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A comprehensive review on utilization of agricultural waste for reinforced structural products: A sustainable perspective

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A comprehensive review is focused on the sustainable utilization of agro waste for reinforced structural products. In the current scenario, farmers' widespread practice of burning agricultural waste has emerged as a major contributor to air pollution, highlighting the urgent need for sustainable waste management solutions. This review underscores the urgency of shifting towards sustainable practices by repurposing agro waste for reinforced structural products, providing an eco-friendly alternative to the environmentally detrimental practice of burning agricultural residues. The ever-growing need for sustainable practices has driven research towards repurposing agricultural waste to create robust structural materials. This review explores diverse agro-waste sources, ranging from crop residues to by-products, field residue, process residue, and industrial residue, and examines their potential as reinforcements in structural products. The review critically evaluates various processing methods, highlighting their impact on the mechanical and structural properties of the resulting products. Additionally, the environmental implications, economic viability, and potential challenges associated with the utilization of agro waste in structural applications are discussed. By consolidating existing knowledge and recent advancements, this review aims to guide future research endeavors and policy decisions in fostering sustainable practices within the construction and manufacturing industries. This review provides insights to support the selection of agro waste for sustainable development, offering alternatives to practices that contribute to pollution.

Keywords: sustainable utilization, structural products, waste repurposing, agro-based materials, environmental impacts

INTRODUCTION

Agriculture has been the backbone of human civilization. It nourishes us with food and provides us with clothing, and essential materials. It nurtures billions from wheat fields to large fruit farms, maintaining a delicate balance. While ensuring food security is the utmost priority, the process generates a significant amount of agricultural waste. The utilization of grape stalks as forage or as a component in feed has been used for the animals. Agricultural waste comes in many forms such as leftover crop residues like corn stalks and fruit peels, animal manure from livestock, and even packaging used for transportation of food. It might seem very small, but the real amount tells a whole different story. Additionally, overflowing landfills struggle to house the ever-growing mountains of waste, creating environmental and social pressures. The impact is a long way, affecting not only the immediate surroundings but also human fitness and standard sustainability. India, being an agro-based country, produces a large amount of agricultural waste; only 25–30% of the 620 million tons of agricultural waste produced each year are used for energy production and animal feed. Utilizing agricultural waste like paddy straw in composite materials exemplifies the circular economy by converting waste into valuable resources. This approach reduces reliance on raw materials, minimizes waste disposal, and mitigates environmental impacts from residue burning. It provides a sustainable input for production while supporting waste valorization, enhancing resource efficiency, and reducing lifecycle waste. The study highlights how such innovations foster sustainable manufacturing and create value chains aligned with circular economy goals.

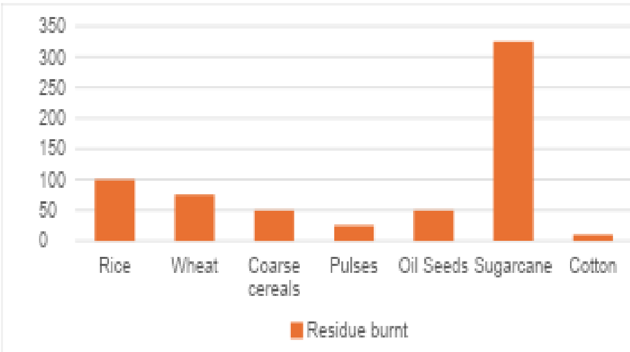

Fig. 1. Annual crop residue burnt in India in million metric tons (2003-2016)

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While affecting the environment, it is also a huge waste of potential resources which can be utilized as a raw material for various products such as hempcrete, bamboo fibers, rice husk composites, etc. To address this challenge, innovative solutions like composting can rework waste into nutrient-rich soil amendments, boosting crop yields and reducing reliance on chemical fertilizers. One of the best ways to address this issue can be the utilization of these residues and byproducts in developing different products such as reinforced composites which will also solve the waste management from composite manufacturing industries and lead to sustainability. The use of agricultural waste in structural products faces challenges, including material variability from crop differences, energy-intensive processing, and adhesion issues with matrix materials, which can impact mechanical performance. Durability concerns, such as water absorption and microbial degradation, also require costly treatments for enhanced stability. To address these challenges, advanced processing techniques, surface treatments, and efficient supply chain management are suggested to improve the viability of agricultural waste in structural applications.

