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A Short Review on the Growth of Lightweight Agronomic Surplus Biomass Composites for Ecological Applications Using Biopolymers

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Abstract: The escalating need to discover innovative approaches for creating sustainable materials, driven by the depletion of Earth's resources and heightened environmental concerns, has spurred numerous studies focusing on agricultural waste management. The significant annual generation of agricultural waste, amounting to approximately 1.3 billion metric tons globally, presents both ecological and financial challenges. This study emphasizes repurposing 60% of this annual agricultural waste, aligning with sustainable economy principles, and investigates the utilization of crop residues (450 million metric tons), straw (200 million metric tons), and other agricultural by-products (150 million metric tons) as supplementary ingredients for high-value goods. The methodology assesses the efficiency of employing 35% of this waste for lightweight biopolymer-based composites, targeting a 45% reduction in the environmental impact associated with conventional waste disposal. Results demonstrate a substantial 40% decrease in traditional waste disposal methods, with a 30% economic benefit realized through the conversion of 35% of agricultural waste into eco-friendly materials. This brief review explores the expanding field of lightweight agronomic surplus biomass materials, with a specific focus on the innovative utilization of biopolymers in creating environmentally friendly composites. It examines the sustainable repurposing and transformation of agricultural waste biomass, highlighting progress in the development of hybrids and emphasizing the myriad ways in which biopolymer-based materials contribute to environmental sustainability.

Keywords: Biopolymers, Sustainable materials, Cellulose, Starch, Natural composites, Lightweight applications, Ecological Applications, Environmentally Friendly Composites

1. Introduction

A sustainable and environmentally sound way of producing composite materials is the use of biomass from agricultural waste in the production process. These substances can be processed to function as polymer matrix reinforcement. Using biomass from agricultural waste as a reinforcing ingredient in composite materials reduces the quantity of waste generated by farming operations and also lessens dependency on non-renewable resources [1-3]. Composites made of biopolymers and biomass obtained from agricultural waste show a great deal of promise for reducing the environmental impact of the composite industry. Composites have a wide range of applications, such as use in the construction materials, automotive, and packaging industries. These materials are an environmentally preferable alternative to traditional composites because of their relatively cheaper cost and biodegradable nature [4]. Additionally, using these goods can lead to the creation of new enterprises and commodities, which would benefit local societies and agricultural producers financially. However, there are a number of limitations to the use of biomass from agricultural waste in the production of composites. These include variations in the waste's accessibility and quality as well as processing complexity [5, 6]. But with more research and development, the use of biomass from agricultural waste to produce composites shows promise for fostering a more sustainable and environmentally aware future. Natural fibres have been used to create textiles, twines, and ropes since the dawn of civilization. These fibres have been important to society. Because natural fibres are reusable, carbonneutral, economically viable, and recyclable, they do not harm the environment [7]. Natural fibres have the potential to be an alternative to synthetic fibres in the composite sector because of their adaptability and accessibility locally. Natural fibres are more environmentally friendly and biodegradable than synthetic ones. These materials are renewable and have exceptional qualities, including being lightweight, low-density, simple to produce and process, and economical [8]. Nowadays, natural fibres are preferred over synthetic ones since they don't pollute landmasses or water bodies and cause less wear and tear on machinery and its parts during processing. In polymer matrices, where polymers are used as binding materials to retain fibres and give dimensional stability, these natural fibres are frequently used as reinforcements. Because of their remarkable strength per unit mass, natural fibres are a highly desirable option for reinforcing materials [9]. Every year, over 30,000,000 metric tonnes of organic fibres are generated, and these fibres are used as acceptable raw materials in a variety of industries, including construction materials, sporting goods, newspaper manufacturing, apparel, and packaging [10]. In order to reduce the environmental impact, it is now necessary to reduce the use of petroleum-based polymeric materials for manufacturing natural fibre-based composite materials. To overcome the above drawback, most of the research has used biobased polymeric materials in recent days [11].

The polymers generated from microorganisms, plants, and animals are known as biopolymers. These are widely accessible renewable resources that are typically used to create environmentally acceptable bioplastics. Large-scale commercial production of biopolymers is carried out for a variety of uses. Although biopolymers currently account for a very modest portion of the polymer industry, it is anticipated that in the future they will replace between 40 and 80 percent of petroleum-based polymers [12, 13]. With a small exception, most biopolymers are biodegradable, meaning they may break down into inorganic compounds, carbon dioxide (CO_2), water (H_2O), and methane (CH_4) under microbiological conditions. Numerous variables, including polymer type, chemical makeup, and environmental circumstances, affect how quickly biopolymers degrade. More recently developed biodegradable polymers have a broader variety of qualities that are almost identical to those of conventional polymers found on the market [14]. Depending on factors including cost, availability, mechanical behaviour, moisture absorption, degradation stability, and biocompatibility, biopolymers are used in particular sectors. The biopolymer component of a biocomposite determines its chemical composition, molecular weight, morphological features, mechanical properties, and processing method. Biopolymers have a lot of uses, however some drawbacks include their hydrophilic nature, poor mechanical qualities, and low lasting degradation ratio in damp environments [15].

To meet the increasing demand driven by global population growth, both food production and transportation have witnessed significant growth. Between 2010 and 2022, primary cereal production experienced a remarkable 60% increase, reaching 10.32 billion tons in 2022 [16]. However, this expansion in the farming sector has led to a substantial increase in waste generation during both manufacturing and disposal processes. The excessive use of materials and the resulting waste production can have adverse effects on environmental quality, disrupting the global ecosystem's balance. Contemporary agricultural technology has indeed boosted crop yields, but it has also brought about unfavourable consequences that have left a lasting impact on the realms of humanity, nature, and the economy [8]. Compared to traditional plastics, which take about 1,000 years to separate, biodegradable plastics separate 60% or more in 180 days or less. Growing garbage piles and landfills have become major ecological hazards and have a number of negative effects on the biological system's verdure. The higher cost of bioplastics compared to conventional polymers regulates market growth in several application segments. The cost of producing bio-based polymers is typically 20% to 100% more than that of conventional polymers. This is mostly due to the high cost of polymerization of bio-based polymers, as most cycles are still in the early stages and have not yet reached economies of scale [17]. There are a number of obstacles in the way of biopolymer synthesis that go beyond using agricultural waste. The cost of production, which includes charges for raw materials and processing, presents financial challenges. Biopolymers may have restricted mechanical and thermal stability, which limits their usage in applications where certain performance standards must be met. Their widespread usage is further impeded by the requirement for enhanced biodegradation control and compatibility difficulties with the current processing infrastructure [18]. Significant issues include overcoming feedstock reliance, achieving consistent quality on a big scale, and managing regulatory obstacles [19, 20]. Furthermore, the general difficulty of the integration of biopolymers into numerous businesses is exacerbated by low market knowledge and acceptability. Notwithstanding these obstacles, continuous research and development initiatives seek to improve the characteristics, lower costs, and increase the range of uses for biopolymers, opening the door for a more sustainable future in polymer technology. Table 1 reveals the overall limitations of the biopolymers.

Table 1. Reveals the overall limitations of the biopolymers

Limitation	Description	References
Production cost	Higher raw material costs, especially for non-agricultural sources. - Complex processing steps contributing to elevated production costs.	[21]
Limited material properties	Varied mechanical properties compared to traditional polymers. - Lower thermal stability, restricting use in high-temperature applications.	[22]
Limited range of applications	Incompatibility with existing processing equipment and infrastructure. - Performance challenges in specific industries (e.g., packaging, medical devices).	[23]
Biodegradability challenges	Difficulty in achieving controlled degradation rates. Potential production of toxic byproducts during biodegradation.	[24]

In the current scenario, people are becoming increasingly aware of the necessity to protect the natural world. This awareness is driven by concerns such as the long-term impacts of plastics, the limited space available for landfills, the depletion of petroleum-based resources, the harmful emissions from burning plastics, and the threats posed to living organisms [25]. Based on earlier studies, the worldwide biopolymers market was estimated to be worth USD 32 billion in 2022 and is projected to rise at a compound annual growth rate (CAGR) of 9.25% to reach over USD 91.15 billion by 2033. Europe had the largest revenue share of any region in 2022—roughly 43.5%. In terms of sales share, the bio-based PET category achieved almost 57% in 2022. The participants in the biopolymers and bioplastics market are continuously using both inorganic and natural methods to further their development [26]. The players have recently achieved many significant breakthroughs in the emerging APAC countries. For instance, Total Corbion established a Polylactic Acid (PLA) Plant in Rayong, Thailand, in 2019, with an annual production capacity of 75,000 tons. Additionally, Indonesia is looking at kelp and other bioplastic options. One local player, Evo ware, provides licensed ocean growth-based packaging. The company is shipping chambers made with ocean growth. The largest end-use market for bioplastics and biopolymers is the packaging sector. In 2022, they accounted for 62% of the global market for bioplastics and biopolymers [27, 28].

