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Exploring the Potential of Bio waste fillers for development of Ecofriendly Polymer Bio-Composites: A review

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Abstract. *Researchers have concentrated on defining a variety of ecological matrix/natural filler combinations in order to develop new versions of biodegradable/ecofriendly composites with superior mechanical characteristics and to produce products with lesser costs. In order to generate more ecofriendly products, producers are exploring various methods to decrease the extent of polymer used in the production of various polymer-based products. Different kinds of fibre/Fine powder (particulate) fillers are frequently blended to the processing of polymer composites, which typically combine the benefits of their constituent phases, in order to overcome the major disadvantages of polymers, such as lesser stiffness and strength, and to develop their uses in various engineering fields. Large amount of bio waste get generated during agri processing, food sector and other process. It was not utilised further for fruitful applications. The many researchers tried to find out possibility of use of these waste as fillers in the development of ecofriendly improved polymer composites. This paper focused on review of research work to explore the use of various bio waste fillers for development of new better composites.*
Keywords: *Polymer, Bio-composites, Bio-waste fillers, Mechanical properties*

1. INTRODUCTION

Composites: are combinations of two or more materials where one of the elements, denoted to as the reinforcing phase, is added in the other material, known as the matrix phase. Ceramic , Metal or polymer are all suitable alternatives for the matrix and strengthening (reinforced) materials.
Classification of Composites: Depending on the matrix used in composites, they can be classified as metal matrix, ceramic matrix and polymer matrix composites. Matrix plays vital role in composites.
Eco-friendly (Green) Composites: The development of biologically ecofriendly (green) composites is currently the focus of attention. Green composites are a particular category of bio composites that are a developing field in polymer science. They consist of an ecologic polymer matrix blended by natural fibres. Due to environmental issues caused by traditionally produced plastics and a rising desire for fossil resource alternatives globally, green composites made from biodegradable renewable resources have attracted a lot of interest.
Classification of Eco-friendly (Green) composites
Eco-friendly (Green) composites are categorized based on matrix and reinforcement of polymer materials; they are distributed into three types as given below

(a) **Totally Green/Renewable composites**: Matrix and reinforcement both are having ecological/renewable resources.
(b) **Partially or semi- Green /Renewable composites:** matrix is sourced from ecological /Renewable resources and reinforced with a man-made (synthetic) material.
(c) **Partially or semi-Green/Renewable composites:** synthetic (artificial) matrix is blended (reinforced) with nature-based bio polymers.

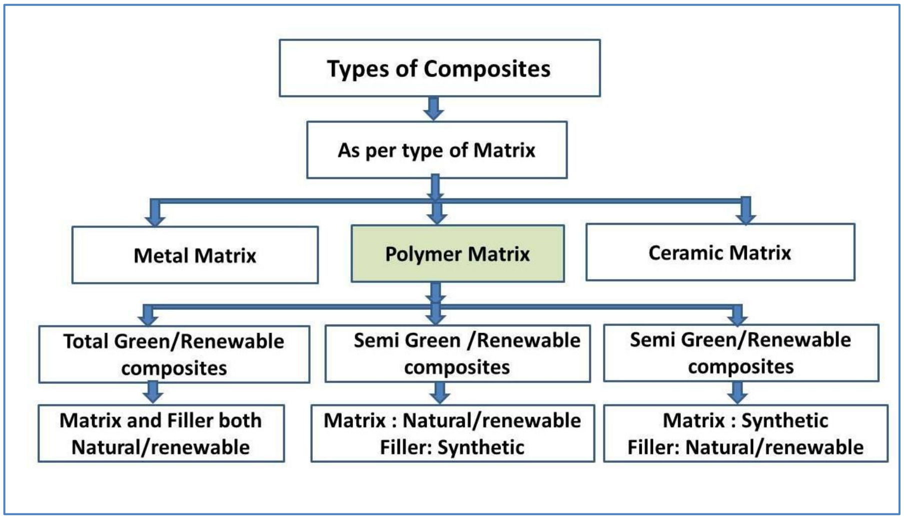

FIGURE 1. Classification of Composites

Novel materials have been found, such as metal matrix composites, polymeric composites and ceramic matrix composites which have all been found to be capable substitutes in a variety of engineering applications when matched to previously used materials, according to studies on composites. Little advancement has been made in using natural fibres or particles as reinforcement for polymeric composites. In a composite, one component, known as the matrix, is equally continuous, while another phase, identified as the reinforcement, is dispersed across the matrix. The Polymer-matrix composite (PMCs) uses particulate/fibers as the reinforcement medium and polymer resin which is a reinforcing plastic having high molecular weight as the matrix. The enhancement of the mechanical/physical properties of high performance superior materials depends greatly on the reinforcement of polymers by particles. To maintain the environment and efforts would be efficiently utilize the unused waste produced by food and allied sectors. Agriculture produces 140 billion metric tonnes of agricultural waste annually throughout the world. This quantity of agricultural waste can be transformed into enormous quantities of valuable resources, including energy, composites, and raw materials equating to about 50 billion tonnes of fuel. Agro waste, which includes leftover leaves, husk, stalk, straw, hull, nut or seed shells and waste wood, is a crucial resource for waste-wealthy plastic composites since it is widely accessible, renewable, and essentially free. The quest for ecological improvements offers a potential replacement for the creation of "new" composites.