Categories of agricultural wastes

There are different categories of agricultural wastes that are produced at every stage of the crop before it reaches the market and is ready to consume. Table 1 shows the types of agricultural wastes produced by different crops.

Agricultural wastes are produced at different stages in crop production. During harvest, leftover plant materials like rice straw, rice husks, and wheat straw fall to the ground and accumulate in the field, forming what's known as field residue [1]. Rice straw proves to be a valuable material for producing insulation boards. These rice straw-wood particle composite boards are manufactured using established methods from the wood-based panel industry [2]. Mohapatra *et al.* found that teak wood dust particles showed a remarkable influence in minimizing the thermal conductivity and linear thermal expansion and are a great eco-friendly composite choice that can be utilized for different thermal applications [3]. Even common onion peels can be a source of wood glue, as demonstrated in the study of Odozi *et al.* [4, 5]. This research shows that a specially treated extract from onion skins can meet the demanding quality standards set by the International Organization for Standardization (ISO) for plywood adhesives [6]. Table 2 presents the types of crop waste and their various applications. Based on the various properties of the crops, their waste can have different potential uses such as production of biofuel, organic fertilizers, animal feed, and industrial products. Based on potential use, agricultural waste can be classified into the following categories.

Agricultural waste used for composites

Composites are formed by combining two or more materials that have quite different chemical and physical properties and they work together to give unique properties. Still, we can easily differentiate the composite materials. In the new material, the components do not form a solution or mixture but remain separate and distinct in the structure [7]. Some examples are shown in Table 3.

Due to high cellulose and low lignin content the tensile strength of the most used natural fiber composites are higher in Natural Fiber Composites (NFCs) as the higher the crystalline parts of cellulose, the stronger is the fiber strength [8]. As also seen in the study of Srivastava *et al.* the addition of bamboo fibers increased the hardness and tensile strength of the composites [9]. In the case of flax and hemp, as observed in the tests done by Kumaar *et al.,* hemp composites showed great flexural strength, boasting an impressive average value of 88.26 N/mm^2. This indicates that hemp fibers play a major role in enhancing a composite's ability to withstand bending forces. On the other hand, flax composites excelled in impact strength, averaging a value of 4 J. This suggests that flax fibers contribute significantly to composite's resistance to sudden impacts [10].

Agricultural waste used in civil structures.

Growth in the human population led to a substantial increase in wastes generated by households, industries, and agriculture, and also the demand has increased in construction building materials. Building materials that are present now are mostly not manufactured by natural resources, the majority of them are manufactured by non-renewable resources. To meet the constant demand for building materials there should be an alternative to non-renewable building materials. Utilization of agricultural waste is the better substitute for manufacturing renewable building materials. Some of the most used building materials that are made from agriculture waste are shown in Table 4.

 Table 1. Types of waste produced by different crops.

