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Review Article

A Review of the Potential Applications of Composites from Agricultural Waste

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Abstract - *The disposal of agricultural waste is a challenge in our environment; it keeps increasing with the increase in population and production. The automotive industry has used agricultural waste, such as macadamia shells, to fabricate automobile door panels. The use of agricultural waste in the automotive industry lessens pollution and promotes sustainability in the environment. This paper reviews how effectively agricultural waste composites can be used in the automotive industry, eliminating waste in the landfill. Agricultural waste composites have a lot of potential in the automotive industry since they are recyclable and biodegradable, which makes disposing of them extremely convenient and eco-friendly. Furthermore, using agricultural waste bio-composites lowers the cost of production of automotive parts. There is still a need for further research into various agricultural waste, which has not been explored in the automotive industry and other applications.*

Keywords - *Automotive industry, Agricultural waste, Composites, Polymers, Bio-Composite.*

1. Introduction

Agricultural operations create a significant amount of waste, which frequently winds up in landfills, and according to predictions, it will rise to 9 billion by 2050 and 11 billion by 2100, respectively [1]. Effective waste management is essential in preserving a habitable ecology. Agricultural waste generation is a significant burden on the environment. The food and forestry industry activities result in large amounts of agricultural byproducts often treated as waste and sent to landfills. Technological advancements have increased agricultural output significantly. Furthermore, the rising population has necessitated increased agricultural production, which has expanded more than three times over the last 50 years [2].

All over the world, the agriculture sector generates approximately 23.7 million tons of food every day [3]. Billions of tons of agricultural waste are produced worldwide in a year [4, 5]. Current agricultural production systems have and are still undergoing significant modifications as a result of the more sustainable development models that have been driven in recent years [6]. They are different types of agricultural waste, as shown in Figure 1. However, this paper focuses on agricultural waste disposed of in landfills. Recycling agricultural waste has both positive economic and environmental advantages. Thus, the economic evaluation of bioenergy from agricultural waste has emerged as a crucial area of study [7-9].

Biopolymer-based composites are produced from agricultural waste biomass when biopolymers and biomass are combined. The term biopolymers describes a class of naturally occurring polymers produced by living things, such as proteins, polysaccharides, and nucleic acids. Agricultural waste is the term used to describe biomass produced from agricultural leftovers. This includes byproducts, including sawdust, animal manure, and leftover crop material, as shown in Figure 1 [10, 11].

Enhancing the recovery efficiency of agricultural waste is anticipated to be made easier by the updated recycling management procedures. Agricultural waste recycling has become a developing industry because of policy support and increased recycling awareness. Agricultural waste is being recycled by farmers more often than being burned or dumped in landfills [13].

In automotive industries, biopolymer-based composites manufactured from biomass derived from agricultural waste offer an environmentally responsible and sustainable alternative to conventional materials. Composites, made by combining biopolymers and agricultural waste biomass, can be used for several things, such as medical equipment, building materials, automotive parts, biofuels, packaging, and soil enhancement.These composites have improved properties over conventional materials and lower the environmental impact of agricultural waste on the environment [14].

