

# The Roles of Vegetable Fibres in Green Chemistry



A. T. Ajiboye, K. O. Otun, H. F. Babamale, and L. B. Abdulra'uf

## 1 Introduction

Green chemistry holds a prominent position in the fabrication of chemical products and processes that lessen or wipe out the utilization and production of harmful substances [1]. In turn, this has provided chemists and researchers worldwide with a captivating technology for groundbreaking research and numerous applications including nanomedicine, drug delivery, nanotechnology, textile technology, catalysis, etc. About 20 years ago, Paul Anastas and John Warner [2] put forward the 12 golden principles that drive green chemistry and which contribute immensely towards sustainable development. These principles, which are summarized in Fig. 1, recommend environmentally benign measures right from the preparation of the material to its synthesis, modifications, analysis, and final use. The key aim is to reduce the environmental and work-related risks associated with industrial operations. Since then, different terminologies have been ascribed to the concept of green chemistry, and these include but not limited to eco-friendliness, cleaner production, atom efficiency, atom economy, sustainable chemistry, renewable energy sources, process integration, and environment-friendliness, among others [3].

Fast-forward to today, the concept of green chemistry has advanced from quantifying the greenness of a chemical process to measurement of variables that include

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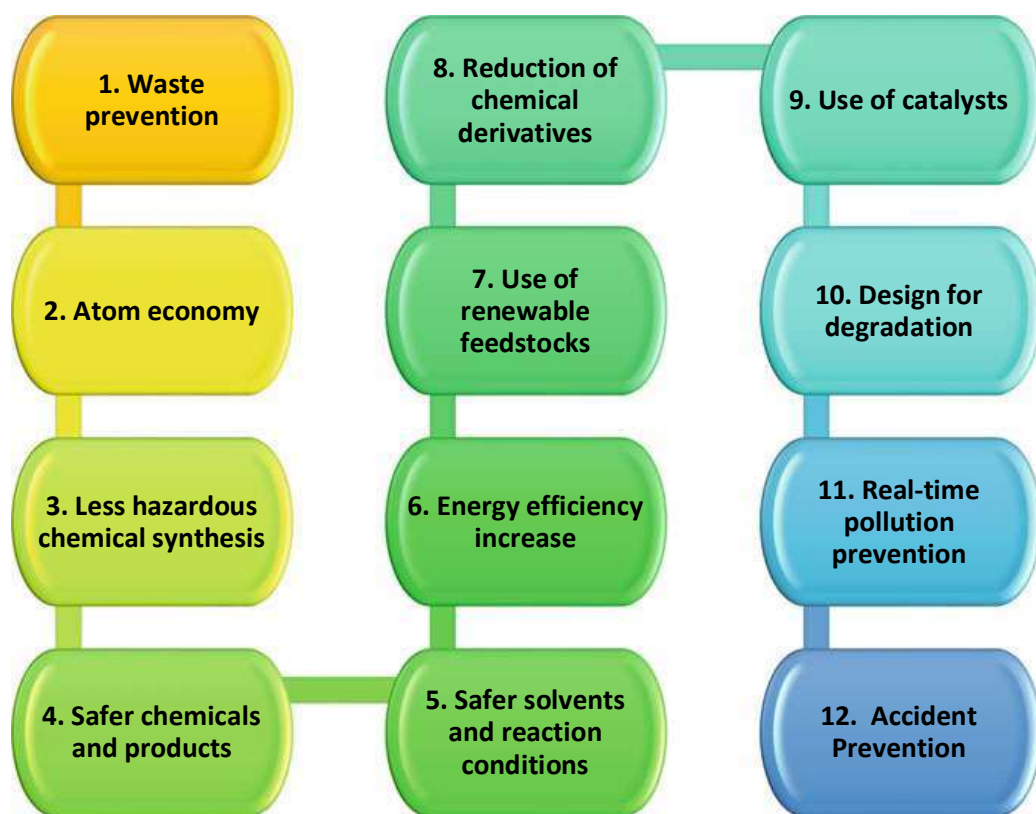


**Fig. 1** The 12 principles governing green chemistry as coined by Anastas and Warner [1]

chemical yield, the cost of feedstocks, safety in managing chemical substances, energy profile, ease of product workup and purification, among others. This has also seen several agencies, countries and institutions showing commitments to the goals of green chemistry such as the US Environmental Protection Agency (EPA) that is fostered with the responsibilities of pollution control for sustainable development. Others include the University of New York which founded Green Chemistry Network in conjunction with the Royal Society Chemistry and established of Journal of Green Chemistry; and we also have National Cleaner production Centre in South Africa (NCPC-SA) that plays a key position in the African Roundtable on Sustainable Production and Consumption (ARSCP), among others [4–6].

Different materials have revolutionized the concept of green, and this includes an indispensable vegetable fiber [7]. The roles played by vegetable fibers in green chemistry and sustainable development cannot be overemphasized. Each year, many synthetic fibers are being substituted and high energy consuming products are also being swapped with vegetable fibers and their composites. The reasons for this are not farfetched; it is because of their numerous environmental and economic benefits which include renewability, recyclability, and low consumption of resources in the production processes, among others [8–10]. They have also been influencing many applications as green, economic, and biodegradable plastic composites [11].