		Agricultural residue		Industrial residue
		Field residue	Process residue	
Crop type	Crop			
Cereals	Rice	Straw, Stubbles	Bran	Husk
	Wheat	Straw, Stubbles	Bran	Chaff
	Maize	Stover	Bran	Corn ribs
	Millets	Stover	Bran	Broken grains
	Barley	Straw	Malt	Chaff
Pulses	Chickpea	Stalks	Hull powder	Pods
	Pigeon pea	Stover	Pea husks	Pods
	Mung bean	Stover	Hulls	Pods
	Urad bean	Stover	Hulls	Pods
	Lentil	Stover	Lentil shells	Pods
Oilseeds	Mustard	Stalks, Stubbles	Oil cakes	Husk
	Groundnut	Stalk	Skins, dust	Shells
	Sesame	Straw	Oil cakes	Hulls
	Castor	Stover	Oil cakes	Shells
	Sunflower	Stubble, Stalks	Oil cakes	Hulls
	Soyabean	Stems, Leaves	Oil cakes	Pods
Fruits & Vegetables	Mango	Leaves, Twigs	Peel, stone, pulp waste	Pedicel
	Banana	Pseudo stem	Peel	Peduncle
	Tomato	Leaves	Peel	Pedicel
	Potato	Haulms	Peel	Root hairs
	Onion	leaves	Outer skin	Root hairs
	Orange	Leave, Twigs	Peel, inner skin	Pedicel
	Pineapple	Leaves	Outer skin, hardy core	Head
Fiber crops	Cotton	Stover	Seed hulls	Ginning waste
	Jute	Leaves	Jute dust	Shells
	Kenaf	Leaves	Hurd, Woody core	Fiber dusts
Spices	Chilli	Stems, leaves	Seeds	Stalks
	Ginger	Leaves	Peel	Trimmings
	Turmeric	Leaves	Peel	Roots
Sugar & Beverages	Sugarcane	Stubble	Bagasse	Leaves
	Tea	Spent leaves	Rolling	Dusts
	Coffee	Pulp, Peel	Parchment coffee	Silverskin
Leafy vegetables	Spinach	Stems	Processing water	_
	Fenugreek	Leaves	_	Pods
Roots & Tubers	Sweet potato	Vines, leaves	Peels	Trimmings
	Tapioca	Leaves	Peels	Trimmings
	Carrot	Leaves	Tops	Trimmings
Trees	Neem	Twigs, leaves	Oil cakes	Oil cakes
	Mango	Leaves, Twigs	Peels, Stones	Pedicel
	Teak	Leaves	Bark	Saw dust
	Sal	Dead leaves	Bark	Saw dust
	Bamboo	Leaves, Culms	Peelings (edible shoots)	Saw dust, Fiber dust

 Table 2. Types of crop waste and their applications

Crop Type: Cereals						
Crops	Rice	Wheat	Maize		Millets	Barley
Field Residue	Straw, Stubbles	Straw, Stubbles	Stover		Stover	Straw
Application	Rice straw-board particle board,	Wheat straw as polymer composite reinforcement	Fodder		Fodder	Algae control
Process residue	Bran	Bran	Bran		Bran	Malt
Application	Livestock feed, boiler fuel	Human consumption	Human consumption		Bioethanol production	Natural sweetener
Industrial residue	Husk	Chaff	Corn ribs		Broken grains	Chaff
Application	Low-cost cellular concrete	Soil preparation, boiler fuel	Human consumption		Human consumption	Mulching, composting, animal bedding
Crop Type: Pulses						
Crops	Chickpea	Pigeon pea	Mung bean		Urad bean	Lentil
Field Residue	Stalks	Stover	Stover		Stover	Stover
Application	Animal feed, soil preparation	Animal feed, biomass, green manure	Mulching, Animal feed, composting		Mulching, animal feed, composting	Biofuel, composting
Process residue	Hull powders	Pea husks	Hulls		Hulls	Lentil shells
Application	Oil absorbent	Biofuel, water treatment	Reinforced materials, animal feed, biofuel		Reinforced materials, animal feed, biofuel	Reinforced materials, animal feed, biofuel
Industrial residue	Pods	Pods	Pods		Pods	Husk
Application	Composting, animal feed	Mulching, composting, animal feed	Composting, mulching		Composting, mulching	Composting, biofuel, building materials and packaging materials
Crop Type: Oilseeds						
Crops	Mustard	Groundnut	Sesame	Castor	Sunflower	Soyabean
Field Residue	Stalks, Stubbles	Stalk	Straw	Stover	Stubble, Stalks	Stems, Leaves
Application	Mulch, fumigants	Mulching, composting	Thatching mulching	Paper production biofuel,	Paper production, composites, biofuel, mulching and composting	Animal feed, composites, biofuel, mulching and composting
Process residue	Oil cakes	Skins, dust	Oil cakes	Oil cakes	Oil cakes	Oil cakes