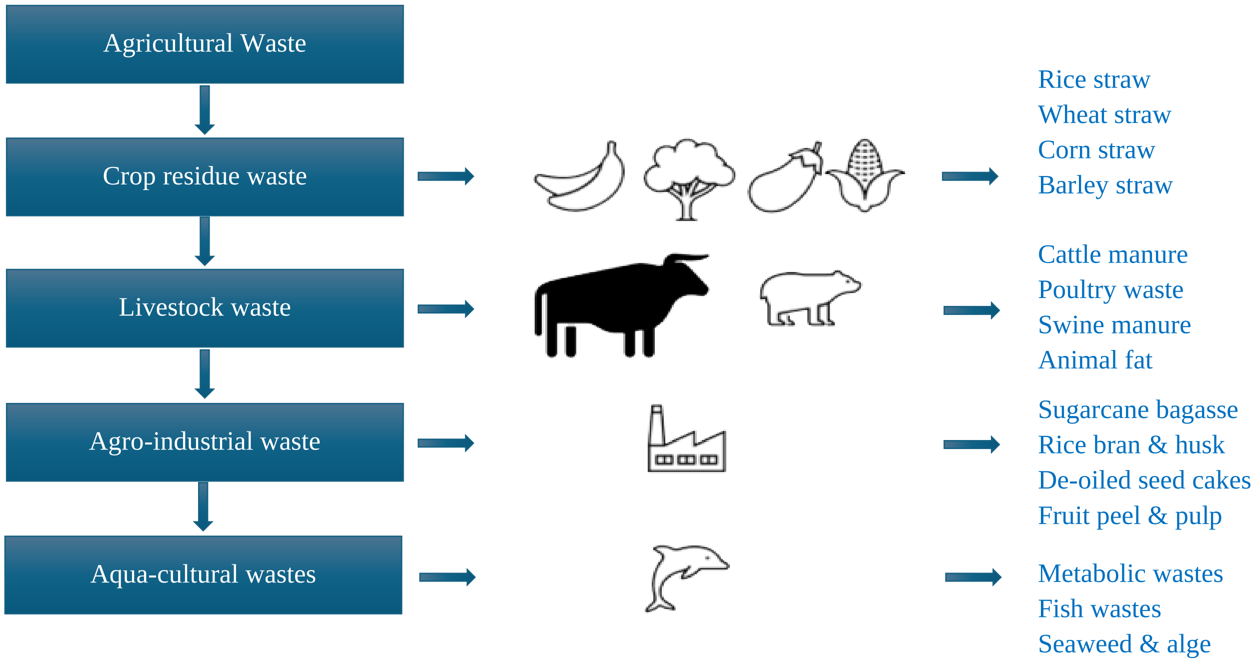

Fig. 1 Waste materials classification [12]

2. Macadamia Shells

Macadamia shells can be used for various creative product designs because they are recyclable and biodegradable [15]. The global macadamia production is around 120,000 tons in shell, equivalent to 36,000 tons in kernel form [16]. Australia's food industry generates 28,000 tons of byproduct empty macadamia shells, disposed of as waste in landfills [17]. The annual worldwide production of macadamia nuts continues to increase, and with it is the generation of waste shells, which account for 65% of the entire nut. In common with other agricultural waste, macadamia nutshells are burned as solid biomass fuel, used as garden mulch, animal bedding, cooking fuel, or thrown away entirely.

It is noteworthy that macadamia nutshells differ significantly from natural wood in terms of their density and structure, although having surprisingly comparable chemical makeup [18]. The nutshell of a macadamia is brittle and hard [19]. Because of the low density of the macadamia shell, it performs better than ordinary ceramics and glass when compared based on specific strength or modulus. It is known to have roughly the same fracture toughness as comparable materials [20]. Empty shells, or macadamia leftovers, are underutilized and typically thrown in the trash. Alternatively, they are burnt and used as garden mulch, animal filler, or chicken litter [21]. Sustainable recycling solutions are vital since the disposal of macadamia nut shells has caused major issues for the nut processing sectors. Making wood polymer composites using macadamia nut shells is one potential remedy. Due to the mechanical characteristics of macadamia shells, they can be used with thermoset resins to create wood-plastic composites (WPC) [23 - 28].

Fig. 2 Macadamia nuts [22]

The macadamia nut industry is still growing worldwide, with shells and other debris comprising around 70% of the fruit's weight [19]. Unfortunately, there is still a lot of untapped potential when using macadamia shells as byproducts [21]. Polymeric composites filled with macadamia nutshells have great promise for producing a range of structural elements, such as sandwich composites, which could be used in the infrastructure, aerospace, and automotive sectors. Additionally, macadamia shells can be treated at high temperatures in a specific low-oxygen environment to provide biochar. Biochar is used in cosmetics, industrial nanopowders, life-saving medical therapies, and carbon filters [29].

