advanced materials from coconut tree

One of the key components of the coconut tree is the high strength fibres that are present both in the husk of the coconuts and the trunk of the tree. The most common source of the fibres is from the husk as they are obtained directly from the shell of the coconut. The shell is therefore not wasted and it reduces debris which has been shown to be a breeding ground for mosquitos. The trunk of the coconut tree is used as coconut log or timber.

11.2: Chemical components of coconut fibres

Coconut fibres contain lignin, a cross-linked phenolic polymer **(Figure 11)**, hemicellulose, a heterocyclic matrix of a polysaccharide **(Figure 12)** and cellulose, a crystalline polysaccharide **(Figure 13)**. These components in coconut fibres are known as coir. As coir exhibits considerable strength that can be applied by itself or reinforced with other suitable materials.

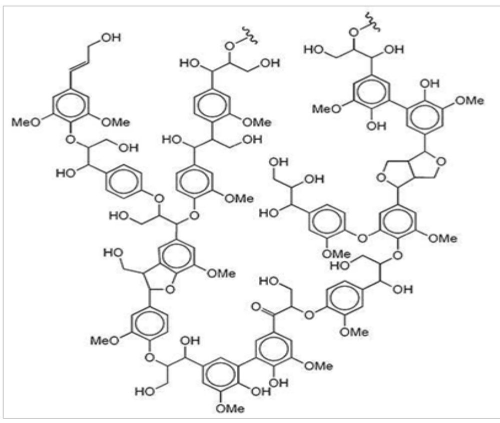

Figure 11: The chemical structure of lignin.

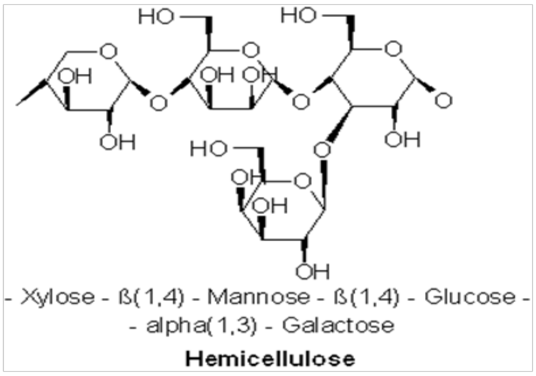

Figure 12: A structure of hemicellulose.

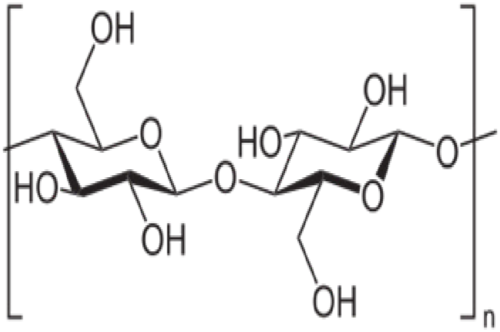

Figure 13: A structure of cellulose, n can be 7,000–15,000 glucose molecules per polymer molecule.

11. 3: Extraction and mechanical properties of coconut fibres

Coconut fibres are extracted from the husk as shown in **Figure 14**, commonly known as coir [19]. Reported the stress-strain relationship for coconut fibres **(Figure 15)** and compared these results with the equivalent results from other natural fibres.

(RB=ramie bast, PL=pineapple, KB=Kenaf bast, SaL=Sansevieria, AL=Abaca, SiL=Sisal

and CH=coconut)

Ede et al. identify that the coconut fibre is the most ductile of those tested as the coconut fibres exhibit an elongation to failure of 4-6 times that exhibited by the other natural fibres. We attribute this observation to the different levels of lignin in these fibres.

(a) A pile of coconut shells

(b) A coconut husk

(c) A pile of coconut coir

(d) coconut husk fibres (coir)

Figure 14: The route to obtaining the coconut husk fibres (coir) from the shell Ede et al. [14] reported the stress-strain relationship for coconut fibres (Figure 15) and compared these results with the equivalent results from other natural fibres.

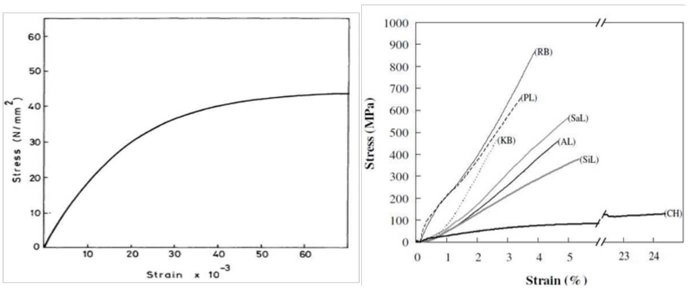

Figure 15: The correlation of mechanical properties of natural fibres (reproduced with permission.