The manufacturing and utilization of plastics have a significantly detrimental impact on the environment, particularly in terms of the release of greenhouse gases and contributions to global warming. The issue of plastic pollution has far-reaching implications, affecting both the environment and the economic structure of society. Working towards a more sustainable business approach is imperative, given the imminent threat of global warming. It is not merely a choice but a responsibility [29]. It is crucial for every industry to employ natural resources, processes, and methodologies that prioritize environmental friendliness while leveraging manufacturing expertise to achieve sustainable growth. From a material perspective, the solution lies in adopting environmentally conscious trends that have given rise to the development of "biomaterials." These biomaterials involve the combination of natural fibers and a support substrate, resulting in a category of material known as biocomposites [30].

Various natural fibers sourced from materials such as hemp, kenaf, jute, flax, and bamboo are used in the production of these biohybrids. biocomposites may employ various types of matrix materials, including synthetic, non-biodegradable, and recyclable options. Many biodegradable matrix materials are derived from organic substances like chitosan, starch, and cellulose. However, it's important to note that not all renewable matrix materials are durable and resistant to degradation [31]. Figure 1 shows the market scenario of biopolymer production. Petroleum-based plastics have become a part of our daily lives because they have the ability to replace a wide range of conventional materials in a variety of applications. Fibre reinforced polymer composites are increasingly being used in high-end industries including aircraft, medicine, and autos [32]. In addition to this financial realm, the majority of commodities derived from petroleum create an unsustainable environment. Therefore, using bio-based materials is an alternate approach to developing ecologically friendly products. The components that make up bio-based materials are those derived from living organisms [33]. "Green composites" are biopolymers reinforced with natural fibres. It's a biopolymer composite that degrades in the presence of heat, light, air, and bacteria, among other environmental elements. Natural fibres are more appealing than synthetic fibres, despite their lower strength and stiffness. Some advantages of using natural fibres are their accessibility, combustibility, biodegradability, and lack of toxicity [34]. However, low processing temperature, excessive moisture absorption of natural fibres, and overall quality fluctuation negatively impact their applicability. Much research has been published on functionalizing natural fibres in order to produce high-performing goods using natural fiber-reinforced biopolymer blends. The structure, resilience, and ecological endurance of a biopolymer composite are primarily controlled by the biopolymer matrices, while the stiffness as well as the strength of the composite are determined by the reinforcing fibre [35]. Biopolymer composites' value-added new uses guarantee their prospective expansion into global markets. There are still many significant worldwide uses for the ecologically sound composite goods that have been created developed, and these efforts are ongoing. The need to close this knowledge gap and provide critical insights into the sustainable transformation and reuse of agricultural waste biomass is what spurred this study. The study aims to fill the gap in the literature by concentrating on the use of agricultural organic waste as additional ingredients for valuable goods, with a special emphasis on the creative application of biopolymers. Lightweight agronomic surplus biomass products have been shown to have numerous ecological advantages. The main driving force is to provide comprehensive knowledge of the sustainable repurposing of such materials, with a focus on the possible environmental advantages and the advancements made in the creation of eco-friendly biopolymer-based composites.

The utilization of biopolymers derived from agriculture as a matrix for developing durable biopolymer-based materials has received limited attention. This research aims to promote the adoption of renewable biopolymer-based materials as competitive alternatives to traditional materials in a wide range of ultralight applications. The goal is to contribute to the development of a more environmentally conscious and sustainable long-term economy. Within the framework of environmentally friendly growth, the study will assess the prospects and viability of these materials from both environmental and economic perspectives. Additionally, it will propose potential applications for sustainable natural composites in the agriculture industry. The outcomes of this study have the potential to advance our knowledge of biomaterial research and lead to the creation of more resource-efficient and ecologically friendly products and processes. The manufacturing process, preparation, and applications of biodegradable composites made from biopolymers such as cellulose, starch, and polylactic acid (PLA) that are currently commercialized and, on the market, as well as those that show greater promise as matrices for natural fibre composites in the future, will be the main topics of this review. In addition to emphasizing the ecological trend, this research intends to make significant contributions to the area by providing quantitative data on the yearly amounts of agricultural waste and suggesting methods for their effective use. By doing this, it closes a significant vacuum in the literature that exists today and emphasises how important it is to investigate sustainable solutions for managing agricultural waste in the context of producing environmentally friendly products.

2. Biobased Polymer Materials

Polymeric biomolecules are comprised of long chains of monomer units linked by covalent bonds, known as biopolymers. Unlike synthetic polymer compounds, biopolymers possess a complex molecular structure that results in a distinctive three-dimensional arrangement. The prefix "bio" implies that these polymers can naturally degrade through biological processes [36, 37]. As a result, biopolymers offer recyclable materials that serve as a compelling alternative to petroleum-based polymers, addressing critical environmental conservation concerns. In contrast, synthetic polymers are human-made materials derived from petroleum products, and they are generally not recyclable [38] . Given the finite nature of oil supplies and their significant contribution to global environmental issues, the environmental benefits of biopolymers become evident. Biopolymers embody a circular approach that encompasses material design, production, usage, and waste management.

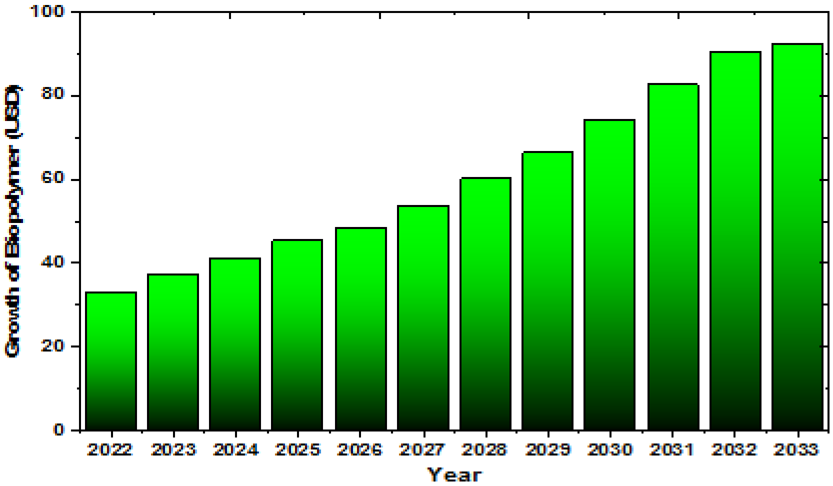

Figure 1. Shows the market scenario of biopolymer production in the year of 2022 to 2033 in USD billions