3. Coconut Shell

The hard, lignocellulosic agro-waste portion of the coconut that is not edible is called the shell. The coconut shell accounts for 15% to 20% of the coconut [30].

Table 1. Properties of coconut [39]

Aggregate impact value (%)	4.26
Los Angeles abrasion value (%)	14.88
Specific gravity	1.45
Water absorption	17.3

Fig. 3 Coconut shell [32]

Due to their superior thermal stability over other agricultural waste, coconut shells could make for highly intriguing filler materials in biodegradable polymer composites [31]. The coconut shell shown in Figure 3 can be crushed into particles, much like wood particles. The majority of the carbohydrates found in coconut shells include cellulose, hemicelluloses, and lignin [30]. Research on natural fibre reinforced polymer composites has been conducted extensively; however, there is very little study on polymer composites based on fillers made of coconut shell particles.Table 1 shows the physical properties of the coconut shells. The use of coconut shell particles as fine and coarse aggregates in concrete with replacement percentages ranging from 0% to 30%, or from 10% to 20% to 30%, is the subject of an experimental investigation on the M20 Concrete strength criteria. Compressive strength and tensile strength for 7, 28, and 56 days with and without coconut shell aggregates, and we've found that the concrete with a 20% coconut shell substitution shows good strength. It has been demonstrated that using coconut shells to partially replace coarse aggregate is feasible [33].

4. Rice Straw

The amount of rice produced worldwide between 2007 and 2017 increased to 756,7 million tons [34]. However, rice straws are generally not disposed of in an environmentally friendly way [35]. These rice straw wastes, which are mostly made up of cellulose, hemicellulose, and lignin, are typically not suitable for use as animal feed [36]. Rice straw's chemical composition is approximately 7.36% silica, 38.7% carbon, 2.37% potassium, 1.13% calcium, 0.53% magnesium, and water [37]. Due to the combustibility of rice straw, open-air burning is considered an accepted disposal method.

Fig. 4 Rice straw [32]

Disposal of rice straw through incineration causes harm to the environment [35]. There has been a lot of research into methods of recycling these byproducts into biomass [38]. Green composites are made of fibre and matrix made from renewable resources. These composite materials are referred to as partially eco-friendly if some of the constituents are not made of renewable materials [39, 40]. Rice straws, as shown in Figure 4, have many advantageous qualities, including low density and renewable nature, making them suitable for use in biocomposites [41]. Rice straw has been used in different applications, such as furniture, interior decoration and the construction of walls and ceilings [42]. Rice Straw Particles and Furcraea foetida Fibre Reinforced Hybrid Composite. In this work, a hybrid composite reinforced with Rice Straw Particle (RSp) and Furcraea Foetida (FF) fiber was created, and its mechanical and physical characteristics were examined. The test samples' density was lowered by 41.87% upon adding 15% weight percent of RSp, and their water absorption (WA) rose as fiber concentration rose. The composite with 5 weight percent and 15 weight percent RSp demonstrated maximum modulus (σtm: 3.67 GPa) and tensile strength (σt: 29.45 MPa), respectively. The maximum flexural strength (σf: 43.12 MPa) and modulus (σfm: 2.09 GPa) were reached at 15% of RSp, whereas the highest impact strength (σi: 101.01 J/m) was seen at 10% of RSp. The RSp reinforced composite's σt (40.21%) and σf (7.76%) were enhanced by the hybridization of FF (20wt.%) fibre reinforcement.

5. Wheat Straw

Since 2007, wheat straw production has been approximately 540 million tons annually worldwide [43]. The majority of these farming wastes are left on the ground to decompose after harvest or burnt in open fields and, cause air pollution [44, 45]. However, some small amounts of wheat straw have been utilized as bedding and nutrition for animals [46]. Another popular use of wheat straw waste is directly chopping and grinding into particles, subsequently used to create composites [47]. Wheat straws can be used to make lightweight composites.