## 2 Vegetable Fibres

Natural fibres, which can also be regarded as vegetable fibers, encircle all forms of fibres extracted from different parts of plants. They are basically grouped into primary and secondary based on their utilization. While those fibers that are produced for their fiber compositions are referred to as primary fibers, the secondary fibers are those obtained from some other preliminary usage as a by-product. Examples of primary fibers include, but not limited to kenaf, jute, sisal, hemp, cotton, while secondary fibers include coir, pineapple, stalks, agave, cereal, oil palm, among others [12]. They may also be classified as leaf, bast, seed, wood, stalk, fruit and grass according to their sources [13]. Vegetable fibres consists of hemicellulose, cellulose, lignin, pectin, waxes and water-soluble compounds, with the exception of cotton fibres containing about 90 wt% cellulose, 5.7 wt% hemicellulose, 1 wt% pectin and 0.6 wt% waxes [14].

### 2.1 Bast Fibres

Bast fibers consist of bundles of fibers in the inner bark of stems of dicotyledonous plants, enclosed by a stem supplying the plant stem with structural stiffness and strength [12, 15]. The bundles have up to 25 basic units of fibers between 22 and 5 mm length and a diameter found with the range of 10–50  $\mu\text{m}$  arranged laterally in a 3D network. Basic fibrils and bundles are reinforced by intercellular components of lignin and pectin, which must be got rid of during the extraction process [16, 17]. In terms of applications, bast fibers are used not only in the textile industry but also to fabricate green composites for applications in construction industries, building materials, nanomedicine, cosmetics, biopolymers etc. [16]. Examples of bast fibre include flax, jute, ramie, hemp, kenaf, among others [12, 15].

#### 2.1.1 Flax

Flax fibres are obtained from the stems of the plant *Linum usitatissimum*. Flax is popular for its diverse applicability because of its intriguing properties including high thermal and mechanical resistant properties. It is a cellulosic fibre like cotton, although it is harder and tougher to handle due to its higher crystallinity [18]. Its applications cut across textile markets, and in the fabrication of thermoplastic matrix composite for automobile components [19–21]. The flax fibres have a smooth handle and look very lustrous. Fibre lengths range from 6 to 65 mm, but they are around 20 mm long on average. Their diameter is approximately 20  $\mu\text{m}$ . It is produced in temperate regions and is one of the world's oldest fiber crops [16, 18].

### 2.1.2 Jute

Jute is a bast fiber, typically obtained from the bark of the white jute plant, *Corchorus capsularis* or tossa jute (*Corchorus olitorius*) [17] from the genus *Corchorus*. It is a long, smooth, shiny and cheap fiber with the highest output volume that can be spun into rough, solid threads [16, 18]. It is also the most flexible fibre available, eco-friendly, natural, robust and antistatic [16]. The fibers contain 61–71% cellulose, 14–20% hemicellulose, lignin (12–13%) and pectin (0.2%) [19]. The best conditions for the growth of jute are provided by Bangladesh, India, and China. Jute is an annual plant that thrives in monsoon climates and grows up to 2.5–4.5 m [18]. In addition to being used as carpet backing, jute scrims, tarpaulins, canvas, tar felts, and soil savers, jute and jute-like mesta fibres are historically used for packing as sacking, hessian bags and soil savers. Jute is also used as technical textiles, geotextiles, agro-textiles, handicrafts [22] and as thermoplastic composites for the automotive door panel industry [23].

### 2.1.3 Hemp

Hemp is another prominent fiber belonging to the *Cannabis* family. It is an annual herbaceous plant native to Central Asia and is known to have been cultivated more than 4500 years ago in China. It grows easily to a height of 4 m without additional chemicals and consumes large quantities of carbon. True hemp is a fine, light-colored, lustrous and strong fiber obtained by retting [16, 24]. Chemically, hemp is composed of cellulose (77%), pectin (1.4%) and waxes (1.4%). In the middle lamellae, pectin is found and glues the elementary fibres to form bundles. The fibre is an embedding part of lignin (1.7%). It encrusts cellulose and contributes to the fiber's hardness and strength. It is found in the primary cell wall of the middle lamella and fibre. Other components of hemp fibres are tannin, resins, fats, proteins etc. In hemp, the content of such components is much higher than in cotton [16]. Hemp is historically used in textile manufacturing, but due to interest in alternative renewable resources, its use has gained relevance in many industries in recent years. Applications have been reported in the manufacture of composites, special cellulose materials (papers), as well as technical textiles, geotextiles and agricultural textiles [25]. Its use has also been well documented in the automotive sector [24].

### 2.1.4 Ramie

Ramie originally belonged to the *Urticaceae* family and is native to Eastern Asia. Ramie fibres are extracted from the nettle family's stem of the plant *Boehmeria nivea*. In fiber bundles, individual fibre cells in stems are connected together by hard-to-remove waxes, hemicelluloses, lignin and pectins. The efficiency of the retting method traditionally used for the extraction of hemp fibers, for example, can therefore not be sufficient to extract ramie fibers from stems. A hybrid microbial

and chemical treatment is, however, very efficient and cost-effective. The chemical composition of ramie fiber is as follows: cellulose (91–93%), hemicellulose (2.5%), pectin (0.63%) and lignin (0.65%). Ramie fibers have excellent mechanical properties, i.e. the strongest in the bast fiber category (45–88 cN/tex) and, like most natural cellulose fibers, when fibers are wet, the strength increases by 25%. The ultimate fiber length is between 120–150 mm and 40–60  $\mu\text{m}$  fiber diameter. Fibres are robust and have strong resistance to attacking bacteria, mildew and insects. Its poor elasticity (elongation at break is 3–7%) is the key drawback of ramie, which means it is rigid and brittle [19]. The fibres are oval to cylindrical in shape and are white and highly lustrous in color. The surface of the fibres is rough and marked by small ridges, striations and deep fissures. By its coarse, thick cell wall, absence of twist, and surface characteristics, ramie fibre can be easily identified [26]. Of all the vegetable fibers, ramie is the strongest and therefore has great potential for advanced applications. It is used for fabrics, ropes and for producing blanks of currency paper [22].