Application	Fillers in reinforced composites	Preservatives, food coloring	Fertilizers animal feed	Biofuel, bioplastic	Fertilizer, composting, mushroom cultivation		Fertilizer, composting
Industrial residue	Husk	Shells	Hulls	Shells	Hulls		Pods
Application	Reinforced composites, rubber production	Nanosheets	Lightweight concrete, biofuel, animal feed	Biomass, reinforced composites	Mulching, fiberboard, biofuel		Composting, animal feed, reinforced composites
Crop Type: Fruits and vegetables							
Crops	Mango	Banana	Tomato	Potato	Onion	Orange	Pineapple
Field Residue	Leaves, Twigs	Pseudo stem	Leaves	Haulms	Leaves	Leave, Twigs	Leaves
Application	Medicine	Natural fibers, composting, paper production	Natural pesticides	Composting, animal feed, biofuel	Natural dye, pest control	Air freshener	Natural fibers, biofuel
Process residue	Peel, stone, pulp waste	Peel	Peel	Peel	Outer skin, hardy core	Peel, inner skin	Outer skin, hardy core
Application	Biofuel, cosmetics	Fertilizer, cosmetics	Food coloring	Composting	Natural dye, com-posting	Bio-plastic	–
Industrial residue	Pedicel	Peduncle	Pedicel	Root hairs	Root hairs	Pedicel	Head
Application	_	Composting	Com-posting	–	–	–	–
Crop Type: Fiber crops							
Crops	Cotton		Jute		Kenaf		
Field Residue	Stover		Leaves		Leaves		
Application	Biofuel, composting, animal feed, compressed fiber panel		medicine		Animal feed, composting, biofuel		
Process residue	Seed hulls		Jute dust		Shells		
Application	Composting, animal feed, packaging materials		Biofuel, biochar		Composite materials, packaging materials		
Industrial residue	Ginning waste		Jute caddies		Fiber dusts		
Application	Boiler fuel		Particle board, biogas		Composite fillers, soil preparation		
Crop Type: Spices							
Crops	Chilli		Ginger		Turmeric		
Field Residue	Stems. Leaves		Leaves		Leaves		
Application	Compost, pest repellent		Fragrance, pest repellent		Medicine, natural dye		
Process residue	Seeds		Peel		Peel		
Application	Pest repellent		Pest repellent		Natural dye, composting		
Industrial residue	Stalks		Trimmings		Roots		
Application	Composting		Composting		Composting		
Crop Type: Sugar and beverages							
Crops	Sugarcane		Tea		Coffee		
Field Residue	Stubble		Spent leaves		Pulp, Peel		
Application	Composting, biofuel		Fertilizers, fragrance		Biogas, cosmetics		

Process residue	Stubble		Spent leaves	Pulp, peel	
Application	Composting, biofuel		Fertilizers, fragrance	Biogas, cosmetics	
Industrial residue	Leaves		Dusts	Silver skin	
Application	Mulching, biofuel, animal feed, animal bedding		Cosmetics, dye	Cosmetics, compost, biofuel	
Crop Type: Leafy vegetables					
Crops	Spinach		Fenugreek		
Field Residue	Stems		Leaves		
Application	Composting		Cosmetics		
Process residue	Stems		Processing water		
Application	Composting		_		
Industrial residue	_		Pods		
Application	_		Biofuel, composting		
Crop Type: Roots & Tubers					
Crops	Sweet potato		Tapioca	Carrot	
Field Residue	Vines, Leaves		Leaves	Leaves	
Application	Composting		Animal feed, medicines	Flavouring	
Process residue	Peels		Peels	Tops	
Application	Food colouring, composting		Animal feed, biofuel, composting	Animal feed, garnish	
Industrial residue	Trimmings		Trimmings	Trimmings	
Application	_		_	_	
Crop Type: Trees					
Crops	Neem	Mango	Teak	Sal	Bamboo
Field Residue	Twigs, leaves	Leaves, Twigs	Leaves	Dead leaves	Leaves, Culms
Application	Medicine, cosmetics, pest repellents	Medicines, Cosmetics	Natural dye, Composting, medicines, animal feed	Plates, packaging, composting, medicines	Composites, plates, composting
Process residue	Oil cakes	Peels, stones	Bark	Bark	Peelings (edible shoots)
Application	Pest repellents, soil preparation fertilizer	Cosmetics	Medicine, natural dyes, animal feeding	Composites, dyes and colouring, medicines	Composting, biofuel, animal feed
Industrial residue	Oil cakes	Pedicel	Saw dust	Saw dust	Saw dust, fiber dust
Application	Fertilizer, pest repellent, soil preparation	_	Composites	Composites	Composites

