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Harnessing Agricultural Waste – from Disposal Dilemma to Wealth Creation and Sustainable Solutions Towards UAVs Airframe Manufacturing – A Review

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ABSTRACT

The escalating global population and subsequent demand for agricultural products have led to a surge in agricultural waste generation, posing significant disposal challenges. Conventional disposal methods such as burning and dumping not only harm the environment but also jeopardize human health and safety. Recognizing the urgent need for sustainable waste management, researchers have increasingly focused on repurposing agricultural plant waste as a valuable resource. This paper presents a comprehensive review of the potential of agricultural plant waste in wealth creation and sustainable development. It highlights the detrimental impacts of current disposal methods and emphasizes the necessity for alternative approaches. By analyzing the physical, mechanical, and chemical properties of plant fibers, particularly cellulose, hemicellulose, and lignin, this review underscores their suitability for diverse applications. Moreover, it explores the emerging trend of utilizing pineapple leaf fiber, a sustainable and lightweight material, in structural applications, such as UAV construction. With its exceptional mechanical properties and biodegradability, pineapple leaf fiber holds promise as a viable alternative to traditional materials, contributing to a more sustainable future. In conclusion, this review advocates for a paradigm shift towards embracing agricultural plant waste as a valuable asset for economic prosperity and environmental sustainability. It underscores the importance of continued research and technological advancements to unlock the full potential of agricultural waste in fostering a circular economy and driving sustainable development globally.

Keywords: UAV, aircraft airframe, agricultural waste, natural fiber composites, waste composites, pineapple, reusing waste, natural waste.

INTRODUCTION

The growth of the agricultural sector highly affects human and economic development. Due to the ever-increasing human population, awareness of increasing agricultural production has been growing. However, the growth of agricultural production comes with the increment of farming activities, which produce large amounts of agricultural waste.

One of the major problems with having an abundant supply of agricultural waste is the disposal method. Due to the massive amount of waste generated, it is not easy for farm owners to dispose of the accumulated waste. Moreover, these wastes are usually improperly managed in developing countries because little information is available on their potential and benefit as raw material if appropriately managed. Improper handling of agricultural wastes will lead to economic loss and threaten human health due to environmental and air pollution [1].

The current disposal method used by the farm owners is through burning. This method could quickly dispose of the waste without large expenses. However, the effect of this method is severely detrimental to the environment and society. One of the side effects due to open burning is air pollution. The burning of agricultural wastes will increase the emission of greenhouse gases, which contributes to global warming, increasing the particulate matter and smog that are detrimental to human health, as well as the deteriorating soil fertility. In addition, the contaminated soil that contains the smoke and dust residue may be channeled to the nearby water source, thus polluting the aquatic environment.

Another common method of disposal is by dumping. Although this method requires little labor and expenses, it increases the landfill area. Furthermore, indiscriminate dumping of agricultural wastes on the farm site will attract a lot of predators and pests, which could compromise the workers' safety. The accumulation of agricultural wastes in the farms could provide ideal conditions for rodents and pests' breeding grounds as well as adequate hiding spaces for snakes. Rodents are known to be carriers of various diseases and crop destroyers. Meanwhile, snakes can attack workers and like to prey on farm animals.

Although having a balanced population of these creatures is incredibly beneficial on farms, an unhealthy population could also threaten workers' safety. Another effect of indiscriminate dumping is flooding. Flooding occurs due to blocked waterways caused by solid agricultural wastes. Thus, many lives and properties were lost during a high flood. Dumping at the landfill site is also another option for agricultural waste disposal. However, unlike indiscriminate dumping, this type is quite expensive due to the need for labor and transportation. This kind of dumping also requires a licensed pickup service, and each landfill needs to be checked earlier to ensure that the agricultural wastes match the landfill requirements.

Burying agricultural waste is also one of many common disposal methods. It is one of the easiest disposal methods depending on the soil condition. However, the problem with this method is that it is labor and energy intensive. Thus, it is much more expensive compared to the dumping and burning method. Furthermore, burying a massive amount of animal waste could negatively impact the soil and water quality near the burial site.

In agricultural activities, such as pineapple production, various waste materials are generated, including leaves, crown, core, peels, and stems [2]. These residues are typically managed through disposal methods such as dumping, burning, burying, or natural decomposition. Similarly, banana production results in the production of waste materials, such as peels, stems, and trunks [3]. These agricultural by-products are commonly disposed of through such techniques as dumping, burning, burying, or natural decomposition. Animal production, another significant agricultural practice, generates a range of waste materials, including left-over feed, wastewater, hatchery wastes, manure, and carcasses. These waste products are typically managed through disposal methods such as dumping, burning, or burying. In leather tanning processes, various waste materials are produced, such as hair, bristle, flesh side, splits, trimmings, fleshing, splits trimmings, shavings, and sludge [4]. The disposal of these residues primarily involves dumping as a common practice. Sugar processing activities generate waste materials, such as bagasse, cane trash, press mud, and molasses [5]. Disposal methods for these by-products include dumping, burning, or burying, depending on local regulations and environmental considerations. On the basis of these studies, it can be concluded that various agricultural activities generate significant quantities of waste materials. These residues, ranging from plant parts to animal by-products and industrial wastes, are managed through disposal methods, such as dumping, burning, burying, or natural decomposition. The environmental impact of these disposal practices underscores the importance of sustainable waste management strategies in agriculture, emphasizing the need for efficient utilization, recycling, and eco-friendly disposal techniques to minimize adverse effects on ecosystems and human health.