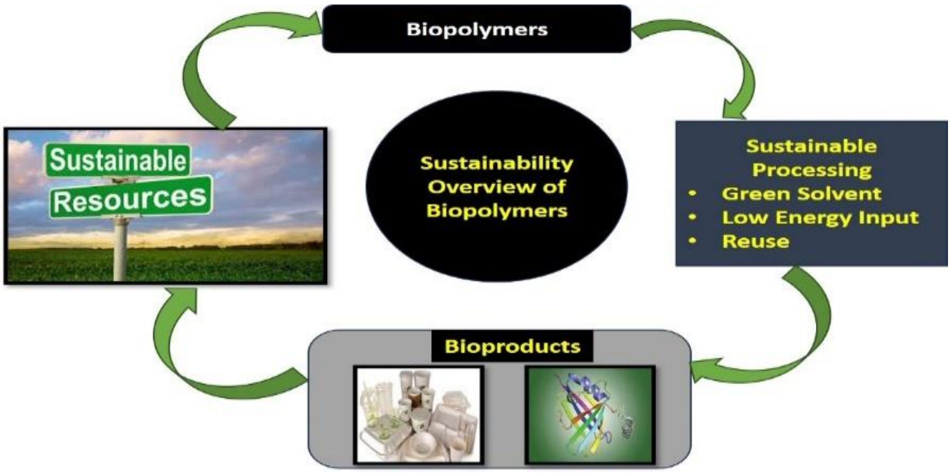

Figure 2. Shows the long-term sustainability of biopolymers

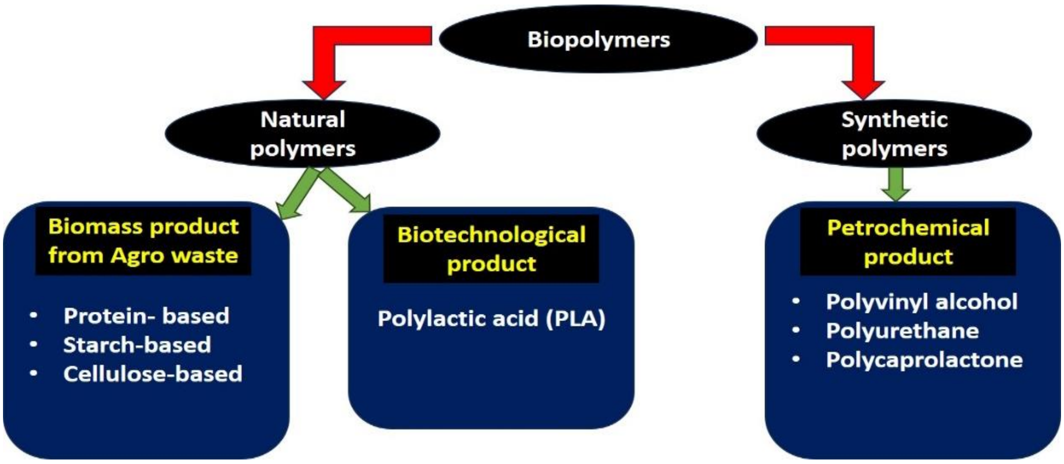

Figure 3. Biopolymer classification

This stands in contrast to the linear lifecycle of synthetic polymers, which rely on petroleum and coal as inputs, transform them into polymer compounds, produce goods, and ultimately dispose of them [39,40]. A summary comparing the long-term sustainability of biopolymers can be found in Figure 2.

2.1 Types of Biopolymers

The global population consumes a significantly greater amount of food each year, either directly or indirectly sourced from plant-based products. Substantial organic matter, often referred to as crop residues, remains after harvest. This organic waste is typically either incinerated in the fields or used as animal feed. However, these agricultural byproducts, such as hardwood sawdust, bagasse, rice husks, and even inedible portions of vegetables and fruits, can be environmentally responsibly repurposed as a starting point for the production of biopolymers [41, 42]. This approach offers a potential solution to the ongoing issues of plastics and pollution. Some examples of biopolymers that can be derived from various plant sources include starches and cellulose. These materials possess superior properties compared to modern synthetic polymers, which contribute to environmental degradation and exacerbate global warming. In fact, they can compete with or even surpass those made from synthetic substances. This article provides an overview of notable biopolymers that can be derived from organic matter [43]. Figure 3 shows the simplified classification of biopolymers.

2.1.1 Cellulose

Cellulose, one of the most common and virtually limitless natural polymers found globally, constitutes approximately half of all plant and algae biomass and serves as the primary structural component of plant cell walls. Green plants generate glucose through the photosynthetic process, converting water and carbon dioxide. Cellulose's unique structure makes it an adaptable substrate for various chemical transformations, significantly influencing its chemical reactivity [44]. The monomers derived from cellulose can be employed to create a diverse range of valuable biopolymers, both traditional and innovative. As a result, cellulose-based plastics present a sustainable alternative to petroleum-based polymers in numerous applications. Materials composed of cellulose, such as organic fibers, nanocellulose, and cellulose derivatives, offer promising prospects for biomaterial development [18]. Utilizing cellulosic biopolymeric polymers as matrix structures in biotechnology applications can enhance multifunctional properties, particularly when used as fillers in biocomposite construction. A growing trend involves replacing talc and glass filaments with organic cellulose fibers to reinforce sustainable polymer blends [45]. Xie *et al.* [46] conducted research investigating the impact of incorporating bamboo cellulose fibers into concrete mixtures, demonstrating significantly improved impact energy absorption and fracture resistance. Similarly, Sumesh *et al.* [47] explored the extraction of cellulose from peanut cake oil, enhancing the temperature and mechanical properties of natural fiber composites. These findings underscore the potential for cellulose-based materials in diverse applications. However, cellulosic composites, typically comprised of fibers, may offer fewer advantages when compared to composites reinforced with fiberglass and carbon fibers. This is primarily due to the lower thermal resistance of cellulosic materials and the incongruence between their hydrophobic polymeric matrix and hydrophilic natural fibers. Additionally, the physical properties of cellulose fibers tend to degrade as humidity levels increase. Therefore, external modifications, such as mechanical bonding and physical alterations of cellulose fibers, are necessary. Chemical treatments, as proposed by Liu *et al.* [48], can enhance the elasticity and thermal stability of organic fiber materials by removing non-cellulose components. Because of their special qualities, biopolymers made from natural and renewable resources are crucial to the food-packaging sector.

The food packaging business uses cellulose widely because of its particular features, structure, and characteristics, making it one of the most common polymers. This section will cover some of the properties of cellulose, its sources, and its use in materials used in food packaging. Among the elements that are most prevalent in nature are cellulose and its derivatives [49]. They may be added to food to increase its nutritional content, and they are edible and biodegradable. The sensory and organoleptic qualities of cellulose, including colour, appearance, scent, flavour, and taste, are also widely recognized. It contributes to a decrease in waste and synthetic packaging material volume. Because of its small weight, less packing material is used. It conveniently encapsulates and integrates a variety of naturally occurring antioxidant and antibacterial compounds. In their 2021 study, Chan *et al.* [50] discussed cellulose's encapsulation properties and how it is used to encapsulate layered-double-hydroxide (Zn/Al)-5-Fu. Moreover, it increases the quality of goods, particularly those that are not packaged, and prolongs the shelf life of food. Additionally, cellulose gives the packing material barrier qualities that lessen the migration and movement of solutes, lipids, gases, and moisture [51].