2.LITERATURE REVIEW OF BIO WASTE FILLERS

Walnut shell powder: A completely natural, biodegradable, long-lasting substance with exceptional strength properties is walnut shells. It has a 1.2–1.4 specific gravity, a MOH hardness of 3.5, and a Rockwell hardness of 91. Walnut shells are resistant to fermentation and work well in a range of pH and temperature situations. They are appropriate blast media for outdoor applications since they are reusable and reclaimable. Ground walnut shell is a good anti- slip addition for floors, ramps, stairs, decks, and swimming pools. Additionally, walnut shell flour is a popular component in the production of rubber and plastic compounds. They are used in burn-out applications to increase ceramics' porosity. Walnut shells have larger concentrations of hydrophobic substances and less of the hygroscopic substances (cellulose and hemicellulose) than cellulosic materials do (lignin).Walnut shell fibres' chemical make-up consists of cellulose (23.9%), lignin (50.3%), hemicellulose (22.4%), and ash (3.4%).

TABLE 1. Composition of Walnut shell

Chemical composition	Cellulose	Ash	Toluene Solubility	Lignin	Cutin	Chlorine	Nitrogen
Wt%	40-60	0.9-1.5	0.5-1.0	20-30	0.8-1.59	0.10	0.10

M.U Obidiegwu [1] the influence of filler content along with particle size is investigated for composite of polypropylene blended with walnut shell powder for mechanical and actual use properties. The particle sizes of 0.10, 0.20, and 0.30 mm and amount of filler contents varies from 0 to 20 wt% .The polypropylene composites manufactured by injection molding process.

The conclusion was there is reduction in flexural strength, elongation at break, tensile strength with rise in walnut shell filler contents.

TABLE 2. Summary of Walnut shell as a bio filler in Composites

Matrix	Method adopted	Testing parameters	Ref.
Polypropylene	Injection moulding	Flexural strength, Elongation at break, tensile strength	[1]
Thermoplastic Starch	Injection molding	Tensile strength, Flexural strength, Elastic modulus, Soil burial degradation	[2]
UF urea–formaldehyde	Hydraulic hot press	Modulus of elasticity, Modulus of rupture, and internal bond strength	[3]
Urea– formaldehyde (UF) resin	Hydraulic hot press	Modulus of elasticity, Modulus of rupture, thickness swelling and water absorption, internal bond strength,	[4]
Polypropylene (PP)	Twin-screw extruder	Tensile strength, Flexural strength, Screw holding strength , Thickness swelling, Nail holding strength ,Water absorption	[5]
Low Density Polyethylene	Hydraulic Press	Average Time of Burning ATB, Elongation at break, Young modulus	[6]
UF urea–formaldehyde	Hydraulic hot press	Modulus of rupture, Modulus of elasticity and internal bond strength	[7]

The authors [2] were conducted research for use of flour of walnut shell up to 40% , nanoclay up to 5% in the matrix of starch of thermoplastic composites. The developed composites shown improvement in elasticity modulus, flexural and tensile strength. The fiber boards of medium density were prepared by [3] using combination of powder of walnut shell and fibers of wood and resin of urea formaldehyde with modified SiO2.The panels testing shows improvement in resistance to water but fall in flexural strength and strength of internal bonds. The walnut shell and almond shells are used combined with resin of urea formaldehyde [4] to develop panels as a replacement for wood particle boards. It has lower swelling, reduced absorption of water and less emission of formaldehyde. The work is [5] carried out for possibility of walnut shell fine powder to make polypropylene hybrid composites and results shown improvement in tensile and flexural strength with blending of 3% of oragoclay. LDPE Composites combined with walnut shells were examined for their mechanical characteristics [6]. The optimal fibres ratio was between 10% and 15%, while the range of additional walnut shells had polyethylene weight values of (0%, 2.5%, 5%, 10%, 15%, 20%, and 25%). When adding walnut shells at a weight ratio of 10%, there was a noticeable increase in the mechanical parameters. The feasibility of employing walnut shell particles in the production of three-layer particleboard was examined in this work [7]. The findings demonstrate that particleboards can be made utilising a blend of wood and walnut shell particles and urea-formaldehyde as the binder. The panels' water resistance was greatly enhanced by the addition of walnut shell particles, however as the walnut shell particle level in the panels increased, the panels' mechanical qualities declined. The author [8] conducted review of composites in which walnut shell was used as a reinforcement to develop composites with improved properties.