Table 3. Natural composites with their chemical content, properties, and uses.

Natural composite	Chemical contents	Properties	Uses
Cotton	Cellulose 88-96% Protein-1.9% Pectin 1.2% Ash-1.2% [11, 12]	Cotton is absorbent, breathable, durable and drapes well.	Used in making clothing, hospitals and medical services as absorbent and saloons.
Bamboo	Cellulose 74% Hemicellulose 13% Lignin 10% [13]	Fire resistance, less shrinkage, anisotropic properties, elastic modulus and tensile strength.	Home furnishing, hygienic clothing, medical and bathroom textiles.
Sisal	Waxes 2% Hemicellulose 10% Lignin 12% Cellulose-70% [14]	High flexibility, high friction resisting and acid-resisting	Door mats, constructing materials, yarn and twine.
Hemp	Hemicellulose-8-18% Cellulose-67-75% Lignin-2-5% [15]	High tensile strength, fiber is finer and biodegradable	Tapestry, rugs, shawls, posters and towels.
Kenaf	Pectin-3-5% Hemicellulose-21.5% Cellulose-45-57% Lignin-8-13% [16]	Lightweight, little elasticity, very fine and strong yarn, low breaking strength.	Animal bedding, packing materials, cloth and paper.
Flax	Wax-1.7% Lignin-2.2% Pectin-2.2% Hemicellulose-18-20.6% Cellulose-71-17% [17]	Less flexible, Fiber is soft lustrous and stronger than cotton.	Building materials, automotive applications, paper and textiles.
Ramie	Wax-0.3% Pectin-1.9% Hemicellulose-16.7% Cellulose-76.2% Lignin-0.7% [16]	Stain-repellent property, high affinity for dyeing and highly absorbent.	Fishing nets, sewing threads, clothing, home furnishing and packing accessories.
Silk	Fibroin-70-80% Sericin-20-30% wax-1-2% [18]	Excellent resilience, good elasticity and higher tensile strength than glass fiber.	Clothing, industries, furniture, medicine and biomaterials.
Jute	Cellulose-71 Hemicellulose-20.4% Lignin-13% Pectin-0.2% Protein-2.5% [16]	High tensile strength with low extensibility, antistatic property, high tenacity and low thermal conductivity.	Aggrotech, Protech, geotextiles, carpets and decorative colour boards.
Coconut	Cellulose-21-43% Lignin-15-45% Hemicellulose 20% [19]	High flexural rigidity, highly variable fiber length and low tenacity.	Coir disk, blocks,Coir net.
Sugarcane	Cellulose-36% Hemicellulose-24% Lignin-21% [20]	More fineness, high tensile strength and low glycaemic level.	Bagasse ash as a binder in concrete gave an improvement in thermal stability.
Banana	Cellulose-55-65% Hemicellulose-19% Pectin-10-15% Lignin-3-5% [17]	Tenacity, fineness, moisture regain, elongation and tensile strength.	Ropes, carpets, clothing garments, home furnishings and traditional costumes.
Nacre	Aragonite-95% Protein-2.5% Polysaccharides-2.5% [21]	Lightweight, high strength and toughness.	For architectural purposes, ceramic tile and marble base.