2.1.2 Polylactic acid

Polylactic acid (PLA) is a bio-based polymer manufactured through microbial fermentation, using lactic acid monomers derived from renewable resources like wheat, corn, sugarcane, grains, and food industry and agricultural waste. A proposed production flow structure for PLA is illustrated in Figure 4. Lactate, a typical metabolic residue or intermediate molecule in many organisms and plants, and the byproducts resulting from PLA's hydrolysis degradation are non-toxic in the natural environment [52]. PLA production consumes fewer resources and emits fewer carbon emissions compared to various synthetic polymers. PLA can effectively replace synthetic polymers in various applications, making it one of the few biopolymers that can be produced at a scale equivalent to that of synthetic polymers [53, 54]. PLA is classified as a thermoplastic, not a thermoset, due to its response to heat. A crucial characteristic of thermoplastic materials is their ability to be heated to their melting point, cooled, and reheated without experiencing significant degradation. As thermoplastics like PLA melt rather than burn, they can be easily reprocessed after being heated. During the crystallization process, PLA forms the geometric structures α, β, and γ. Mechanical forces and stretching create the β form, while α-PLA is produced through cold crystallization. The rapid development of semi-crystalline regions in PLA contributes to its fast crystallization rate [55]. The level of crystallization influences several polymer properties, including melting temperatures, tensile strength, impact resistance, toughness, and rigidity, as demonstrated by Natrayan *et al* [37]. Polylactic acid (PLA) is widely acknowledged for its numerous advantages, including biocompatibility, moderate durability, and cost-effectiveness. Additionally, PLA films exhibit exceptional UV-light-blocking properties. However, these films lack flexibility and are brittle and thin. PLA is not suitable for high-stress applications due to its poor hardness and fragility, and its inertness makes surface modifications challenging [56]. PLA also faces thermal stability issues as ester bonds break down at elevated temperatures, leading to a reduction in molecular weight [14]. This degradation can occur even below PLA's boiling point and accelerates significantly after dissolution. Various methods, such as esterification, polymer hydrolysis removal, and oxidative breakdown, are employed to address this issue. Variables such as moisture levels, lactic acid content, and particulate proportions influence the extent of thermal decomposition. Figure 4 shows the various biopolymer structures [57, 58]. Compared to polyhydroxy acids (PHAs), PLAs are significantly less expensive to produce, although they are still more expensive than polyethylene (PE) and polypropylene (PP) derived from oil.

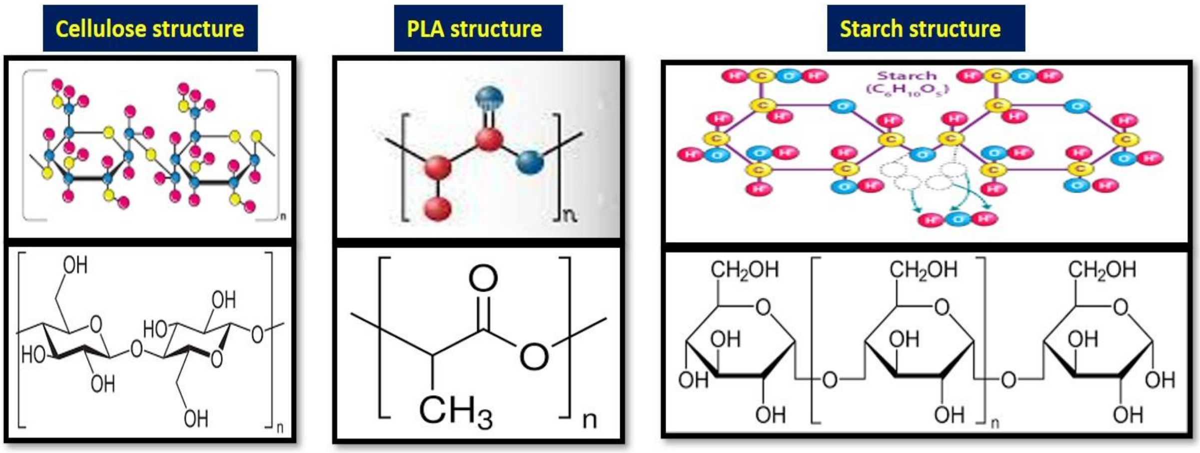

Figure 4. Shows the various biopolymer structures

The majority of bio-based materials are still in the improvement stage and are not as well marketed as their petrochemical counterparts, who have been expanding rapidly for more than 50 years. The cost of biodegradable plastics currently ranges from USD 2/kg to USD 6/kg, whereas the cost of conventional plastics is between USD 1/kg to USD 2/kg. The main reasons for the low uptake of bioplastics in many endeavours are higher R&D and creation expenses due to limited scope development and the stark cost difference compared to traditional oil-based plastics [59].

2.1.3 Starch

Among the more frequent polysaccharides in the natural world, starch is frequently discovered in biomass derived from plants. There are two types of starch: the polymer with a linear structure, amylose, and the branching polymer, amylopectin. For millennia, starch has been extensively used for a variety of tasks, including the production of pulp, which is among the most widespread uses [60]. Additionally, large volumes of starch are used in the textile industry to strengthen threads throughout the process of weaving. Foodstuffs, tubes, and beans are among the most prevalent sources of starch; potatoes, wheat, maize, and paddy are the main sources of carbohydrates [61]. Granules are another widely available type of starch. Because of their powerful hydrogen bonds and cyclical framework, starch molecules have an organized crystalline area and a hard shape. This property explains why starch has an elevated boiling point and glass transition temperatures. It also explains why starch is only soluble in hot water and has restricted solubility in frigid water and liquor. The starch granules grow and depart from their semi-transparent form when they come into contact with liquid [62]. The small particles of amylose and amylopectin that break down slowly decompose to form an arrangement that is capable of retaining water. Starch may be transformed into a thermoplastic material known as starch that is thermoplastic (TPS) by a procedure known as cornstarch gelatinization. When combined with filler or additional troops, TPS may be used to create bio polymers. Grylewicz *et al*. [63] looked into how an electrostatic solvent changed the mechanical properties, water absorption, thermal behavior, and wetness at the interface of thermoplastic starchy hybrids made from potato starch and wood fibers. The results of the study demonstrated a connection between the previously indicated characteristics of the biocomposites and the deep electrostatic solvents. Limestone reinforcing was incorporated into the starch substrate utilizing the solvent-based casting process at varying dolomite loadings in an independent study conducted by Osman *et al.* [64] According to the research, the biocomposite was impacted by the filler loading into the starch matrix. Remainders and garbage from agriculture are some of the most plentiful and affordable sources of renewable energy. The worldwide buildup of such wastes may result in harmful emissions and increased disposal expenses. Reusing the biomass to generate bio composites is the most effective way to address this dilemma [65]. The technique of mixing at least one substance generated from the environment to create a new composite substance is known as "bio-composite manufacture." Using waste from agriculture in its natural state as either a strengthening agent, a matrix, or possibly both is how agriculture residue-based materials, or biocomposites, are created [66]. Table 2 shows instances of biological composites made from agricultural residues that come from naturally as well as synthetic resources. The revenue distribution of starch-based biopolymers across various regions is as follows: North America commands a 26% share, Asia Pacific holds 22%, Europe leads with 43.50%, Latin America contributes 5%, and Middle East Asian countries represent 3.5%. These percentages reflect the current market landscape, and there is a strong indication that these figures will witness growth in the coming years. The data suggests a positive trajectory for the starch-based biopolymer market, with potential expansions and increased market shares projected for the foreseeable future [34].

To improve the degradation of common polymers, including polypropylene, polyethylene, and polystyrene, granular starch may also serve as a filler. Granulates of starch are frequently surface processed or chemically changed to impose a hydrophobic nature in order to increase interaction with polyolefins. Furthermore, because of its limited influence on the melt flow properties of the majority of synthesised plastics and its thermal resistance, starch is an appropriate filler ingredient for the production of environmentally acceptable biocomposites [67, 68]. The size, shape, and compliance of the filler with the matrix of polymers all have a significant impact on the properties of biocomposites. In their research, Perez et al. [69] used starch nanocrystals created by acid hydrolysis to reinforce a rice starch-based film. The addition of the nano starch increased the film's crystallinity, but adding too much of it caused the film's crystallisation to diminish. The resultant films' thermal endurance and moisture resistance qualities were also improved by adding more starch nanoparticles. Gelatinous starch and taro starch nanomaterials were employed in a different investigation by Aaliya *et al.* [70] to strengthen corn starch films. The thermal endurance of the maize starch films was improved by the addition of starch nanomaterials.

3. Application of composite from Agricultural waste

Natural fibers from farming methods were previously employed for a variety of goods, including construction supplies, clothing, and canvases. The straw, sawdust, invasive plants, and excrement are examples of crop residue items that are recycled and turned into things that are beneficial to the ecosystem and the economy, as well as energy [75]. Natural fibers have been used for a long time, but in numerous uses, their popularity has declined since the beginning and middle of the 20th century with the invention and commercialization of artificial ones, including carbon dioxide, glass, and aramid yarns.