From the current disposal method, it can be seen that it can significantly impact the health of society and the environment. Thus, current researchers have studied various ways to change the existing forms of disposal that would mitigate the negative impact on the economy, society, and environment. One such method is recycling agricultural waste and converting it into an alternative income for the locals [6, 7]. Therefore, an alternative income generation could be established instead of losing money due to improper means of waste management. This will also keep the environment and society safer. An example of a product that would be beneficial by introducing agricultural waste into its manufacturing process is UAV airframe manufacturing.

In the context of UAV airframe manufacturing, the choice of materials and manufacturing processes significantly impacts both the economic and environmental aspects of production. The use of lightweight yet durable materials not only enhances the performance and longevity of UAVs, but also reduces operational costs and environmental footprint compared to traditional materials like metals [8]. The current research efforts in UAV airframe manufacturing are paralleled with those in waste management, aiming to mitigate negative impacts on both society and the environment. By adopting advanced recycling techniques and utilizing sustainable materials, manufacturers can minimize waste generation and environmental pollution associated with production processes. This proactive approach not only promotes environmental stewardship, but also fosters economic benefits through reduced material costs and enhanced operational efficiency.

Furthermore, integrating sustainable practices into UAV airframe manufacturing offers opportunities for local communities to benefit economically. For instance, by repurposing agricultural waste into composite materials or other useful products for UAV construction, communities can generate alternative sources of income, while contributing to environmental conservation efforts. This dual benefit supports the establishment of sustainable livelihoods and reinforces the resilience of local economies against adverse environmental impacts. In essence, by aligning with innovative waste management strategies and sustainable manufacturing practices, UAV airframe manufacturing not only advances technological capabilities but also underscores its role in fostering economic prosperity and environmental sustainability for present and future generations.

The sourcing of materials for UAV airframes faces several significant challenges, particularly concerning the reliance on traditional composites like fiberglass and carbon fiber. These challenges primarily revolve around cost, sustainability, and environmental impact. In terms of cost constraints, traditional composite materials, such as carbon fiber are known for their high performance and strength-to-weight ratio, making them ideal for aerospace applications. However, the manufacturing process of carbon fiber involves intensive energy consumption and labor costs, resulting in high material costs [9]. This cost factor can be prohibitive for widespread UAV deployment, especially in the sectors requiring large-scale UAV fleets, such as agriculture or logistics.

In terms of the environmental sustainability, the production of traditional composites like carbon fiber involves the use of non-renewable resources and chemicals that pose environmental challenges [10]. For instance, carbon fiber production generates significant greenhouse gas emissions, and the materials themselves are not easily recyclable. This lack of recyclability leads to environmental concerns about waste disposal and long-term sustainability.

Another challenge with the traditional material is the vulnerability of the supply chain. The supply chain for traditional composite materials can be vulnerable to geopolitical factors, market fluctuations, and limited production capacities [10]. This dependency can result in supply shortages or price volatility, affecting the reliability and scalability of UAV manufacturing operations. This can be solved with replacing with agricultural wastes due to their abundant supply.

To address these challenges, researchers and manufacturers are exploring several avenues and one of it is by developing the product by using sustainable alternatives. Research is focused on developing sustainable alternatives to traditional composites, such as bio-based composites using agricultural waste or recycled materials. These materials aim to reduce environmental impact and dependence on non-renewable resources. Furthermore, advances in material science enable the optimization of existing materials and the development of new composites with improved performance characteristics, such as enhanced durability and reduced weight. In addition, efforts are underway to improve the recyclability of composite materials and promote a circular economy approach where materials can be reused or repurposed at the end of their lifecycle.

Hence, this review aimed to highlight the significance of agricultural waste as a type of wealth and its potential as an alternative material in UAV airframe manufacturing. Researchers and manufacturers are exploring several avenues to address these challenges, one of which involves developing sustainable alternatives. Research is focused on creating bio-based composites using agricultural waste or recycled materials to reduce environmental impact and dependence on non-renewable resources. Furthermore, advances in material science optimize existing materials and develop new composites with enhanced durability and reduced weight. Efforts also enhance the recyclability of composite materials, promoting a circular economy where materials can be reused or repurposed at the end of their lifecycle.

CONVERTING AGRICULTURAL WASTE TO WEALTH

In recent years, many researchers have explored the possibility of recycling agricultural waste instead of using the traditional disposal method. This effort is more prevalent in developing countries, since it offers an alternative source of income for the population living below the poverty line [11]. Another reason is that there is still no organized waste management in third-world countries, contributing to uncontrolled waste in landfills [12]. Currently, three types of agricultural wastes identified could be utilized and converted into an alternative income generation, as shown in Figure 1. Thus, this section discussed the possibility of using agricultural wastes in different types of applications based on the type of agricultural waste.