### 2.1.5 Kenaf

Kenaf belongs to the Hibiscus family and is obtained from *Hibiscus cannabinus* by its fibres. It is a new generation in the USA and demonstrates strong potential for use in composite goods as a raw material. In India and Bengal, it is known as mesta, in South Africa as stock root, in Indonesia as java jute, and in Taiwan as ambari [18, 23, 27]. There are two types of fibers in Kenaf: long bast fibre bundles in the cortical layer and short bast fibers in the ligneous region. The elementary fibres are small, with a fibre length varying from 3 to 7 mm and a diameter of 21  $\mu\text{m}$  on average. With rounded edges, the cross-sections are polygonal and the lumens are mainly wide and oval to circular in shape [26]. Kenaf has a high rate of growth, growing in about 4–5 months to heights of 4 to 6 m. There is great interest in this plant in Malaysia as it grows rapidly and can produce two crops per year in the local climate [23, 27]. Kenaf fibres contain about 45–57% of cellulose, 21.5% hemicelluloses, 8–13% lignin and 3–5% pectin. Kenaf fibres are coarse, brittle and difficult to process. Their breaking strength is similar to that of low-grade jute and is weakened only slightly when wet. There are many potential specific utilization possibilities for kenaf whole stalk and outer bast fibres, including paper products, textiles, composites, building materials, absorbents, etc. [17].

## 2.2 Leaf Fibres

Leaf fibers are sometimes referred to as stiff or cordage fibers found in the leaf fibrovascular systems of perennial, monocotyledonous plants cultivated in the Philippines, Central America, East Africa, Indonesia and Mexico [28]. They have restricted commercial value, primarily because they are stiffer and coarser than the bast fibers in general texture. By mechanically scraping away the non-fibrous material, the fibres

are normally collected from the leaves. The fibres of the leaves are primarily used for the manufacture of cordage and ropes. Sisal, abaca henequen [16] and pineapple are the most important fibres of this group.

### 2.2.1 Sisal (*Agave sisalana*)

Sisal fibre is a hard fibre derived from the fresh leaves of the *Agave sisalana* plant. It is normally obtained by a method of decortication, in which the leaf is smashed between rollers and then scraped mechanically. The length of the sisal fibre spans between 0.6 and 1.5 m and ranges from 100 to 300  $\mu\text{m}$  in diameter [17]. The content of cellulose in sisal fibres is around 70%. The fiber consists of multiple elongated fiber cells narrowed to both ends. Middle lamellae, consisting of hemicelluloses, lignin and pectin, bind fibre cells together. A cross-sectional sisal fibre is composed of around 100 fibre cells. The dimension of the cross-section of sisal fibres is neither circular nor reasonably uniform. The size of the lumen varies, but it is generally well defined. The longitudinal form is roughly cylindrical. It is fairly coarse and rigid with sisal fibre. The tensile properties of the sisal fibres along its length are not uniform. The fibres extracted from the root or lower parts of the leaf have a lower tensile strength and modulus. There is a lower tensile strength and modulus in the fibres derived from the root or lower sections of the leaf. The fibers at the midspan become stronger and stiffer, and the fibers extracted from the tip have mild properties. Because of its high cellulose and hemicellulose content, the lower grade fibre is processed by the paper industry. In the cordage industry, medium grade fibre is used for the manufacture of cords, balers and twine binders. After preparation, the higher quality fibre is processed into yarn and used by the carpet industry [16].

### 2.2.2 Abaca (Manila Hemp)

Abaca or Manila hemp is harvested around the trunk of the abaca plant from the leaf sheath (*Musa textilis*). In the form of strands, commercial fibers are used, and the strands are made of bundles of individual fibers in turn. Individual fibres are smooth and fairly uniform in diameter when separated from the strands by boiling in an alkali solution. In relation to wall thickness, the lumens are high. Cross-marking is unusual, with pointed and sometimes flat and ribbon-like fibre ends. The technical fibres have a length of 2–4 m. The single fibers have narrow pointed ends and are relatively smooth and straight. Individual fiber diameters vary from 14 to 50  $\mu\text{m}$  and from 2.5 to 13 mm in length [26]. Chemically, abaca contains 76.6% of cellulose, 14.6% of hemicellulose, 8.4% of lignin, 0.3% of pectin, 0.1% of wax and fat. As one of the strongest of all natural fibres, Abaca is known to be three times stronger than cotton and half that of sisal, and is much more resistant than other vegetable fibres to saltwater decomposition. Abaca is a lustrous, yellowish white fibre. Abaca fibres are primarily used for the development of ropes and handicraft goods [25].