11.4: Products of coir

Coconut husk fibres or the coir exhibit low thermal conductivity. While being stiff and this is indicative of good insulation properties for several building applications. There are different applications of coir, such as floor mats, doormats and brushes.

11.5: Coconut fibres and composites – current research and development

Have studied the constituents of coconut fibres using ionic dyes. The composition and functional groups of raw coconut fibre were changed by successive removal of lignin and hemicellulose. These fibres were analysed by Fourier Transform InfraRed and, Thermogravimetric composition analysis. They were dyed with anionic (acid, reactive) and cationic (basic) dyes separately. Absorption performance was assessed by surface and core colour uptake. The removal of lignin resulted in reduction of uptake of anionic (acid and reactive) dyes, while increase in uptake of cationic (basic) dye. Treatment causing removal of hemicellulose improved uptake of basic dye due to structural swelling. An increase in α-cellulose (29.9%), favours uptake of a reactive dye to a higher extent of acidity. The loss of lignin occurred in case of both delignification and hemicellulose removal treatments to the extent of 6.3% and 11.9% respectively. Consequently uptake of acid dyes reduced. Conclude that treatment causing higher removal of hemicellulose is beneficial and loss of lignin is disadvantageous for absorption of dyes. These results assist in understanding the effect of constituents of lignocellulose on the absorption of dyes commonly used in textile processing.

12. Composites

Coconut composites have been recently studied for advanced applications. Have investigated polyamine determination using the enzymes loaded with chitosan/coconut fibre with zinc oxide nanoparticles. Polyamines are essential components in all living cells that play an important role in regulating normal growth, metabolism and cellular proliferation. In this study, polyamine oxidase was co-immobilized in novel chitosan/coconut fibre/zinc oxide nanoparticles (CS/CF/nZnO) hybrid support to yield a polyamine sensing strip. The strip worked optimally at pH 7.0, temperature 25° C and 6 min of incubation time. The strip was employed for polyamine determination in some of the locally grown fruit and vegetables and the results were found to be comparable, reliable and reproducible.

The properties of coconut husk fibre **(Figure 16)**, oil palm fruit fibre and sugarcane bagasse fibre have been investigated as potential building materials. The experiments on length and diameter, specific weight, tensile strength, modulus of elasticity, moisture content and water absorption tests on the fibres have been conducted to determine their properties for probable use as reinforcement in composite. The fibres with different properties behave similarly in damp conditions. The study concludes that all the fibres possess properties that are acceptable as natural fibres to be used as reinforcement in soil blocks.

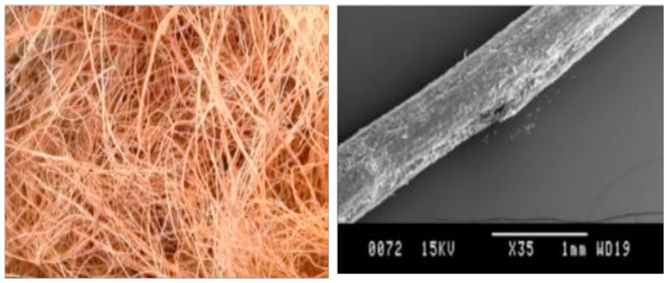

Figure 16: Optical photograph and SEM micrograph of coconut fibres (reproduced with permission, Similarly, Khan et al. [19] have studied the mechanical properties of the medium strength concrete (MSC) and medium strength coconut fibre reinforced concrete (MSCFRC). The MSCFRC content was found to have enhanced durability as compared with the MSC sample. They have concluded the improved mechanical properties of the MSCFRC is suitable for civil engineering applications such as high rise building and bridges.

Scheme 1: The scheme of ethanol and vinegar processing.

Coconut water + Yeast (fermentation) →ethanol + acetobacter (bacteria)

13. Conclusion

1. As previous generations found, the coconut tree provides an abundance of sustainable materials, without the conflict between food and material production.

2. With regard to the coir, the husk fibres have striking properties of large ductility and low thermal conductivity.

3.It is a source of hemicellulose and cellulose as well as lignin.

4.There are already commercial building products with the coconut fibre as a reinforcing element.

14. Acknowledgements

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