Crop waste

Crop wastes from plants consist of cellulose, hemicellulose, and lignin. Due to the advances in the manufacturing field, current technologies can extract these components into their pure structural form. Figure 2 shows the basic structure of plant fiber. Cellulose is mainly used to produce textiles [13], paper [14], and pharmaceuticals [15]. Cellulose is mainly used in these industries due to

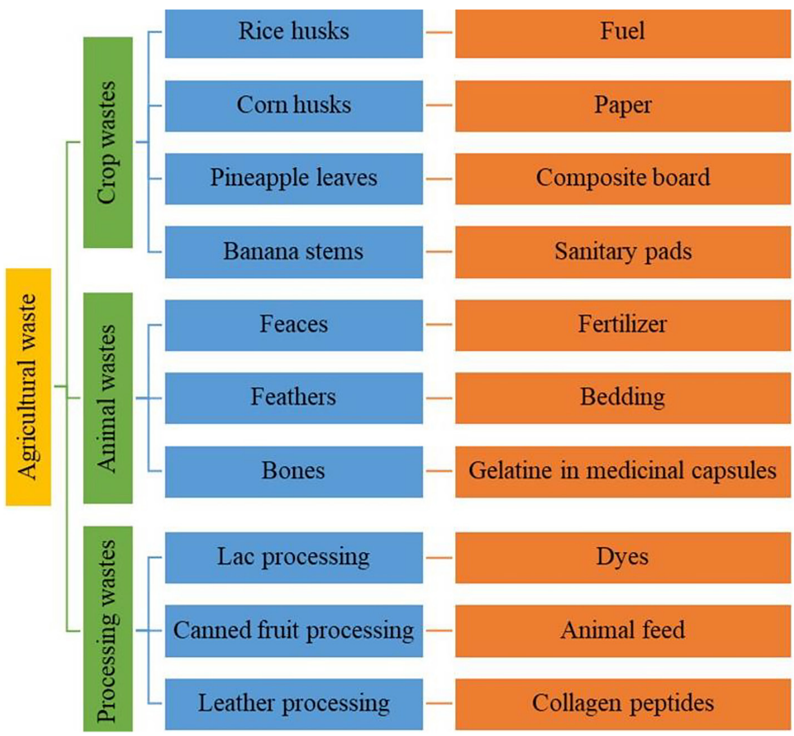

Figure 1. Types of agricultural wastes and some examples of wastes that can be utilized to generate wealth

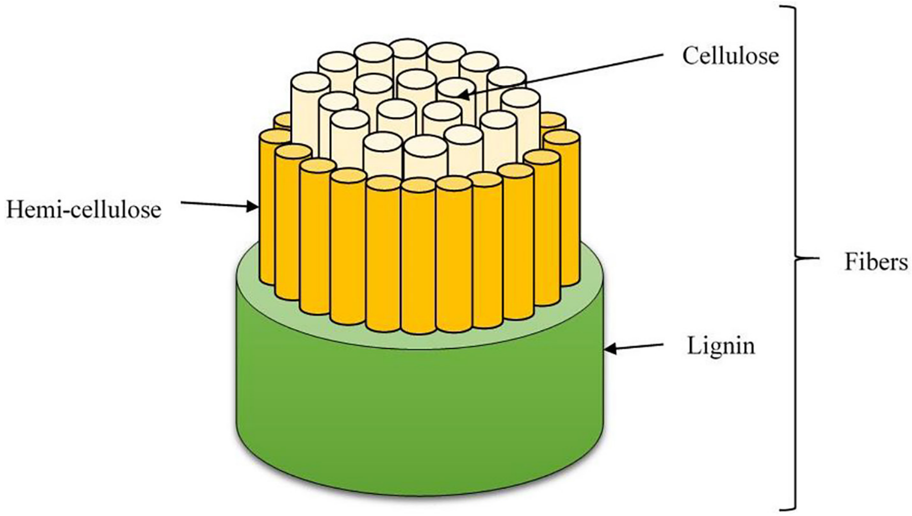

Figure 2. Basic architecture of plant fiber

the presence of fibrils, which are small thread-like structures that could be exposed by beating or refining to provide a large area for bonding. Therefore, cellulose fiber could develop physical and chemical bonding with other fibers when its condition changes from wet to dry. Biofuel is also one of the applications made from cellulose or lipids to replace gasoline and diesel, respectively. Many modern vehicles are designed to operate on the biofuels developed from plants.

As for hemicellulose, it provides support and strength to the cellulose structure [16]. The unique characteristics of cellulose fibers are high tensile strength, flexibility, water-insolubility, and chemical stability. Hemi-cellulose is also commonly used to ferment alcohol that can be applied in cosmetics, coatings, and pharmaceuticals [17]. Hemicellulose is biodegradable, non-toxic, and has a lower molecular weight than cellulose.

Lignin characteristics are similar to cellulose and hemicellulose, with good biocompatibility and low toxicity. However, lignin is unique because it has high carbon content [18]. Therefore, lignin can be transformed into a composite or carbon material by extracting the carbon in this construction. The materials made from lignin are not only cost-efficient, but also environmentally friendly. In the most recent studies, lignin is used to produce epoxy resin suitable for printed board circuits in the electrochemical industry [19], wound dressing in the medical industry [20], 3D printing lignin-polymer composite materials in the manufacturing industry [21], and much more.

Besides their structural form, crop wastes can be used in fiber form, which is widely used in the composites field as a reinforcement material. In composites, fibers are found in two primary forms: short and long. Composites with the long form of fibers are stronger, however they usually have anisotropic properties, whereas the short form of fibers are isotropic, less expensive and easy to obtain. Some of the products that were made by using the powdered or short-fibered form are briquettes made from charred coconut husks and shells [22], bio-packaging made from bagasse [23], and biogas from rotting vegetables [24]. Meanwhile, for long fibers, there are products such as clothing or textiles made from corn husks [25], sanitary pads made from banana stems [26], and plastics made from avocado pits [27].