### 2.2.3 Henequen

A close relative of the sisal plant is the Henequen (*Agave fourcroydes*) plant of the agave family. The henequen plant is native to Mexico, where since pre-olumbian times it has been a source of textile fibre. Many variables may affect the properties of the fibre, including climatic conditions, plant age, soil type, method of extraction, etc. Approximately 77% of cellulose, 4–8% of hemicellulose, 13% of lignin and up to 6% of pectin and waxes are composed of Henequen fibre [25, 29]. These fibres have adjustable diameters, which are bigger at the tail end and smaller at the end of the fiber. The diameter is often related to the origin of the fibre; fibres produced at different spots have different diameters. The cross-section of the fiber varies from a bean-like shape at the end of the tail to a rounded shape at the end of the fiber. Henequen fibres, like sisal, are smooth, straight, yellow and easy to degrade in salt water. Henequen has low break elongation and low modulus compared to other leaf fibres, but a relatively high tenacity, which makes it ideal as a polymer reinforcement [25].

### 2.2.4 Pineapple Leaf Fibre

Pineapple leaf fibre is collected by mechanical or retting methods from the leaves of pineapple. Pineapple leaf fiber is a natural fiber option that is more compatible and has a strong chemical composition [30]. It is composed of high quantity of cellulose (81.27%), low contents of hemicelluloses (12.31%) and lignin (3.46%) [31]. Its higher cellulosic content is comparable to that of stem fibers of oil palm, coir and banana [32]. In producing threads for textile fabrics, sporting equipment, baggage, cars, cabinets, and mats, pineapple leaf fibre is used [30]. It is also used in cosmetics, medicine, chemical-coating biopolymers [33, 34] and in the manufacture of paper in Malaysia [35].

## 2.3 Seed-Hair Fibres

The seed-hair fibres are manufactured from the plant's seed or fruit [36]. They are cellulosic fibers that are often bound or encapsulated in husk to hairs or fibres that may be fibrous and commercially relevant. These include kapok, cotton, coir, etc.

### 2.3.1 Cotton Fibre

The fiber of cotton is derived from seeds of the plant species *Gossypium*, belonging to the genus *Malvaceae*. It's a shrub native to the world's tropical and subtropical regions. It could rise to  $0.5 \pm 1.5$  m in height. In the United States, nearly all commercial cotton is the species *Gossypium hirsutum* (upland cotton) and *G. Barbadosense*

Barbadense (Egyptian cotton). There are two types of cotton fibers: longer fibers known as lint, and shorter fibers recognized as linters. Although linter fibers are shorter ( $2 \pm 7$  mm) and more cylindrical, lint fibers are smooth and twisted and have thicker cell walls than lint fibers. Upland cotton has a length of  $15 \pm 30$  mm of medium fiber and a width of around 20 m ( $12 \pm 38$  m) of fiber. Egyptian cotton has a length of  $20 \pm 40$  mm of medium fiber and a width of 22 m ( $15 \pm 40$  m). Cotton fibres constitute of 80–90% of cellulose, 6–8% of water, 0.5–1% of waxes and fats, 0–1.5% of protein, 4–6% of hemicellulose and pectin, and 1–1.8% of ash [37].

Cotton is hydrophilic, and in water, the fibres swell greatly. In water, fibres are flexible and their wet tenacity is up to 20% higher than their dry tenacity (25–40 cN/tex). Compared to hemp fibres, the strength and initial cotton modulus are lower, although its elongation at break (5–10%) and its elastic recovery are higher. The fibres are alkali-resistant but acid-degraded. Cotton has low microbial resistance, burns rapidly and effortlessly, can be boiled and sterilized, and does not lead to inflammation or other allergies [37, 38]. Cotton seed fiber, as well as cellulosic textile fiber, is the world's most important natural textile fiber for the manufacture of garments, household goods and industrial products[39].

### 2.3.2 Coir

Coir is the fiber of seed hair collected from the coconut husk and is a major agricultural waste in Malaysia [40]. Coir is a natural fiber that has a high proportion of lignin. This high proportion of lignin makes the fiber of the coir very resistant to bio-degradation. Coir fibre is commercially used to produce brushes, rugs, sacks, doormats, insulation panels, mattresses and packaging materials [41]. Coir is also used for soil erosion and prevention of sedimentation [42].

### 2.3.3 Kapok Seed Fibres

Kapok (*Ceiba pentandra*) contains 35–50% of cellulose, 22–45% of hemicelluloses, 15–22% of lignin and 2–3% of waxes, and is a highly lignified organic seed fiber. It also contains smaller starch amounts, around 2.1% of proteins, and iron (1.3–2.5%) inorganic substances. Kapok contains 70–80% air and offers outstanding thermal and acoustic insulation [16]. Kapok is a cylindrically shaped, smooth, unicellular, twist-less fabric. With characteristic air bubbles in the lumen, kapok fibers are transparent by microscope inspection. The wall structure of the kapok cell varies from other natural cellulosic fibres. The primary cell wall, directly connected to the superficial properties of the fibers, consists of short microfibrils, rectangularly oriented to the fibre surface. Microfibrils in the secondary cell wall run almost parallel to the axis of the fibre [26, 43–46]. Given the alpha-cellulose material, kapok is more like wood than flax and other plant fibres. The average polymerisation degree is 6600 [44]. Kapok fibres, with a diameter of 20–43  $\mu\text{m}$ , are 10–35 mm long. The thickness of the cell wall is around 1–3  $\mu\text{m}$ . 0.84 cN/dtex (93.3 MPa), Young's module 4