Table 2. Agricultural waste based composite materials and their properties

S.No	Composite	Fabrication and Processing methods	Properties	References
1	Paunch/ PHBV	The fiber is mixed dry and then melted together. After being sieved to the proper sizes, the powdered paunch was dried in a vacuum oven. The procedure of extrusion was utilized to manufacture the dry mixture blends.	The flexural modulus rose as the fiber percentage increased.	[71]
2	corn husk/ Corn starch/	Maize husk was used as reinforcement after the maize starch was dissolved in distilled water and combined with fructose. The conventional solution casting technique was utilized to generate an array of composite films.	The addition of maize husk improved the composite's young's modulus, breaking strength, and crystallization indices.	[72]
3	Pork bone powder/PLA	The bone powder was altered with n-butanol to improve its compatibility and dispersibility in the PLA matrix. After being combined and treated, the PLA and modified powder were made into filaments that could be utilized in 3D printing.	There were improvements in the tension and bending properties of the produced material.	[73]
4	wood biochar/ sewage sludge biochar/ PLA/	Injection molding was used after the raw components were mixed to produce fabrication.	The inclusion of biochar increased the material's retention of water and stiffness. When contrasted with wood biochar, the composite made with sewage waste charcoal filler exhibited comparatively superior mechanical and thermal properties.	[74]

Figure 5. Bio composite application in household, construction and automobiles (a) House hold box tray; (b) Vehicle door; (c) House door; (d) Chair; (e) Fiber based pipe; (d) Smart bridge.

Substantial economic and technical breakthroughs during this century required the use of substances with extremely reliable and consistent qualities; for example, newly manufactured fibers passed the test, whereas natural fibers did not. Recently, there has been a surge in enthusiasm for developing novel eco-composites that capitalize on the environmentally friendly qualities of biological composites as well as the simplicity with which their physical features may be altered. However, the majority of biological composites are still in the midst of research and development, with only a small number having been created and marketed [76, 77]. For instance, Kumar et al. [78] created an epoxy-based material using nitride boron nanoparticles and leftover corncobs with the goal of enhancing the composite's toughness for practical uses while also making trash disposal more economical and environmentally beneficial. The majority of uses for biological composites are not structural or load-bearing. Organic fiber-strengthened biological composites are widely used in home goods, automotive items, and wrapping, with the main motivating element being their minimal mass [79, 80]. The common applications of biocomposites in the automotive, home goods, and technological and innovative industries are depicted in Figure 5.

4. Conclusion and future scope

In conclusion, the exploration of utilizing biomass from crop residue to create renewable biopolymer-based materials for lightweight applications represents a ground breaking avenue with substantial potential to address critical ecological and financial challenges. This review underscores the pressing need for sustainable alternatives in the face of environmental concerns and resource depletion. The comprehensive analysis of recent advancements, particularly the application of polymers that decompose and innovative techniques for producing high-performance, environmentally friendly materials, highlights the significance of this emerging field. The necessity for such investigations becomes evident as these biocomposites, incorporating biopolymers like polylactic acids (PLA), thermoplastic starch, and cellulose derived from crop residue, present a viable opportunity to replace traditional materials across diverse sectors such as home construction, automobiles, maritime industries, and packaging. The enhanced mechanical qualities and sustainability attributes of these composites offer a compelling rationale for the shift towards their widespread adoption.

Furthermore, this review is crucial because it investigates sustainable biopolymer-based products from agricultural residue, addressing pressing environmental and economic issues. It addresses the pressing need in light of resource depletion and environmental concerns for sustainable alternatives. The study discusses new developments that have added to the conversation about sustainable materials, such as biodegradable polymers and creative production methods. It highlights the useful uses in the packaging, automotive, marine, and construction industries and highlights how these biocomposites have the potential to be revolutionary. It is imperative to acknowledge renewable materials as feasible alternatives in many industries, alleviate the ecological footprint, and decrease dependence on limited resources. The assessment concurrently addresses economic and environmental issues by promoting a cost-effective and environmentally sustainable supply chain through the utilization of agricultural leftovers. It acts as a spur for development, encouraging more study and useful applications for a robust and ecologically conscientious future. This review's call to action, which asks businesses to adopt sustainable alternatives and help create a more environmentally friendly and sustainable world, is what makes it so urgent.

References

[1] S. Nagappan, S.P. Subramani, S.K. Palaniappan, B. Mylsamy, Impact of alkali treatment and fiber length on mechanical properties of new agro waste Lagenaria Siceraria fiber reinforced epoxy composites. Journal of Natural Fibers, 19 (2022) 6853–6864. https://doi.org/10.1080/15440478.2021.1932681

[2] M. Ali, A. Alabdulkarem, A. Nuhait, K. Al-Salem, G. Iannace, R. Almuzaiqer, Characteristics of agro waste fibers as new thermal insulation and sound absorbing materials: Hybrid of date palm tree leaves and wheat straw fibers. Journal of Natural Fibers, 19 (2022) 6576–6594. https://doi.org/10.1080/15440478.2021.1929647

[3] F. Ortega, F. Versino, O.V. López, M.A. García, Biobased composites from agro-industrial wastes and by-products. Emergent Materials, 5 (2022) 873–921. https://doi.org/10.1007/s42247-021-00319-x

[4] V.S. Shankar, G. Velmurugan, D.E. Raja, T. Manikandan, S.S. Kumar, J. Singh, M. Nagaraj, A.J.P. Kumar, A Review on the Development of Silicon and Silica Based Nano Materials in the Food Industry. Silicon, (2023) 1–10. https://doi.org/10.1007/s12633-023-02748-1

[5] G. Velmurugan, S.S. Kumar, J.S. Chohan, R. Sathish, S.P. Selvan, S.A.M. Abraar, D.E. Raja, M. Nagaraj, S. Palani, Hybrid calotropis gigantea fibre-reinforced epoxy composites with SiO2's longer-term moisture absorbable and its impacts on mechanical and dynamic mechanical properties. Materials Research Express, 10 (2023) 115302. https://doi.org/10.1088/2053-1591/ad0bc8

[6] A. Vinod, M.R. Sanjay, S. Siengchin, S. Fischer, Fully bio-based agro-waste soy stem fiber reinforced bio-epoxy composites for lightweight structural applications: influence of surface modification techniques. Construction and Building Materials, 303 (2021) 124509. https://doi.org/10.1016/j.conbuildmat.2021.124509

[7] A. Karimah, M.R. Ridho, S.S. Munawar, D.S. Adi, R. Damayanti, B. Subiyanto, W. Fatriasari, A. Fudholi, A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations. Journal of Materials Research and Technology, 13 (2021) 2442–2458. https://doi.org/10.1016/j.jmrt.2021.06.014

[8] M.V. Madurwar, R.V. Ralegaonkar, S.A. Mandavgane, Application of agro-waste for sustainable construction materials: A review. Construction and Building Materials, 38 (2013) 872–878. https://doi.org/10.1016/j.conbuildmat.2012.09.011

[9] G. Velmurugan, S.S. Kumar, J.S. Chohan, A.J.P. Kumar, T. Manikandan, D.E. Raja, K. Saranya, M. Nagaraj, P. Barmavatu, Experimental Investigations of Mechanical and Dynamic Mechanical Analysis of Bio-synthesized CuO/Ramie Fiber-Based Hybrid Biocomposite. Fibers and Polymers, (2023) 1–20. https://doi.org/10.1007/s12221-023-00432-0

[10] A. Verma, K. Joshi, A. Gaur, V.K. Singh, Starch-jute fiber hybrid biocomposite modified with an epoxy resin coating: Fabrication and experimental characterization. Journal of the Mechanical Behavior of Materials, 27 (2018) 1–16. https://doi.org/10.1515/jmbm-2018-2006

[11] K.K. Sadasivuni, P. Saha, J. Adhikari, K. Deshmukh, M.B. Ahamed, J.J. Cabibihan, Recent advances in mechanical properties of biopolymer composites: a review. Polymer Composites, 41 (2020) 32–59. https://doi.org/10.1002/pc.25356