Animal waste

Generally, animal waste means any substances emitted by animals in solid or liquid states. Some examples of animal solid wastes are feces, animal bedding, animal carcasses, and many others. Liquid wastes include urine, blood, and wastewater. Reusing animal waste is not new in agricultural management and it is usually pre-treated before application. The most common ways solid waste was applied include fertilizer and animal feeds [28]. Another method is converting them into energy [29] and biogas [30]. However, with the current technology, more applications are being proposed to utilize animal wastes in product manufacturing, especially in the form of fibers. One such example was using poultry feathers, hair, fur, and many more by extracting fibers from these materials [31]. These fibers are valuable as reinforcement material in composites or fabrics in textiles. Cashmere fiber is a fine, soft hair collected while shearing goats [32]. The fibers were obtained from goat hairs during its combing process during the spring season when the goats naturally shed their winter coat. It is composed of keratin, a protein with high sulfur content, which gives cashmere its softness and warmth. The cashmere is eight times warmer than ordinary wool. The fine texture of the fibers makes them softer than wool.

Chicken feathers are a waste product obtained when birds are molted during the molting season or after the chicken has been processed into meat [29]. The most interesting property of feathers that attracted much attention is their extremely low density and hydrophobic nature. Due to their hydrophobic nature, feather composites have high resistance to decay fungi and termites. This fiber also has high tensile strength, compressive strength, and impact resistance, with thermal and sound insulation properties, which are highly suitable for structural materials.

Processing waste

Processing waste can be defined as the end products obtained from various processing industries, which were discarded and not utilized. These wastes could be turned into valuable products if the proposed utilization could generate revenues exceeding its cost for reprocessing. Processing waste is the main reason for the high accumulation of landfills and environmental pollution [33]. There are mainly two types of processing waste based on their properties, which are biodegradable and non-biodegradable. Biodegradable processing waste comprises rotting fruits and vegetables, papers, and wool waste, while non-biodegradable processing waste comprises plastics, bottles, cans, and many more.

In the lac processing industry, lac, the resinous secretion of the lac insect (*Kerria lacca*), was used to produce several types of products such as lac dye, lac mud, and gummy mass. The sticklac was converted into a seedlac with the lac resin (shellac) and the water-soluble lac dye [34]. The dye has a deep red color suitable for use as a coloring material, and due to its non-toxicity, it is also used as a food colorant [35]. As for the lac mud, it was produced from the primary processing of lac. Lac mud is usually discarded due to the lack of a proper disposal method. Currently, in India, lac mud is used as an organic manure for vegetable production [36]. It was reported that there was an increased yield rate for vegetable production. This shows that lac mud could improve soil fertility and help sustain the lac production system. The gummy mass produced in the lac industry is the by-product waste obtained from aleuritic acid production [37]. It is a sticky material that will not dry at ambient temperature. Therefore, this material was proposed as a coating material, gasket cement compound, and composite board.

Processing wastes is also prevalent within the canned fruit processing industry. The pineapple processing factories produced many by-products from processing canned pineapple fruits. The factories usually discard around 80% of pineapple parts, including the fruit core, crown, peels, leaves, stems, and wastewater from washing fruit and juice production [38]. Most pineapple parts were pulverized into smaller bits for animal feeds, whereas the wastewater was processed into alcohol and sold to the pharmaceutical company to produce medicinal products.

Wool waste fibers are a by-product that comes from different steps in wool processing, which is unsuitable for textile use [39]. However, due to its unique properties, it is being used in different applications. The chemical properties of wool waste fibers include a high nitrogen content, which makes them useful as a fertilizer. It is also composed of keratin, a protein with high sulfur content, which makes wool naturally flame resistant and resilient to stretching and compression. The mechanical properties of wool waste fibers include high elasticity and good resistance to compression. Meanwhile, the physical properties of wool waste fibers include a fine texture and a natural crimp, with a soft and fluffy feel that makes them helpful to act as thermal and sound insulators or as pillow stuffing.

Like wool, silk waste fibers refer to short silk fibers obtained during silk processing, which cannot be reeled due to technological constraints [40]. Due to its high protein content, silk waste fiber is usually processed into animal feeds. The silk waste fibers can be incorporated into composites to fabricate a high strain to failure composites with good deformability and impact resist. Silk waste fiber also contains amino acid structures most similar to human skin and has an antibacterial function. These features are a unique characteristic of silk waste fibers that are highly beneficial in cosmetic applications.

AGRICULTURAL WASTE AS FIBER POLYMER-REINFORCED MATERIAL

In recent years, the effort exerted by researchers to develop greener products has significantly increased. Ecological awareness has started to sprout and is a significant factor driving more sustainable and environmentally friendly research. Some of the most significant growths and applications are found within the field of composites as reinforced material. Due to the rapid growth of manufacturing technology, extracting fibers from agricultural waste and developing green products is now possible. These agricultural waste fibers have a range of chemical, mechanical, and physical properties that make them useful for various applications, such as clothing, textiles, composites, and packaging. The section below discussed the physical, mechanical, and chemical properties of agricultural waste in its fiber form.