GPa, and 1.2 percent breaking elongation are the tensile strength [36]. Kapok has an outstanding capacity for liquid retention due to its large lumen. Its outstanding insulating thermal and acoustic properties, high buoyancy and strong absorption of oil and other non-polar liquids distinguish kapok from other cellulosic fibers. Kapok is primarily used in stuffing and nonwovens; it is seldom used in yarns, mainly because of its fibers' poor cohesiveness and durability, brittleness and low strength. In the field of technical textiles, yachts and furnishing of vessels, insulating materials in cooling systems, sound insulation, industrial filtration of wastewater, elimination of spilled oil from water surfaces and reinforcement components in polymer composites, kapok has new potential [43]. A photograph of some extracted vegetable fibres is shown in Fig. 2.

### 3 Roles of Vegetable Fibers in Green Chemistry

Vegetable fibers which are a class of natural fibers have received a huge attention from researchers across the globe due to their intriguing characteristics such low density, biodegradability, ease of recyclability, and low price [47]. Additionally, vegetable fibers are renewable and have a CO<sub>2</sub>-neutral life cycle, especially when compared with their synthetic components (such as glass and carbon) [48]. The use, reuse and recycling of vegetable fibers subside environmental hitches, and subsequently make them highly influential in green chemistry. Many countries have abundance of vegetable fibers in their unprocessed forms which can serve as a continuous source of renewable materials that require less amount of energy and less difficulty to process [49].

Vegetable fibers, which may also be referred to as lignocellulosic fibers, contain majorly cellulose and have found limited applications when they are present in their raw forms [50]. However, they can be refined or chemically modified to afford distinct properties that are useful in sustainable and green technology. One of such modifications is the transformation of vegetable fibers to produce biocomposite materials because of their cost effectiveness, recyclability, and ability to compete favorably with respect to strength per weight of material. The vegetable fibers-derived materials are versatile and valuable resources with several benefits. Their eco-friendliness, low density and availability have endeared them to several applications in textile industry, paper making, construction, automotive industry, among others. Apart from the polymers, several other synthetic materials have been functionalized with vegetable fibers hybrid composites containing vegetable fibers and filler materials [51].