[12] A. George, M.R. Sanjay, R. Srisuk, J. Parameswaranpillai, S. Siengchin, A comprehensive review on chemical properties and applications of biopolymers and their composites. International Journal of Biological Macromolecules, 154 (2020) 329–338. https://doi.org/10.1016/j.ijbiomac.2020.03.120

[13] J.R. Robledo-Ortíz, A.S. Martín del Campo, J.A. Blackaller, M.E. González-López, A.A. Pérez Fonseca, Valorization of sugarcane straw for the development of sustainable biopolymer-based composites. Polymers, 13 (2021) 3335. https://doi.org/10.3390/polym13193335

[14] G. Velmurugan, K. Babu, Statistical analysis of mechanical properties of wood dust filled Jute fiber based hybrid composites under cryogenic atmosphere using Grey-Taguchi method. Materials Research Express. 7 (2020). https://doi.org/10.1088/2053-1591/ab9ce9

[15] P. Zarrintaj, F. Seidi, M.Y. Azarfam, M.K. Yazdi, A. Erfani, M. Barani, N.P.S. Chauhan, N. Rabiee, T. Kuang, J. Kucinska-Lipka, M.R. Saeb, M. Mozafari, Biopolymer-based composites for tissue engineering applications: A basis for future opportunities, Composites Part B: Engineering. 258 (2023) 110701. https://doi.org/10.1016/j.compositesb.2023.110701

[16] R. Phiri, S.M. Rangappa, S. Siengchin, O.P. Oladijo, H.N. Dhakal, Development of sustainable biopolymer-based composites for lightweight applications from agricultural waste

biomass: a Review. Advanced Industrial and Engineering Polymer Research, 6 (2023) 436-450. https://doi.org/10.1016/j.aiepr.2023.04.004

[17] S. Adjei, S. Elkatatny, A highlight on the application of industrial and agro wastes in cement-based materials. Journal of Petroleum Science and Engineering, 195 (2020) 107911. https://doi.org/10.1016/j.petrol.2020.107911

[18] V. Ganesan, B. Kaliyamoorthy, Utilization of Taguchi Technique to Enhance the Interlaminar Shear Strength of Wood Dust Filled Woven Jute Fiber Reinforced Polyester Composites in Cryogenic Environment. Journal of Natural Fibers, (2020). https://doi.org/10.1080/15440478.2020.1789021

[19] M. Matheswaran, P. Suresh, G. Velmurugan, M. Nagaraj, Evaluation of Agrowaste/Nanoclay/SiO2-Based Blended Nanocomposites for Structural Applications: Comparative Physical and Mechanical Properties, Silicon. 15 (2023) 7095–7108. https://doi.org/10.1007/s12633-023-02570-9

[20] D. Arunkumar, A. Latha, S. Suresh Kumar, J.S. Chohan, G. Velmurugan & M. Nagaraj, Experimental Investigations of Flammability, Mechanical and Moisture Absorption Properties of Natural Flax / NanoSiO 2 Based Hybrid Polypropylene Composites. Silicon, 15 (2023) 7621–7637. https://doi.org/10.1007/s12633-023-02611-3

[21] J. Li, X. Hao, W. Gan, M.C.M. van Loosdrecht, Y. Wu, Recovery of extracellular biopolymers from conventional activated sludge: Potential, characteristics and limitation. Water Research, 205 (2021) 117706. https://doi.org/10.1016/j.watres.2021.117706

[22] M. Mahamaya, S.K. Das, K.R. Reddy, S. Jain, Interaction of biopolymer with dispersive geomaterial and its characterization: An eco-friendly approach for erosion control. Journal of Cleaner Production, 312 (2021) 127778. https://doi.org/10.1016/j.jclepro.2021.127778

[23] N.S.K. Gowthaman, H.N. Lim, T.R. Sreeraj, A. Amalraj, S. Gopi, Advantages of biopolymers over synthetic polymers: Social, economic, and environmental aspects. Biopolymers and their Industrial Applications, (2021) 351–372. https://doi.org/10.1016/B978-0-12-819240-5.00015-8

[24] J. Joshi, S.V. Homburg, A. Ehrmann, Atomic force microscopy (AFM) on biopolymers and hydrogels for biotechnological applications-Possibilities and limits, Polymers. 14 (2022) 1267. https://doi.org/10.3390/polym14061267

[25] S. Sanjeevi, V. Shanmugam, S. Kumar, V. Ganesan, G. Sas, D.J. Johnson, M. Shanmugam, A. Ayyanar, K. Naresh, R.E. Neisiany, O. Das, Effects of water absorption on the mechanical properties of hybrid natural fibre/phenol formaldehyde composites. Scientific Reports, 11 (2021) 1-11. https://doi.org/10.1038/s41598-021-92457-9

[26] S. Sekar, S. Suresh Kumar, S. Vigneshwaran, G. Velmurugan, Evaluation of mechanical and water absorption behavior of natural fiber-reinforced hybrid biocomposites. Journal of Natural Fibers, 19 (2022)1772-1782. https://doi.org/10.1080/15440478.2020.1788487

[27] B.E. Tokula, A.O. Dada, A.A. Inyinbor, K.S. Obayomi, O.S. Bello, U. Pal, Agro-waste based adsorbents as sustainable materials for effective adsorption of Bisphenol A from the environment: A review. Journal of Cleaner Production, 388 (2023) 135819. https://doi.org/10.1016/j.jclepro.2022.135819

[28] S.A. Varghese, H. Pulikkalparambil, K. Promhuad, A. Srisa, Y. Laorenza, L. Jarupan, T. Nampitch, V. Chonhenchob, N. Harnkarnsujarit, Renovation of Agro-Waste for sustainable food packaging: A Review. Polymers, 15 (2023) 648. https://doi.org/10.3390/polym15030648

[29] R. Shrivastava, N.K. Singh, Agro-wastes sustainable materials for wastewater treatment: Review of current scenario and approaches for India. Materials Today: Proceedings, 60 (2022) 552–558. https://doi.org/10.1016/j.matpr.2022.01.460

[30] S. Birania, S. Kumar, N. Kumar, A.K. Attkan, A. Panghal, P. Rohilla, R. Kumar, Advances in development of biodegradable food packaging material from agricultural and agro-industry waste. Journal of Food Process Engineering, 45 (2022) e13930. https://doi.org/10.1111/jfpe.13930

[31] M. Iniguez-Moreno, M. Calderón-Santoyo, G. Ascanio, F.Z. Ragazzo-Calderón, R. Parra-Saldívar, J.A. Ragazzo-Sánchez, J.A. Ragazzo-Sánchez, Harnessing emerging technologies to obtain biopolymer from agro-waste: application into the food industry. Biomass Conversion and Biorefinery, (2023) 1–18. https://doi.org/10.1007/s13399-023-04785-7

[32] Y.G. TG, S. Ballupete Nagaraju, M. Puttegowda, A. Verma, S.M. Rangappa, S. Siengchin Biopolymer-Based Composites: An Eco-Friendly Alternative from Agricultural Waste Biomass. Journal of Composites Science, 7 (2023) 242. https://doi.org/10.3390/jcs7060242

[33] H.P.S.A. Khalil, E.B. Yahya, F. Jummaat, A.S. Adnan, N.G. Olaiya, S. Rizal, C.K. Abdullah, D. Pasquini, S. Thomas, Biopolymers based aerogels: A review on revolutionary solutions for smart therapeutics delivery. Progress in Materials Science, 131 (2023) 101014. https://doi.org/10.1016/j.pmatsci.2022.101014

[34] V. Ganesan, V. Shanmugam, B. Kaliyamoorthy, S. Sanjeevi, S.K. Shanmugam, V. Alagumalai, Y. Krishnamoorthy, M. Försth, G. Sas, S.M.J. Razavi, O. Das, Optimisation of mechanical properties in saw-dust/woven-jute fibre/polyester structural composites under liquid nitrogen environment using response surface methodology. Polymers, 13 (2021). https://doi.org/10.3390/polym13152471