Table 2. Properties of wheat straw [50]

Properties	Untreated	Treated
Bulk density $\rho_{bulk,}$ dried (kg m^{-3})	100	100
Porosity (%)	0.90	0.90
Specific heat capacity C_P(J kg^{-1}K^{-1})	1735	1745
Thermal conductivity λ(W m^{-1}K^{-1})	0.061	0.059
Vapour diffusion resistance factor μ (dimensionless)	5	5
Moisture content at RH=80%	0.14	0.15

Composites with densities less than the total density contributions from all materials used to construct them are considered lightweight [48, 49]. The properties of wheat straw are shown in Table 2. The properties of wheat straw give the possibility of their use in interior panel composites in the automotive industry. Chopped wheat straw reinforcement and epoxy resin matrix, or hybrid resins varied up to 50% and 70% Dammar volume fractions, were used to produce composites. The maximum flexural strength of 35.6 MPa, compression strength of 28.8MPa and tensile strength of 14.58 MPa were obtained from fabricated composites [51].

6. Corn Straw

The most common food crop farmed worldwide is corn [52]. With the United States and China controlling half of the worldwide market, it has expanded throughout numerous nations [53]. Consequently, there is also a lot of corn straw (CS) waste. The corn straw is mostly composed of cellulose, hemicellulose, and lignin. Corn straw is a plentiful and renewable biomass resource that is frequently utilized for water purification, feed and green composites [54-56]. However, corn straw recycling is important for protecting the environment and conserving resources [57]. Corn straw is an industrial raw material source with a wide range of possible uses, such as filler material [58]. The utilization of agricultural residues can successfully lower costs in the artificial panel manufacturing business, promote sustainability, and minimize air pollution generated by the combustion of corn residues [59].

The chemical composition of corn straw is shown in Table 3. Wheat straw development of transparent composites using wheat straw fibres for light-transmitting building applications was fabricated through the effective impregnation of pre-polymerized methyl methacrylate (MMA) into wheat straw (TCWS), transparent composites were accomplished [60]. The bio-based composites had excellent mechanical and light transmittance qualities because the microscopic morphology examination revealed that WSF had a strong binding performance with polymethyl methacrylate (PMMA). Tensile strength of 58.19 MPa, impact strength of 4.26 kJ/m2, haze of 54.63%, light transmittance of 74.63%, and thickness of 3 mm were observed in the TCWS with 30 weight percent WSF. According to TCWS's thermal property test, the material has outstanding thermal insulation ability, with a heat conductivity of 0.07 Wm−1k.

Table 3. Composition of corn before and after pretreatment (mass fraction) [64]

	Cellulose	Hemicellulose	Lignin
Untreated	37.6	25.8	17.4
With CH_3COOH	42.5	24.6	16.9
with NaOH	45.9	24.2	15.6

Additionally, TCWS demonstrated superior UV resistance and thermal dimensional stability. In light of this, TCWS may find use in the transparent building industry. Consequently, there may be opportunities for TCWS to be applied in the field of transparent structures. Compared to wood fiber transparent composites, the novelties of this study are in turning low-cost agricultural leftovers into high-value transparent composites with increased thermal insulation qualities for light-transmitting construction applications [60].

7. Barley Straw

Barley is a globally significant grain crop, farmed in over 44 million hectares with a yield of 141 million tons of grain [2]. Barley straw serves as a significant source of lignocellulose, which can be utilized as a reinforcement for polymeric matrices or as a raw material in various industrial processes [61, 62]. However, barley straw has the challenge of excessive moisture absorption. Nevertheless, lightweight bio-aggregates (lignocellulosic materials) like barley straws have been the subject of several studies that have attempted to improve the properties of lightweight bio-composites or eco-materials by lowering the rate at which the bio-aggregates absorb water. Physically treating barley straws, for instance [63]. Barley straw and a biobased polyethylene (BioPE) polymer matrix were used to create biobased composites. BioPE is 100% recyclable and entirely biobased. Regarding material performance, research was done on the materials' flexural characteristics. Achieving a proper distribution of reinforcement within the plastic led to elevated increases in flexural strength. An increase in flexural strength of almost 147% was obtained at 45 weight percent of reinforcement. A barley straw fibre flexural strength factor was used to determine the mean contribution of the fibres to the flexural strength, and the result was 91.4. With coupling factors ranging from 0.18 to 0.19, the intrinsic flexural strength of the barley straw fibres could be predicted using the micromechanical analysis, reaching up to about 700 MPa [64].