Physical and mechanical properties of fibers

Fiber reinforcement materials are generally used to add rigidity and restrain the propagation of cracks within composites. These fibers enforce the mechanical strength of the matrix while retaining or reducing the weight of the composites. Plant fibers from crop waste can be extracted in various ways, such as retting, scraping, decortication, or steam explosion after harvest season. Meanwhile, animal fibers are collected by shearing during the shedding season. As for processing waste fibers, they are collected from discarded materials following plant or animal processing. The physical and mechanical properties of fibers extracted from agricultural waste are summarized in Table 1. Table 1 shows that the mechanical strength of animal fibers and processing waste fibers are much lower compared to plant fibers. As for the fiber densities, those characterizing plant-based fibers are much lower compared to animal-based fibers. Therefore, it can be concluded that plant fibers have a higher specific strength, which is highly significant in structural applications. This shows that plant fibers work better in composites than animal fibers and processing waste fibers. Therefore, to better understand how the fibers could affect the mechanical properties of the composites, knowing the chemical composition of fibers is essential, which was further discussed in the next section.

Chemical properties of fibers

The chemical properties of fibers will differ from one to another. The chemical composition of the fibers will help determine the suitability of the fibers for their chosen application. In structural applications, the amount of cellulose and hemicellulose in plant fibers and protein in animal fibers will determine the strength and stiffness of the fibers as a reinforcement material [75]. Fibers with more cellulose/hemicellulose or keratin will help reinforce and strengthen composites.

As for lignin in plant fibers, it provides rigidity to the fiber, further strengthening its tensile strength. In addition, lignin is hydrophobic. This specific characteristic provides the water resistance of composites. Therefore, a higher amount of lignin will have better water resistance. Thus, it can be used as a resin to produce printed board circuits or as a replacement for polymer films.

Table 1. Physical and mechanical properties of fibers extracted from agricultural waste

Types	Materials	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)
Crop waste	Pineapple leaf fiber [41–44]	0.95–1.53	460–1244	4.4–43
	Banana stem fiber [45–48]	0.22–0.96	210–914	16.4–32
	Bamboo fiber [49–52]	0.6–1.4	206.5–630	17–36
	Corn husk fiber [53–55]	1.16–1.49	180–256	4.6–15.9
	Sugarcane bagasse fiber [56–58]	0.88–1.2	20–290	3–27.1
Animal waste	Milk protein/casein fiber [59–61]	1.3	37–116	2.1–7.4
	Chicken feather fiber [62–65]	0.78–0.90	130–220	3.0–4.5
	Yak fiber [66]	1.32–3.41	270.05	45.09
	Gelatin fiber [67–70]	1.2–1.58	91–170	2.0–3.1
Processing waste	Wool waste fiber [62,71,72]	1.29–1.31	130–210	2.6–3.6
	Silk waste fiber [73]	1.32–1.33	165.3–248.8	3.8–6.1
	Recycled cotton fiber [74]	1.5–1.6	287–597	5.5–12.6

Furthermore, lignin has high carbon content, which could be used to make carbon fibers.

Similar to lignin, pectin increases the mechanical properties of the composites. Due to its unique characteristic as an adhesive in plant cell walls, it is highly suitable for gel making or coating. In addition, pectin is well known for its biocompatibility and anti-microbial characteristics. Thus, it is commonly applied in the production of food, biomedicines, and drugs. Table 2 shows the chemical composition of agricultural waste fibers.

From Table 2, it can be seen that the difference between plant fibers and animal fibers is their main composition, where plant fibers are mainly made up of cellulose, whereas animal fibers are mainly made up of protein. Meanwhile, processing waste fibers are discarded products processed from their primary source or have fully served their purpose as packaging or fabrics.

Due to the increasing animal welfare awareness, current research is mainly directed toward plant fibers. Although there are several innovative ways to collect animal fibers that could avoid killing them (such as peace silk), the process requires complicated procedures that end up making the materials more expensive. Similar to animal fibers, innovations in converting processing waste into recycled fibers were also researched and proposed. However, the additional procedure to convert them into useful fibers also requires higher production costs. However, unlike animal fibers and recycled fibers, the extraction of plant fibers is much cheaper. The raw materials can be transformed directly into valuable fibers without undergoing complicated extraction procedures. Therefore, there is an increasing trend for the innovation of animal fibers using plant fibers such as wool (made from a blend of cotton and calotrope) and silk (made from lotus, agave, or aloe vera).

Plant fibers are renewable, cruelty-free, and have a lower carbon footprint. Therefore, they are preferable, especially among vegan enthusiasts. Some plant fibers are derived from stems and leaves of a plant or tree that was harder to extract in high amount due to the absence of proper equipment. However, with the current technology, the extraction of these fibers has become possible. One such example corresponds to the pineapple leaf fibers.

PLANT FIBER COMPOSITES FOR STRUCTURAL COMPONENTS

Over the years, various studies were conducted using plant fibers in composites. As it was mentioned in previous sections, plant fibers are abundantly available and renewable. Thus, their raw materials are incredibly cheap, making them ideal for low-income countries. Furthermore, many researchers have discovered that plant fibers have