[35] Y. Liu, S. Ahmed, D.E. Sameen, Y. Wang, R. Lu, J. Dai, S. Li, W. Qin, A review of cellulose and its derivatives in biopolymer-based for food packaging application. Trends in Food Science & Technology, 112 (2021) 532–546. https://doi.org/10.1016/j.tifs.2021.04.016

[36] S. Suresh Kumar, S. Thirumalai Kumaran, G. Velmurugan, A. Perumal, S. Sekar, M. Uthayakumar, Physical and mechanical properties of various metal matrix composites: A review. Materials Today: Proceedings, 50 (2021) 1022–1031. https://doi.org/10.1016/j.matpr.2021.07.354

[37] N. Lakshmaiya, S. Kaliappan, P.P. Patil, V. Ganesan, J.A. Dhanraj, C. Sirisamphanwong, T. Wongwuttanasatian, S. Chowdhury, S. Channumsin, M. Channumsin, K. Techato, Influence of Oil Palm Nano Filler on Interlaminar Shear and Dynamic Mechanical Properties of Flax/Epoxy-Based Hybrid Nanocomposites under Cryogenic Condition, Coatings. 12 (2022) 1675. https://doi.org/10.3390/coatings12111675

[38] S.B. Nagaraju, H.C. Priya, Y.G.T. Girijappa, M. Puttegowda, 9-Lightweight and sustainable materials for aerospace applications. Lightweight and Sustainable Composite Materials, Elsevier, (2023) 157–178. https://doi.org/10.1016/B978-0-323-95189-0.00007-X

[39] A. Das, T. Ringu, S. Ghosh, N. Pramanik, A comprehensive review on recent advances in preparation, physicochemical characterization, and bioengineering applications of biopolymers. Polymer Bulletin, 80 (2023) 7247–7312. https://doi.org/10.1007/s00289-022-04443-4

[40] J. Ma, J. He, X. Kong, J. Zheng, L. Han, Y. Liu, Z. Zhu, Z. Zhang, From agricultural cellulosic waste to food delivery packaging: A mini-review. Chinese Chemical Letters, 34 (2023) 107407. https://doi.org/10.1016/j.cclet.2022.04.005

[41] E. Padoan, E. Montoneri, G. Bordiglia, V. Boero, M. Ginepro, P. Evon, C. Vaca-Garcia, G. Fascella, M. Negre, Waste biopolymers for eco-friendly agriculture and safe food production. Coatings, 12 (2022) 239. https://doi.org/10.3390/coatings12020239

[42] Z. Ding, V. Kumar, T. Sar, S. Harirchi, A.M. Dregulo, R. Sirohi, R. Sindhu, P. Binod, X. Liu, Z. Zhang, M.J. Taherzadeh, M.K. Awasthi, Agro waste as a potential carbon feedstock for poly-3-hydroxy alkanoates production: Commercialization potential and technical hurdles. Bioresource Technology, (2022) 128058. https://doi.org/10.1016/j.biortech.2022.128058

[43] P. Choudhary, A. Pathak, P. Kumar, N. Sharma, Commercial production of bioplastic from organic waste–derived biopolymers viz-a-viz waste treatment: A minireview. Biomass Conversion and Biorefinery, (2022) 1–11. https://doi.org/10.1007/s13399-022-03145-1

[44] A. Agarwal, B. Shaida, M. Rastogi, N.B. Singh, Food packaging materials with special reference to biopolymers-properties and applications. Chemistry Africa, 6 (2023) 117–144. https://doi.org/10.1007/s42250-022-00446-w

[45] H. Rana, A. Sharma, S. Dutta, S. Goswami, Recent Approaches on the Application of Agro Waste Derived Biocomposites as Green Support Matrix for Enzyme Immobilization. Journal of Polymers and the Environment, 30 (2022) 4936–4960. https://doi.org/10.1007/s10924-022-02574-3

[46] X. Xie, Z. Zhou, Y. Yan, Flexural properties and impact behaviour analysis of bamboo cellulosic fibers filled cement based composites. Construction and Building Materials, 220 (2019) 403–414. https://doi.org/10.1016/j.conbuildmat.2019.06.029

[47] K.R. Sumesh, K. Kanthavel, V. Kavimani, Peanut oil cake-derived cellulose fiber: Extraction, application of mechanical and thermal properties in pineapple/flax natural fiber composites. International Journal of Biological Macromolecules, 150 (2020) 775–785. https://doi.org/10.1016/j.ijbiomac.2020.02.118

[48] Y. Liu, J. Xie, N. Wu, Y. Ma, C. Menon, J. Tong, Characterization of natural cellulose fiber from corn stalk waste subjected to different surface treatments. Cellulose, 26 (2019) 4707-4719. https://doi.org/10.1007/s10570-019-02429-6

[49] B. Aaliya, K.V. Sunooj, M. Lackner, Biopolymer composites: a review. International Journal of

Biobased Plastics, 3 (2021) 40–84. https://doi.org/10.1080/24759651.2021.1881214

[50] J.X. Chan, J.F. Wong, A. Hassan, Z. Zakaria, 8 - Bioplastics from agricultural waste. Biopolymers and Biocomposites from Agro-Waste for Packaging Applications, (2021)141–169. https://doi.org/10.1016/B978-0-12-819953-4.00005-7

[51] N.S.N. Arman, R.S. Chen, S. Ahmad, Review of state-of-the-art studies on the water absorption capacity of agricultural fiber-reinforced polymer composites for sustainable construction. Construction and Building Materials, 302 (2021) 124174. https://doi.org/10.1016/j.conbuildmat.2021.124174

[52] N. Lakshmaiya, V. Ganesan, P. Paramasivam, S. Dhanasekaran, Influence of Biosynthesized Nanoparticles Addition and Fibre Content on the Mechanical and Moisture Absorption Behaviour of Natural Fibre Composite. Applied Sciences, 12(24), (2022) 13030. https://doi.org/10.3390/app122413030

[53] Y. Zhou, J. Chen, X. Liu, J. Xu, Three/Four [Dimensional Printed PLA Nano/Microstructures: Crystallization Principles and Practical Applications. International Journal of Molecular Sciences, 24 (2023) 13691. https://doi.org/10.3390/ijms241813691

[54] R. Brunšek, D. Kopitar, I. Schwarz, P. Marasović, Biodegradation Properties of Cellulose Fibers and PLA Biopolymer. Polymers, 15(17) (2023) 3532. https://doi.org/10.3390/polym15173532

[55] S. Ramanadha reddy, N. Venkatachalapathi, A review on characteristic variation in PLA material with a combination of various nano composites. Materials Today: Proceedings, (2023). https://doi.org/10.1016/j.matpr.2023.04.616

[56] V. Ganesan, V. Shanmugam, V. Alagumalai, Composites Part C : Open Access Optimisation of mechanical behaviour of Calotropis gigantea and Prosopis juliflora natural fibre-based hybrid composites by using Taguchi-Grey relational analysis, Composites Part C: Open Access. 13 (2024) 100433. https://doi.org/10.1016/j.jcomc.2024.100433

[57] E. Finocchio, C. Moliner, A. Lagazzo, S. Caputo, E. Arato, Water absorption behavior and physico-chemical and mechanical performance of PLA-based biopolymers filled with degradable glass fibers. Journal of Applied Polymer Science, 140 (2023) e54578. https://doi.org/10.1002/app.54578

[58] T.A. Swetha, A. Bora, K. Mohanrasu, P. Balaji, R. Raja, K. Ponnuchamy, G. Muthusamy, A. Arun, A comprehensive review on polylactic acid (PLA)–Synthesis, processing and application in food packaging. International Journal of Biological Macromolecules, 234 (2023) 123715. https://doi.org/10.1016/j.ijbiomac.2023.123715