Table 4. Properties of barley straw [50]

Properties	Value
Bulk density $\rho_{bulk,}$ dried (kg m^{-3})	100
Porosity (%)	0.89
Specific heat capacity C_P(J kg^{-1}K^{-1})	1645
Thermal conductivity λ(W m^{-1}K^{-1})	0.052
Vapour diffusion resistance factor μ (dimensionless)	5
Moisture content at RH=80%	0.13

8. Benefits of Agricultural Waste Materials

Synthetic composites, often made of non-renewable materials and not biodegradable, have an adverse effect on the environment when disposed of [65, 66]. The application of biomass from agricultural waste as a biopolymer-based composite shows a wide range of potential applications not only in automotive but across several industries[67-70]. Natural fillers have several advantages over conventional ones, including being less expensive, having high toughness, low density, strong specific strength qualities, and reducing tool wear [71]. Cars utilizing natural fibre composites are lighter, hence lowering their fuel consumption [72]. Natural fibre composites have advantages in the automotive industry, giving better thermal and acoustic qualities [73, 74].

9. Application of Agricultural Waste in the Automotive Industry

The automotive manufacturing industry is responsible for 60–70% of the global air pollution causes [75, 76]. Vehicles release a great deal of harmful gasses, including lead and fine particulates, hydrocarbons (HC), nitrogen oxides (NOX), and carbon monoxide (CO) [77-79]. According to projections, the current rate of car production worldwide will triple by the end of 2050 (ReF). The transportation sector will have a greater impact on climate change as a result of the increase in Carbon Dioxide (CO_2) and other hazardous equivalent gas emissions [75]. The environment is under pressure as a result of this increase in worldwide production, to the point where soil, air, and water resources are being compromised [80]. Ford used coconut shells and rubber from waste tyres to fabricate battery housing, structural guards, lightweight armrests, applique brackets and door cladding [81, 72]. Biocomposites made of renewable resources, including agricultural waste, have a lot of promise to help automobiles and developers as the environment and petroleum supplies are depleted quickly. Due to their unique qualities, biocomposites can be used to produce dashboards, headliners, seat backs, and wood trim [75, 72]. seat fillers, and other non-structural interior components.

They can also be used for thermoacoustic insulation. Audi now employs polyurethane and loose/sisal natural fibers for door trim panels, while certain of its car models use biocomposites based on cellulose for boot lid finish panels, door panels, and seatbacks [84]. Ford also uses agricultural waste to produce parts, such as cabin storage bins composed of polypropylene and wheat straw, which increase farmer revenue and decrease pollution [85].

Fig. 5 Lightweight bio-composites applications[82],[83]

10. Conclusion

Agricultural waste has a lot of potential end uses, and this trend will only grow as more ecologically conscious and sustainable transportation methods are adopted. The automotive sector reduces and simplifies the disposal of agricultural waste, thereby removing potential risks from landfills. Unlike most synthetic fillers, agricultural waste is biodegradable, recyclable, and inexpensive. Sustainable biopolymer-based composites for lightweight applications made from biomass from agricultural waste are a promising field that holds great promise for solving some of the most important environmental and financial issues of our day. These composites not only offer improved mechanical qualities and biodegradability, but they also have the potential to replace conventional materials in various applications, such as home, automotive, maritime, and packaging. Utilizing agricultural waste has the potential to generate employment opportunities and reduce the cost of components in the automotive industry.

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