Table 2. Chemical properties of agricultural waste fibers

Types	Materials	Chemical properties (%)		
Crop waste	Pineapple leaf fiber [3,41,43,44,76]	Cellulose: 64.4–72.1 Hemicellulose: 4.9–21.7	Lignin: 4.3–13.6 Pectin: 1.3–1.6	Ash: 0.8–5.0
	Banana stem fiber [45–48,77]	Cellulose: 39.2–64 Hemicellulose: 10.2–27.8	Lignin: 11.4–27.8 Pectin: 2.1–2.8	Ash: 3.9
	Bamboo fiber [78–80]	Cellulose: 36.1–55.7 Hemicellulose: 11.4–19.2	Lignin: 16.9–28.5 Pectin: < 1	
	Corn husk fiber [53, 55, 81]	Cellulose: 43–45.7 Hemicellulose: 31–40	Lignin: 2–22	Ash: 0.4–6.4
	Sugarcane bagasse fiber [57,82]	Cellulose: 30–55 Hemicellulose: 20–28.3	Lignin:18–26 Pectin: 0.6–0.8	Ash: 3–10
Animal waste	Milk protein/ casein fiber [83]	Carbon: 53 Hydrogen: 7.5	Oxygen: 23 Nitrogen: 15	Sulfur: 0.7 Phosphorous: 0.8
	Chicken feather fiber [65,84,85]	Protein: 82–91 Carbon: 64.5	Nitrogen: 10.4 Oxygen: 22.3	Sulfur: 2.6
	Yak fiber [86,87]	Protein: 65–95 Carbon: 51.1–58.3	Nitrogen: 13.5–18.2 Oxygen: 20.7–32.1	Sulfur: 2.1–2.3
	Gelatin fiber [88–90]	Protein: 98–99 Carbon: 48–50.5	Nitrogen: 14.4–17 Oxygen: 25.2–29.4	
Processing waste	Wool waste fiber [91,92]	Protein: 33 Carbon: 50	Nitrogen: 14–25 Oxygen: 10	Sulfur: 0.1–0.2
	Silk waste fiber [91,93]	Protein: 78–95	Nitrogen: 16.4	Sulfur: 3.7
	Recycled cotton fiber [94]	Cellulose: 90–94 Moisture: 6–7	Protein: 1–1.5 Pectin: 0.9	Ash: 1.2

good mechanical properties, which could be used in various applications. Table 3 summarizes the mechanical properties of the plant fiber composites and their structural application.

From Table 3, it can be seen that most of the research shows that natural fiber composites have enhanced the mechanical properties of conventional materials such as plastics. Furthermore, by optimizing the design of the products, the properties exhibited by the natural fiber composites could surpass steel and aluminum, as proven by Jain's team [95]. In addition, the lightweight of the natural fiber composites is also ideal for reducing the weight of the structural components.

POSSIBILITY OF USING A PINEAPPLE LEAF FIBER-REINFORCED COMPOSITE AS AN ALTERNATIVE IN UAV CONSTRUCTION

Pineapples are produced worldwide, and as the population increases each year, the amount of production also increases, as shown in Figure 3. The pineapple production and harvesting area has been increasing steadily since 2012 and peaked in 2018 with 1088.42 k hectares of area harvested and 28.29 M tonne of production. In 2019 and 2020, it decreases significantly due to the COVID-19 pandemic. Currently, the amount of pineapple produced is around 28.71 M tonne with 1059.2 k hectares of area harvested. The three top producers are the Philippines, Costa Rica, and Brazil, as shown in Figure 4.

Meanwhile, Figure 5 shows that Asia has the highest pineapple production. These data sets were obtained from the Food and Agriculture Organization of the United Nations [96]. From these data, a massive number of pineapples are produced each year. Thus, the amount of pineapple waste increases along with pineapple production. Some of the wastes produced from pineapple plantations are the crown, stem, peels, and most of them are the leaves. These wastes will accumulate at the plantation site after each harvest.

In Malaysia especially, due to the lack of proper equipment, the pineapple leaf waste will usually end up being dumped or buried underground at the plantation site to degrade naturally. Figure 6 shows the accumulation of pineapple leaf waste. Over time, this will compromise the workers' safety at the plantation site. Thus, instead of discarding these leaves, they can be turned into valuable fibers

Table 3. Mechanical properties of plant fiber composites and its application

Type of composites[1]	Density (g/cm^3)	Tensile strength (MPa)	Young's Modulus (GPa)	Flexural strength (MPa)	Flexural Modulus (GPa)	Application	Results
PALF + GF + Epoxy	1.142	49.28	1.57	152.21	6.86	Car bumper	After optimizing the car bumper design, the deformation of the hybrid composites is less than that of steel and aluminum [93].
Olive + BF + Epoxy	1.200	31.28–37.09	-	56.70–65.64	-	Floor panels, automotive interior	The hybrid composite shows better mechanical strength compared to the non-hybrid composite [94].
Cashew nut shell + hemp + Epoxy	-	136.00	-	168.00	-	Morphing wing UAV	The mechanical properties of the composites were enhanced with the addition of cashew nut shells and hemp [95].
JF + SG + KF + CASP + Epoxy	-	60.43	-	-	-	Theather interior	The sound absorption and mechanical properties were enhanced after CASP addition [96].
JF + Wool + Epoxy	-	40.00	-	99.00	-	Automobile interior	Hybrid composites have better mechanical properties than automotive thermoplastics [97].
Banana + SGB + Epoxy	-	73.48	-	77.50	-	Automobile, aircraft, building, sports, and household applications	The properties were enhanced after the addition of fibers [98].
BF + Phenolic	1.080	421.50	-	211.19	-	Drone wings, wind turbine blades	The bamboo fiber composites exhibit superior mechanical properties compared to aluminum, steel, and titanium alloy [99].
PALF + JF + Epoxy	1.074	32.16	1.32	-	-	Brake and accelerator pedals,	Hybrid composites show better mechanical properties compared to non-hybrid composites [100].

Note: PALF – pineapple leaf fiber; GF – glass fiber; RC – reinforced concrete; BF – bamboo fiber; UAV – unmanned aerial vehicle; JF – jute fiber; SG – snake grass; KF – Kenak fiber; CASP – custard apple seed powder; SGB – sugarcane bagasse.