[59] G. Velmurugan, J.S. Chohan, S.A. Muhammed Abraar, R. Sathish, S. Senthil Murugan, M. Nagaraj, S. Suresh Kumar, V. Siva Shankar, D. Elil Raja, Investigation of Nano SiO2 Filler Loading on Mechanical and Flammability Properties of Jute-Based Hybrid Polypropylene Composites. Silicon, 15 (2023) 7247–7263. https://doi.org/10.1007/s12633-023-02578-1

[60] L. Natrayan, S. Kaliappan, B.S. Sethupathy, S. Sekar, P.P. Patil, G. Velmurugan, T. Tariku Olkeba, Effect of Mechanical Properties on Fibre Addition of Flax and Graphene-Based Bionanocomposites. International Journal of Chemical Engineering, 2022 (2022). https://doi.org/10.1155/2022/5086365

[61] G. Velmurugan, S.S. Kumar, J.S. Chohan, A.J.P. Kumar, T. Manikandan, D.E. Raja, K. Saranya, M. Nagaraj, P. Barmavatu, Experimental Investigations of Mechanical and Dynamic Mechanical Analysis of Bio-synthesized CuO/Ramie Fiber-Based Hybrid Biocomposite, Fibers and Polymers. (2023). https://doi.org/10.1007/s12221-023-00432-0

[62] G. Velmurugan, V. Siva Shankar, M. Nagaraj, M. Abarna, B. Rupa, S.K. Raheena, Investigate the effectiveness of aluminium trihydrate on the mechanical properties of hemp/polyester based hybrid composites. Materials Today: Proceedings, 72 (2023) 2322–2328. https://doi.org/10.1016/j.matpr.2022.09.399

[63] A. Grylewicz, T. Spychaj, M. Zdanowicz, Thermoplastic starch/wood biocomposites processed with deep eutectic solvents. Composites Part A: Applied Science and Manufacturing, 121 (2019) 517–524. https://doi.org/10.1016/j.compositesa.2019.04.001

[64] A.F. Osman, L. Siah, A.A. Alrashdi, A. Ul-Hamid, I. Ibrahim, Improving the tensile and tear properties of thermoplastic starch/dolomite biocomposite film through sonication process. Polymers, 13(2), (2021) 274. https://doi.org/10.3390/polym13020274

[65] G. Velmurugan, V. Siva Shankar, M. Kalil Rahiman, D. Elil Raja, M. Nagaraj, T.J. Nagalakshmi, Experimental Investigation of High Filler Loading of SiO_2 on the Mechanical and Dynamic Mechanical Analysis of Natural PALF

fibre-Based Hybrid Composite. Silicon, 15 (2023) 5587–5602. https://doi.org/10.1007/s12633-023-02464-w

[66] G. Velmurugan, V. Siva Shankar, M. Kalil Rahiman, R. Prathiba, L.R. Dhilipnithish, F.A. Khan, Effectiveness of silica addition on the mechanical properties of jute/polyester based natural composite, Materials Today: Proceedings, 72(4), (2023) 2075–2081. https://doi.org/10.1016/j.matpr.2022.08.138

[67] S. Wang, P. Zhang, Y. Li, J. Li, X. Li, J. Yang, M. Ji, F. Li, C. Zhang, Recent advances and future challenges of the starch-based bio-composites for engineering applications. Carbohydrate Polymers, 307, (2023) 120627. https://doi.org/10.1016/j.carbpol.2023.120627

[68] M.M. Reza, H.A. Begum, A.J. Uddin, Potentiality of sustainable corn starch-based biocomposites reinforced with cotton filter waste of spinning mill. Heliyon, 9 (2023) 27. https://dx.doi.org/10.2139/ssrn.4335483

[69] E. Pérez-Pacheco, C.R. Rios-Soberanis, J.H. Mina-Hernández, V.M. Moo-Huchin, Use of cellulose fiber from Jipijapa (Carludovicapalmata) as fillers in corn starch-based biocomposite film. Iranian Polymer Journal, 33, (2024) 157-168. https://doi.org/10.1007/s13726-023-01244-y

[70] B. Aaliya, K.V. Sunooj, A. Vijayakumar, P. Krina, M. Navaf, P.P. Akhila, P. Raviteja, S. Mounir, M. Lackner, J. George, M.R. Nemțanu, Fabrication and characterization of talipot starch-based biocomposite film using mucilages from different plant sources: A comparative study. Food Chemistry, 438, (2023) 138011. https://doi.org/10.1016/j.foodchem.2023.138011

[71] C.M. Chan, D. Martin, E. Gauthier, P. Jensen, B. Laycock, S. Pratt, Utilisation of Paunch Waste as a Natural Fibre in Biocomposites. Polymers, 14(18) (2022) 3704. https://doi.org/10.3390/polym14183704

[72] V. Alagumalai, V. Shanmugam, N.K. Balasubramanian, Y. Krishnamoorthy, V. Ganesan, M. Försth, G. Sas, F. Berto, A. Chanda, O. Das, Impact response and damage tolerance of hybrid glass/kevlar-fibre epoxy structural composites. Polymers, 13(16), (2021) 2591. https://doi.org/10.3390/polym13162591

[73] M. Wan, S. Liu, D. Huang, Y. Qu, Y. Hu, Q. Su, W. Zheng, X. Dong, H. Zhang, Y. Wei, W. Zhou, Biocompatible heterogeneous bone incorporated with polymeric biocomposites for human bone repair by 3D printing technology. Journal of Applied Polymer Science, 138(13), (2021) 50114. https://doi.org/10.1002/app.50114

[74] A. Pudełko, P. Postawa, T. Stachowiak, K. Malińska, D. Drozdz, Waste derived biochar as an alternative filler in biocomposites - Mechanical, thermal and morphological properties of biochar added biocomposites. Journal of Cleaner Production, 278 (2021). https://doi.org/10.1016/j.jclepro.2020.123850

[75] G. Velmurugan, L. Natrayan, Experimental investigations of moisture diffusion and mechanical properties of interply rearrangement of glass/Kevlar-based hybrid composites under cryogenic environment. Journal of Materials Research and Technology, 23 (2023) 4513–4526. https://doi.org/10.1016/j.jmrt.2023.02.089

[76] T.G. Yashas Gowda, S. Ballupete Nagaraju, M. Puttegowda, A. Verma, S.M. Rangappa, & S. Siengchin, Biopolymer-Based Composites: An Eco-Friendly Alternative from Agricultural Waste Biomass. Journal of Composites Science, 7(6) (2023) 242. https://doi.org/10.3390/jcs7060242

[77] S. Agarwal, S. Singhal, C.B. Godiya, S. Kumar, Prospects and applications of starch based biopolymers. International Journal of Environmental Analytical Chemistry, 103 (2023) 6907–6926. https://doi.org/10.1080/03067319.2021.1963717

[78] S.N. Kumar, R. Jain, K. Anand, H. Ajay Kumar, Utilization of Agro Waste for the Fabrication of Bio Composites and Bio plastics—Towards a Sustainable Green Circular Economy. In: Sandhu, K., Singh, S., Prakash, C., Subburaj, K., Ramakrishna, S. (eds) Sustainability for 3D Printing. Springer Tracts in Additive Manufacturing. Springer, Cham. https://doi.org/10.1007/978-3-030-75235-4_7

[79] Z. Tabassum, A. Mohan, N. Mamidi, A. Khosla, A. Kumar, P.R. Solanki, T. Malik, M. Girdhar, Recent trends in nanocomposite packaging films utilising waste generated biopolymers: Industrial symbiosis and its implication in sustainability. IET Nanobiotechnology, 17(3), (2023) 127–153. https://doi.org/10.1049/nbt2.12122

[80] K.F. Chai, W.N. Chen, Potential of food and agricultural wastes as sustainable medical materials for neural tissue engineering. Current Opinion in Biomedical Engineering, 28 (2023) 100476. https://doi.org/10.1016/j.cobme.2023.100476

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G. Velmurugan & Jasgurpreet Singh Chohan: Conceptualization, Writing an original draft and Methodology; M. Abhilakshmi & S. Harikaran: Investigation; M.P Shakthi dharshini & C.H. Sai Nithin: Review and Editing.

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