Table 4. Agro waste and its application in civil structures.

Agro waste	Properties	Further application in civil structures
Hemp	Low density and low resistance to microorganisms, high strength and stiffness [22].	Lime/concrete/panel/loose fill, building blocks
Paddy straw	High crack resistance, increases intensity, Enhanced toughness, good thermal insulation [23].	Brick/plaster/concrete
Olive	Enhances both strength and durability, reduces the effective water-cement ratio [24].	Panel/lime/concrete
Bamboo	Increases compressive strength and ductility of concrete [25].	Concrete beams

Groundnut shells	Shows average strength [26].	Concrete panels cast
Rice husk	Good in thermal insulation [27].	Mud mix, blocks, wall cover, particle board and cardboard
Honeycomb wax	Long-lasting, prevents moisture [28].	Polishing on wood, Encaustic painting
Coconut shell	Abrasion-resistant properties, high toughness, and good durability [29].	Manuscripts, aggregate in mud flooring
Bagasse	High compressive strength, low thermal conductivity [30].	Bagasse ash can be used as a cement in concrete production
Banana leaf ash	Reduces water absorption, consistency and increases setting time of cement [31, 32].	As a cement mortar
Coconut coir	Low thermal conductivity, can be stretched beyond its elastic limits[33].	Low-cost concrete structures especially in earthquake regions.
Oaktree cork	Lightweight and high insulation [34, 35].	Cork board, Walls, and floors mating(37).
Coffee husk	Shows an increase in compressive strength and water absorption [36].	Hand-made bricks and mortar
Mycelium	Lightweight and high in thermal insulation [37][38].	Only bricks

Table 5. Mechanical charecteristics of banana fiber, hemp fibe and jute fiber.

Mechanical properties	Jute fiber	Bamboo fiber	Hemp fiber
Compressive strength	20.9MPa	15.8MPa-24.2MPa	19.5MPa-26.4MPa
Impact strength	94.46KJ	63.54KJ	10.94KJ
Youngs modulus	13-26.5Gpa	27-40Gpa	17-70Gpa
Tensile strength	300-700MPa	600MPa	270-900MPa
Density	1.3-1.49G/cm3	1.2-1.5G/cm3	1.47G/cm3
Flexural strength	32.36MPa	200-300MPa	156.78MPa

Study of mechanical properties of jute, bamboo, and hemp natural fibers.

Sustainable development and global warming have escalated the need to produce natural materials that reduce carbon emissions. Plant fibers have emerged as novel materials that is readily available, biodegradable, feasible, and have high specific strength. Although these materials lack a few properties like they are not suitable for some polymer matrices, the fibers might accumulate together during processing and these materials absorb moisture readily which reduces their mechanical strength. Natural fibers have turned into a demandable product in recent days. Composites based on natural fibers are becoming a major requirement for civil structures, wrapping, home decor, and furnishings. They show satisfactory mechanical properties, and they are biodegradable and renewable. Based on the weight of the fibers mechanical properties are influenced. Lesser mechanical properties are shown when more than enough fibers are added to a composite and there will be no compatible bonding between matrix and fiber also it shows less values of impact and flexural strength. The cell wall composition of natural fibers can also impact the mechanical properties of the natural fibers. Table 5 shows the mechanical characteristics of hemp fiber, jute fiber and bamboo fiber.

Uses of crop byproducts

Balaji *et al.* explored the impact of varying ratios of sisal fibers to coconut sheath fibers on the mechanical properties of crop residues. They found that increasing the proportion of sisal fiber led to enhanced tensile strength, flexural strength, and impact strength. However, the most favorable results were observed at a 40% sisal fiber content. At this ratio, with 40% short sisal fibers and the remaining 60% consisting of naturally woven coconut sheath fibers, the composite material exhibited optimal performance. This combination resulted in a tensile strength of 68.5 MPa, a flexural strength of 128.8 MPa, and an impact strength of 18.95 kJ/m² [39]. Table 6 shows the chemical compositions of several crop residues and their properties.