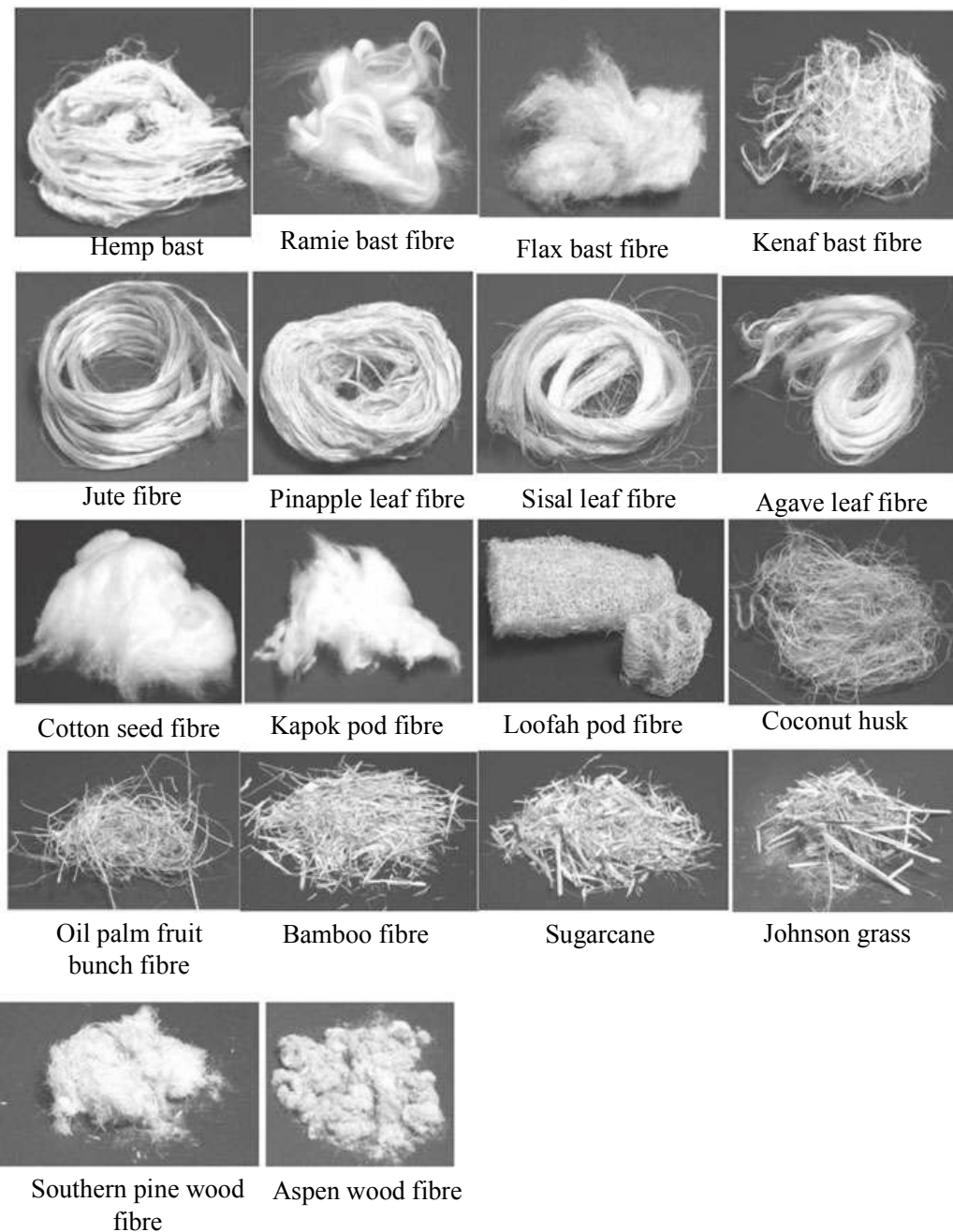


**Fig. 2** Photographs of some vegetable fibres [12]

### ***3.1 Green and Sustainable Paths Towards Vegetable Fiber Composites***

As mentioned earlier, for vegetable fibers to have much pronounced roles in green technology, they must be functionalized with other materials to produce composites with proven applications in different fields. These composites need to either be 100%

green or partially green for sustainability as depicted in Fig. 3. By green composites, we mean those composites whose compositions are all sourced from renewable resources and which can mitigate emission of CO<sub>2</sub> and lessen over-reliance on petroleum products. In contrast, the partly green composites are those in which one of their components is not derived from renewable resources. Some of the petroleum-derived polymers that can be used to reinforce vegetable fibers include polyethylene, polypropylene, epoxy, unsaturated polyester, vinyl ester, among others. They can be processed by several techniques that include compression molding, extrusion, injection molding, sheet molding compound, etc. [52]. The resultant properties of the bio-based composites produced depends on intrinsic properties of the constituents that make up the composites, the processing techniques adopted, compatibility and interfacial adhesion between the polymer and the fiber [53].

Meanwhile, the scourge of global warming and other related environmental challenges have given rise to the more sustainable use of vegetable fibers as composite materials. Benefiting from the intriguing properties of vegetable fibers, the composites derived from vegetable fibers exhibit substantial toughness, flexibility, ease of processing, availability, low cost, and minimal environmental risks. However, the formation of these composites may suffer from some challenges such as lack of interfacial adhesion emanating from lack of compatibility between the hydrophilic vegetable fibers and hydrophobic host matrices [54]. Several approaches have been deployed to overcome this challenge which include but not limited to chemical methods or grafting hydrophilic fibers with hydrophilic chemical species [55]. Although the use of toxic chemicals is not sustainable and can limit the greenness of the vegetable fibers from which the composite was derived.

Alternatively, finding sustainable solutions that combine environmentally benign methodologies while preserving the goals of enhancing interfacial adhesion between matrix and filler is only the way to go as far as green chemistry is concerned. In the light of this, scientists have found, for instance, biobased matrices as appropriate and renewable hosts for interaction with the hydrophilic groups of the vegetable fibers

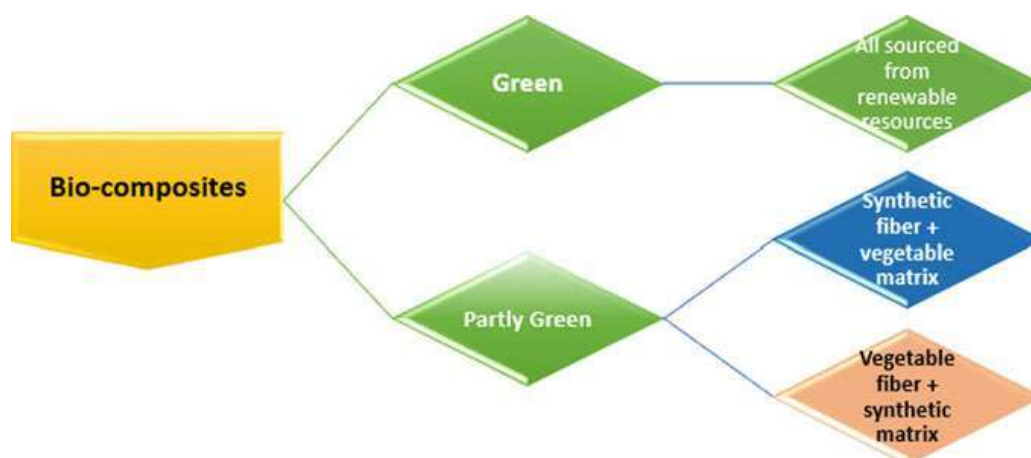


**Fig. 3** Classification of biocomposites into green and partly composites (Adapted from [56])

[57]. Examples of this could be seen in several studies involving the use of soybean as host to synthesize vegetable fibre-derived composites with outstanding interfacial adhesion [58–61]. Moreover, another sustainable approach is the fabrication of all cellulose composites in which both the matrix and reinforcement contained entirely cellulose, thus enhancing the interfacial adhesion to produce composites with excellent properties [62]. Evidently, green biocomposites are, without an iota of doubt, the solution not only to the ever-increasing environmental threat but in overcoming the obstacles associated with petroleum products and their supply. Because of the high demand of vegetable fibers globally, the market size of composites of natural fibers is expected to hit 6.5 billion USD by 2021, with about 11.7% compound annual growth.