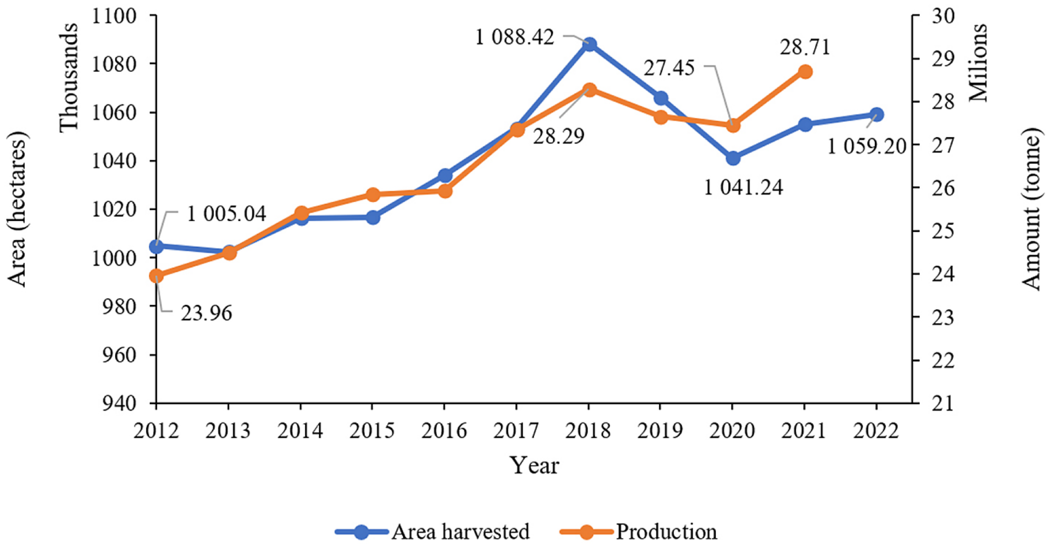

Figure 3. Pineapple produced and area harvested per annual from 2012 until 2022

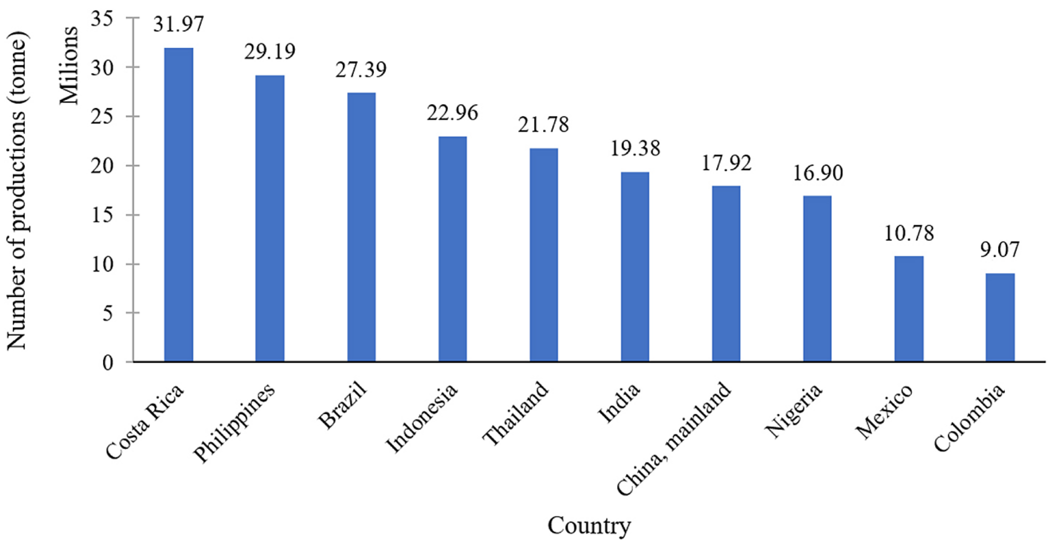

Figure 4. The top 10 pineapple producers

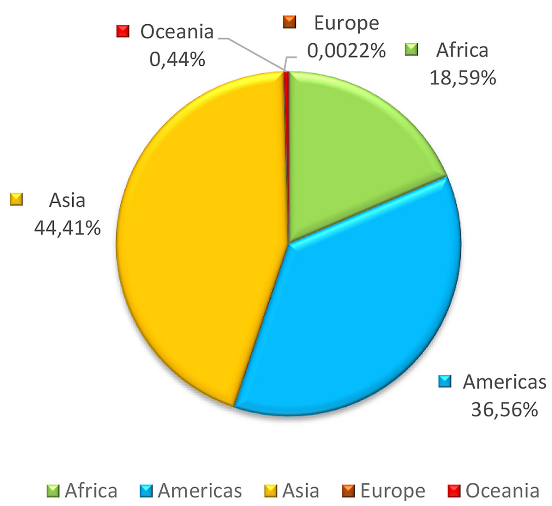

Figure 5. Pineapple production by region

widely used in composites. Pineapple leaf fiber is a natural textile fiber extracted from the leaves of the pineapple plant. It is a sustainable material that has been gaining attention in recent years for its potential applications in various industries, including fashion and textiles. The fiber is strong, flexible, and lightweight, making it a versatile material for various applications, including structural applications, due to its unique properties.