Table 6. Chemical properties of different crops.

Crop	Chemical contents	Properties
Rice [40, 41]	38% cellulose, 25% hemicellulose, and 12% lignin, 6.1% silica	• Good insulating properties. • Rich source of cellulose which helps in reinforcement of biopolymer composite materials.
Wheat [42]	33.5–40% cellulose, 21–26% hemicellulose, and 11-23% lignin 3.6% silica and silicates, 3.6% crude protein	• Good insulating properties. • Rich source of cellulose which helps in reinforcement of biopolymer composite materials.
Jute [43]	64.4% cellulose, 12% hemicellulose, 0.2% pectin, 11.8% lignin	• Rich source of lignin which provides good tensile strength.
Coconut [44]	27.7% pentose, 26.6% cellulose, 29.4% lignin	• Pentose-derived hemicellulose can be used as fillers and extenders in composites. • Rich source of lignin which provides good tensile strength.
Orange peel [45]	23% sugar, 22% cellulose, 25% pectin and 11% hemicellulose	• Cellulose and hemicellulose contents provides good reinforcement properties.
Sugarcane bagasse [46]	50% cellulose, 25% hemicellulose and 25% lignin	• Rich source of lignin which provides good tensile strength.
Mustard oil cakes [47]	35.65% crude protein, 10.28% crude fiber, 0.69% ether extract, 7.61% total ash and 1% acid insoluble ash	• Mustard oil cake powders increases the tensile strength of the composites if use as fillers.
Banana fiber [48]	71.08% cellulose, 12.61% hemicellulose and 7.67% lignin	• Great reinforcement properties due to presence of cellulose and hemicellulose.
Bamboo fiber [10]	74% cellulose, 13% hemicellulose and 10% lignin	• Great reinforcement properties due to presence of cellulose and hemicellulose.

Structural products made by using agricultural waste

Carbon nanotubes (CNTs), reinforced polymer composites. Carbon nanotubes (CNTs) are structures composed of cylindrical molecules, shaped by hexagonally arranged hybridized carbon atoms. Microscopic graphene sheets fold into these tiny cylinders, occasionally capped with spherical fullerenes, giving rise to carbon nanotubes. The distinct electrical characteristic of carbon nanotubes (CNTs) arises from the presence of delocalized electrons along the z-axis. Kushwaha *et al.* conducted a study comparing a hybrid composite reinforced with bamboo/CNTs to an epoxy composite of bamboo treated with alkali [49].

Natural fillers as potential modifying agents for epoxy composition. Epoxy resins have excellent properties; hence, they are being used heavily in industries.The fillers provide a balance between adequate strength, reduced weight, and biodegradability, meeting the growing emphasis on eco-friendly considerations in composite material development [50].

Hempcrete as building blocks. Hempcrete, crafted from hemp and a binder containing natural hydraulic lime with a minimal cement content, offers a robust and self-insulating construction solution adaptable to diverse purposes. Its applications range from timber frame infill to insulation and, when mixed with aggregate, even for floor slabs. With a carbon-negative impact, hempcrete emerges as a compelling option for sustainable construction, playing a pivotal role in achieving low embodied carbon objectives and adhering to rigorous sustainable building standards [51].

Application of sugarcane bagasse. Sugarcane bagasse composites (SBC) offers notable mechanical strength. The higher fiber content in the SCB/lime mixture results in enhanced thermal insulation, surpassing conventional materials such as clay brick or hempcrete. Moreover, lime composites exhibit improved water resistance, maintaining minimal loss of mechanical strength even when saturated [52].

Bioplastic made by banana peel. Bioplastics made by banana peel can be a key to solve the inability of synthetic plastic to degrade. The banana peel-based biodegradable film is the most promising option, given its superior degradability [53].

Particle board from rice husk. Rice husk, a byproduct from rice mills, offers potential as a sustainable building material due to its lightweight yet strong structure. The high concentration of amorphous silica on its surface acts as a natural binding agent [27].