Recently, Guigo et al. prepared all green composites that comprise flax fibers and resins of humins. It was shown that humins offer good adhesion between the fiber and the matrix, which formed a good interface and enhanced their tensile properties. In this study, the use of humins for functionalizing vegetable fibers is attractive because both are green and can effectively solve the problems related to compatibility of the host and substrate [63].

Overall, as much as it is highly important to use vegetable fibers to make up for the drawbacks of synthetic fibers, it is equally critical to employ treatment methods that will not defeat the main objectives of green chemistry.

## **4 Vegetable Fibers and Composites for Different Green Applications**

Recently, focus has been shifted to vegetable fibers to make up for the drawbacks experienced in using synthetic reinforcement to fabricate polymeric matrix composites employed for various applications in building, textile, and automotive industries, among others. For instance, materials made from vegetable fibers are well known and have been increasingly used to make building materials especially in developing countries because of the inherent advantages [64]. In Europe, hemp and flax are cheaply available and are regarded as captivating vegetable fibers to replace glass fibers in composites. However, design of sustainable green composites with enhanced properties that can withstand not only high-performance lightweight demands but also the strict environmental conditions is quite challenging. Reinforcement of two or more vegetable fibers is one of the techniques that combine the advantages of the two materials and exhibit superior mechanical performance and environmental impacts, leading to excellent sustainability [65]. Herein, we will discuss ways in which vegetable fibers have contributed to the green and sustainable developments in different applications.

## 4.1 *Green Automobiles*

Vegetable fibers such as flax, hemp, jute or kenaf have been largely used in automotive industry to make different materials. For vegetable fibers and their composites to offer green solutions in automotive sector, they must possess desirable qualities in addition to their eco-friendliness. The use of biocomposites in this industry is not only environmentally benign but also reduce weight via replacement of high-density synthetic fibers with low-density vegetable fibers [66]. Interestingly, lightweight vehicles minimize cost with respect to cost of production and fuel consumption, which will subsequently lessen the release of CO<sub>2</sub> to the atmosphere. For instance, in 2012, Yang and coworkers reported that when the weight of a vehicle is reduced by 25%, there was an equivalent decrease in the consumption of crude oil by 250 million barrels, and this corresponded to a total reduction in CO<sub>2</sub> emission to the tune of 220 billion pounds per annum [67].

Furthermore, Alves et al. [68] replaced glass fiber, a synthetic fiber with jute fiber (vegetable fibers) to fabricate structural frontal bonnet for a vehicle. It is noteworthy to mention here that the jute fiber did not only reinforce the bonnet but also enhanced the environmental activity of the whole vehicle, simply because of the lower weight of the vegetable fibers when compared with the conventional ones, even though Witik et al. were of the contrary opinion that weight reduction of automobile parts does not always lead to enhanced environmental performance [69].

In another study, Luz et al. examined the environmental implications of substituting talc with sugarcane bagasse fiber to reinforce composites that make up automotive parts [70]. It was concluded from their study that bagasse carbon absorption was observed during cultivation, which ultimately mitigates greenhouse gas emissions and ensures cleaner production processes.

In summary, it is obvious that the advances in green chemistry via the use of vegetable fibers are not only useful for weight reduction of automobile parts and clean environmental but also beneficial for renewable and sustainable development. Additionally, vegetable fibers can be modified to generate biocomposites which can serve as good substitutes or even perform better than the synthetic polymer-fiber composites. As a result of this, they can proffer solution to waste disposal challenges of synthetic polymer-based composites.

## 4.2 *Green Building Technology*

Vegetable fibers represent a promising solution to optimize environmental sustainability in construction companies. Unlike synthetic fibers, vegetable fibers have widened the field of applications in construction sectors because of their excellent hygrothermal and sound insulation characteristics. Additionally, these materials also allow good storage of carbon because of the sequestration of CO<sub>2</sub> during agricultural

activities. Of course, the trees do not only absorb CO<sub>2</sub> as they grow, but also requires less energy to process them into construction materials [71].

Furthermore, for a material to be useful in green building technology, they must possess characteristics such as ease of recyclability, renewability, and minimal consumption of resources during production chains. Interestingly, vegetable fibers match perfectly all these requirements and can sometimes exist in form of fiber mats with credible sustainability features, by being biodegradable and retrievable [72]. Moreover, these fibers can be reinforced with cement, sand, and other materials to improve their properties. Based on this, it is reasonable to replace petroleum-based composites with biocomposites to reduce their rate of impacts on human health and environment. In summary, to foster the growth of sustainable construction materials, the use of vegetable and green materials has to be prioritized to minimize the risks associated with climate change and other health risks.

### 4.3 Green Textile Industry

One of the goals of textile manufacturers is to find sustainable and biodegradable materials for their products to get rid of the negative impacts of man-made fibers (acrylic, polyester, nylon, etc.) [73]. This is because all the processes involved in textile production have impacts on the environment and human health in one way or the other. These effects are shown in Fig. 4.