Pineapple leaf fiber can be used in structural applications in various ways, such as reinforcing material, building material, furniture, and textiles. In composites, pineapple leaf fiber can be used as a reinforcing material. When mixed with a resin matrix, the fiber can add strength and stiffness to

Figure 6. Accumulation of pineapple leaves at the plantation site

the composite material. The resulting material can be used in various structural applications, such as building materials, automotive components, aerospace airframes and constructions formed by bolted connections [97–100]. As a building material, pineapple leaf fiber can be used to create eco-friendly building materials, such as tiles, panels, and insulation. These materials can be used in construction and provide a sustainable alternative to traditional building materials. Pineapple leaf fiber can also be manufactured into chairs, tables, and lamps. The fiber can be woven into different patterns to create a unique look and strengthen the furniture. Finally, pineapple leaf fiber can be transformed into clothing, bags, and accessories in textiles. The fiber is lightweight, breathable, and has natural antibacterial properties, making it an attractive option for fashion designers.

Pineapple leaf fiber is a sustainable and environmentally friendly material that can be used in various structural applications. Its unique properties make it a versatile material that can be used in different ways to provide strength, durability, and style to various products. As the demand for sustainable materials increases, pineapple leaf fiber is likely to become an even more critical material for structural applications in the future.

Currently, studies have also been exploring the use of pineapple leaf fiber in UAV applications. One of the main advantages of using pineapple leaf fiber in the manufacturing of drones is its lightweight and high strength-to-weight ratio. This makes it an ideal material for constructing UAVs frames, which must be strong and lightweight to achieve optimal flight performance [101, 102] whether for small aircrafts or multirotors designed for heavy lifting [101, 102]. Additionally, pineapple leaf fiber has been shown to have good mechanical properties, such as high tensile strength, making it resistant to deformation and breakage. This is a crucial feature for multirotor copters frames, which must withstand flight stresses and potential crashes [103]. Another advantage of using pineapple leaf fiber is its biodegradability, which makes it an environmentally friendly option for many kinds of UAV construction. Pineapple leaf fiber can decompose naturally, unlike other synthetic materials commonly used in drones manufacturing, which can take hundreds of years to break down. Table 4 shows the mechanical properties of pineapple leaf fiber composites.

From Table 4, it can be seen that depending on the matrix, the mechanical properties of the composites will differ. By comparing composites of the same amount of composition (40%), epoxy yields better mechanical properties compared to polypropylene. Furthermore, with the addition of fiber treatment, the mechanical properties of the composites have been further enhanced. As for natural rubber and Polylactic acid with 25% fiber, it shows that the Polylactic acid composite has better tensile strength, whereas natural rubber composite has better elasticity. In addition, with a proper fiber treatment and compatible matrix, the mechanical properties of the pineapple leaf fiber composites could exceed a pure polymer that is frequently used for the manufacturing of UAVs, as shown in Table 4.

Currently, there is no specific experimental study which uses pineapple leaf fiber composites to manufacture a UAV airframe. However, the study conducted by Balakrishnan et al., investigated the fatigue and impact properties of hybrid composites reinforced with kenaf [110]. The research aimed to assess the suitability of these composites for structural applications. The findings indicated that the kenaf hybrid composites exhibit the potential for a long term, low to moderate load bearing structure with reduced product weight and cost. The kenaf fiber used in this investigation is also a type of

Table 4. Mechanical properties of pineapple leaf fiber composites

Fiber	Matrix	Fiber treatment	Composition of fiber (%)	Density (g/cm³)	Tensile strength (MPa)	Young's Modulus (GPa)
Pineapple leaf fiber	Polypropylene [104]	None	40	-	58	1.7
	Epoxy [105]	Alkaline (NaOH)	40	1.18	93.8	4.2
	Natural rubber [106]	None	25	1.09	11.1	0.3
	Polylactic acid [107]	None	25	-	96.8	-
	Polyester [108]	Silane	-	-	55	2.3
None	Polylactic acid [109]	None	0	1.27	56	3.4
	Acrylonitrile-Butadiene-Styrene [109]	None	0	1.05	26–31	2.18–2.23

natural fiber which has an almost similar properties with pineapple leaf fibers. The tensile strength of typical kenaf fibers is around 780 MPa [111], whereas pineapple leaf fiber is around 413 MPa up to 1627 MPa [112]. Therefore, using this comparison as a benchmark, it is possible to manufacture a UAV airframe with better mechanical strength that could bear moderate load with reduced airframe weight and production cost.

Using pineapple leaf fiber in drone manufacturing shows promise as a sustainable and lightweight alternative to traditional materials. This material has the potential to revolutionize the UAV industry and contribute to a more sustainable future.

CONCLUSIONS

The rapid growth of manufacturing technology has opened endless possibilities for using agricultural waste as another source of wealth. It can be said that there is no such thing as agricultural waste, but only things that science has still not found a way to utilize. Each of these materials has unique advantages that could help solve an existing problem. The review found that many agricultural wastes had been utilized in various production of ecological products. As manufacturing technology progresses, more waste can be converted into valuable products. The physical, mechanical, and chemical properties of extracted waste fibers show that these agricultural wastes can produce better advanced composite materials suitable for structural applications. This also holds true for pineapple leaf fiber composites. Fiber extraction, done through scrapping, made the extraction tedious for farmers. Thus, plantation owners prefer to discard the leaves instead of utilizing them. However, acquiring a large amount of pineapple leaf fibers at a shorter time has become much easier with the emerging extraction technology. As studies on the utilization of agricultural waste progress, more manufacturing and extracting technologies are being developed. Thus, this will create a sustainable economy that will benefit a country's development.

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