Corn starch based biodegradable plastic and composite. Corn starch is a widely used biomaterial renowned for its cost-effectiveness and versatility in various applications. It consists of approximately 25%amylose and 75% amylopectin, two distinct polysaccharides that contribute to its unique properties. This makes corn starch an environmentally friendly option, particularly in applications where biodegradability is desired [54].

SUMMARY & FUTURE SCOPE

Agricultural waste, a significant pollution source, holds promise in structural applications such as hempcrete, rice husk particle board, and oil cake-based composite fillers, contributing to sustainability. Products like low-cost cellular concrete with rice husk and rice straw-wood particle boards offer potential as eco-friendly alternatives, surpassing conventional construction materials in performance. The economic advantage of utilizing these low-cost agricultural wastes is substantial. However, future research should focus on refining manufacturing techniques and enhancing product performance to compete effectively with established structural products. Additionally, numerous untapped oilseed, fruit, and vegetable waste resources remain, presenting opportunities for further exploration in structural applications. Cereal wastes, including stover, leaves, and stems, currently employed in bioethanol and composting, also warrant investigation for broader structural utilization.

Rice straw is a renewable resource, and it has good thermal insulation properties which could make it a good replacement for conventional insulation materials such as fiberglass or rockwool. However, rice straw insulation boards may have lower fire resistance than conventional insulation and may also be more susceptible to mold growth. Further research is needed to improve the fire resistance and mold resistance of rice straw insulation boards. This can improve the strength and durability of concrete, as well as its insulating properties. Wheat straw is a renewable resource, and it has good mechanical properties that could make it a good replacement for conventional wood flooring materials. However, wheat straw is susceptible to moisture absorption and may not be as durable as wood flooring materials. More research is needed to improve the moisture resistance of wheat straw flooring. Carbon nanosheets are a type of nanomaterial with a wide range of potential applications, including in batteries, solar cells, and water filters. Using groundnut shells as a source of carbon for carbon nanosheets could help to reduce the environmental impact of their production. Onion skins contain a substance called quercetin, which has adhesive properties. Glues made from onion skins could be a more sustainable alternative to conventional wood glues. However, more research is needed to determine the strength and durability of onion skin glues. Bioplastic is a type of plastic that is made from renewable resources such as plant starches or oils. Bioplastics can degrade more quickly than conventional plastics, which can help to reduce plastic pollution. Using orange peels as a source of material for bioplastic could help to reduce the environmental impact of plastic production. Tableware packaging made from sugarcane bagasse could be a more sustainable alternative to conventional packaging materials such as polystyrene or polyethylene. Cation exchangers are materials that can remove cations (positively charged ions) from a liquid. They are used in a variety of applications, including water treatment and industrial processes. Using polymerized corn cob as a cation exchanger could be a more sustainable alternative to conventional ion exchange resins. Hempcrete has good insulation properties and is fire resistant. It is a relatively new building material, but it has the potential to be a more sustainable alternative to conventional concrete. Bamboo is a renewable resource with good strength-to-weight ratio. Bamboo could be a good replacement for steel in concrete beams.

Addressing the challenges associated with the widespread use of agricultural waste products in construction requires concerted efforts. Variability in quality poses a significant hurdle, necessitating research into methods to produce consistent and high-quality building materials from these residues. Moreover, the high cost of collecting, processing, and transporting agricultural waste materials needs to be addressed through innovative and cost-effective solutions. Further research and development are essential to optimize processing techniques, improve material characterization, and enhance supply chain logistics. Despite these challenges, leveraging agricultural waste in construction holds promise for sustainability, offering opportunities to reduce reliance on finite resources, minimize waste generation, and mitigate greenhouse gas emissions. Collaborative efforts between researchers, industry stakeholders, and policymakers are crucial to realizing the full potential of agricultural waste products as sustainable sustainable building materials and advancing the construction industry's transition to more eco-friendly practices.

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