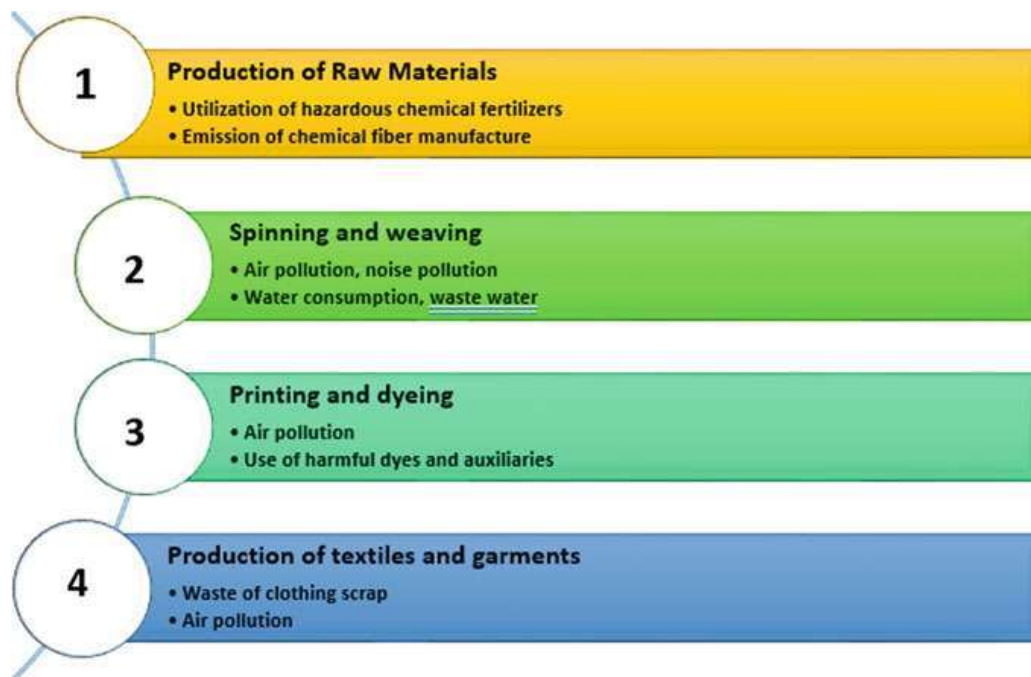


**Fig. 4** Processes involved in textile making and associated effects on environment and human health

**Table 1** Applications of vegetable fibers for green applications

| S/N | Application        | Example                                                 | References |
|-----|--------------------|---------------------------------------------------------|------------|
| 1   | Storage devices    | Supercapacitors, lithium ion batteries                  | [76]       |
| 2   | Electronic gadgets | Cable wires, optical fibers                             | [77]       |
| 3   | Housing            | Door panels, upholstery, interior designs, carpet, mats | [78]       |
| 4   | Sport equipment    | Ball, tennis racket                                     | [79]       |
| 5   | Transportation     | Railway interior design, bonnet, vehicle doors, etc     | [80]       |

However, vegetable fibers are biodegradable and can satisfy the demands of these manufacturers. Cotton is a renowned natural fiber with a big market share in textile industry, although its cultivation involved widespread use of toxic chemicals and large amount of water which calls for economical and environmental concerns [74]. As a result of this, other sources of natural fibers including hemp, flax, banana, sisal, bamboo and organic cotton, can be used as ecofriendly and energy-efficient bioresources in textile industry. Of all these, organic cotton can serve as a sustainable replacement for the conventional cotton. Another vegetable fiber on the list is the bamboo that is 100% biodegradable and naturally regenerative [75]. It has shown good promise in the textile industry due to its exceptional sustainable properties that can help satisfy human needs and at the same time helps keep our environment green. The widespread use of green chemistry, balanced by economic and market realities in the textile industry, would obviously pave the way for a future of cleaner and more environmentally sustainable goods. Other potential applications of green fibers are summarized in Table 1.

## 5 Challenges of Vegetable Fibers in Green Chemistry

Despite the successes recorded by vegetable fibers in green technology, they do experience some drawbacks which may limit their practical green applications. These include:

1. Vegetable fibers incorporating polymeric composites have some disadvantages that include lack of compatibility between hydrophilic fibers and hydrophobic matrices. As such, this requires adequate use of physical and chemical pretreatment processes for the adhesion of the vegetable fiber and host matrix.
2. Vegetable fibers are prone to biodegradation; hence composites derived from them are at higher risk of degradation under applications when compared with the synthetic fibers.
3. Vegetable fibers have sometimes; low mechanical properties and poor moisture resistance and this may limit their applications to interior and non-structural applications.

## 6 Conclusions

In recent times, rapid economic boom coupled with technological advancement have generated significant advancement in human endeavors, while at the same time, led to environmental pollution and destruction of natural resources around the world. In light of this, global attention is being paid to the new paradigm and innovations based on renewability and sustainable development where the terms such as ‘green’, “ecofriendly”, atom economy, atom efficiency, environmentally benign, etc. are the order of the day. In this chapter, we have summarized the properties vegetable fibres, discussed their roles in green chemistry and highlighted the challenges that limit their applications in different fields. Vegetable fibers represent one of the largest renewable resources known. They are excellent candidates that can replace synthetic fibers such as glass and carbon fibers in composite applications. When vegetable fibers are used as precursors in fabricating composite materials, they bring both economic and environmental benefits, and subsequently advance the course of green chemistry. Consequently, they have a role to play in the fight against global warming and other environmental challenges. In addition, because they are biodegradable, they can be employed as thermal energy at the end of their life cycle, hence not contributing to the landfill crisis. However, their applications in green chemistry can be limited by factors that include lack of compatibility between hydrophilic fibers and hydrophobic matrices in the course of transforming them to composites for enhanced applications in building, textile, automotive, paper making, among others.

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