Egg shell powder: In the process of creating composites, which utilise nylon black and polyamide as matrix materials, reinforcement was egg shell particles. Using an injection moulding method, polyamide/nylon black egg shell composites are created in this research [9]. The test sample specimens were made as per ASTM guidelines. Egg shell consists of structure of three-layers, specifically the cuticle on the external surface, a spongy layer and an internal lamellar (or mammillary) layer. The biochemical configuration (by weight) of eggshell contains calcium carbonate - 94%, calcium phosphate-1%, magnesium carbonate -1%, and organic matter -4% such as type sulfated polysaccharides, X-collagen and other proteins [9].This research examined the mechanical,thermal properties of a polypropylene matrix changed when eggshell was added as a bio-filler. Cleaning, heating, grinding, and sieving the eggshell to a 212 m particle size came first. Then, using a mixer machine, propylene and eggshell powder were combined in ratios of 9:1, 7:3, and 5:5. Finally, hot press and then cold press machines were used to form the composite mixes.

TABLE 3. Composition of an Egg shell

Chemical Composition	**CaCO3**	**S**	**Mg**	**P**	**Sr**
Wt%	95-96	2.36	0.404	0.501	0.0737

TABLE 4. Summary of an Egg shell powder as a bio filler in Composites

Matrix	**Method adopted**	**Testing parameters**	**Ref.**
Natural rubber latex foam (NRLF)	Not mentioned	particle size, Scanning electron microscopy (SEM), surface morphology,X-ray fluorescence (XRF), and FTIR ,TGA	[9]
Polypropylene	hot press and cold press	Fourier transformed infrared (FTIR) ,Thermo gravimetric analysis (TGA), tensile test	[10]
Natural rubber	Moulding method	Tensile strength and tear strength, Hardness, specific gravity, elongation at break	[11]
PLA	Single barrel extruder	SEM and XRD, Tensile and Flexural test, Biodegradability	[12]
PLA	Composite Film casting method	Tensile strength and modulus FTIR spectral, TGA, X-ray, and microscopic analyses	[13]
Corn starch	Casting technique	Scanning electron microscopy (SEM), Moisture content, swelling power, water solubility, water absorption, Transmission electron microscopy (TEM)	[14]

The findings of this study [10] demonstrated that the composite's tensile stress and strain were improved by using egg shell powder reinforcement as a bio filler. In comparison to pure PP, which disintegrated at a greater temperature, the produced composite's thermal stability has been improved by thermal degradation at various ratios. The PP:ES ratio is the ideal one to manufacture the green eggshell/polypropylene bio composite (7:3). Before exploring the created bio composites possible uses as consumer end products or industrial applications, future research should examine their biodegradability. The research [11] adopted moulding process with different weight ratios of banana stem fiber as 5%, 10%, 15%, 20% and egg shell powder to create the egg shell powder-banana stem fiber natural rubber composites. PLA blended with powder of eggshell composites were analsyed for mechanical properties and biodegradability and egg shell power was added in the amount of 10,15 and 20% [12]. Mechanical testing indicates that the mechanical firmness of the PLA-calcium carbonate bio-composite reduced compared to that of pure PLA. It was concluded that PLA-ESP bio composites are eco-friendly. The Poly(lactic acid)/Egg shell powder (PLA/ESP) composite films [13] were made utilising the film casting process using chloroform as the solvent. 1 to 5 weight percent of ESP was put into PLA. Tensile, FTIR spectral, X-ray, thermogravimetric and microscopic examinations of the films were performed. The composite films' tensile strength and modulus were discovered to be greater than PLA and improved with ESP content up to 4 weight % before decreasing. In the case of % elongation at break, a different pattern was seen.

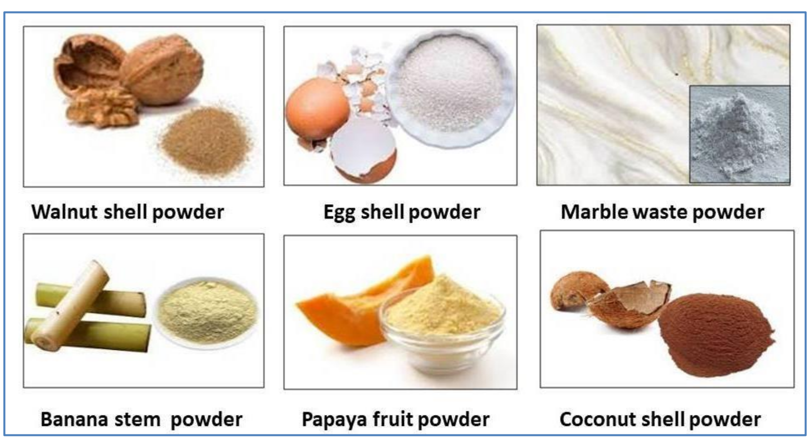

FIGURE 2. Various bio waste filler for development of polymer composites

White Marble Powder: The Rajasthan region accounts for 85–90% of all Indian marble excavations Since the world's consumption is now increasing and the estimated residual resources should be sufficient for hundreds of years based on the present production rates, it is not currently anticipated that the production of marble will diminish. The existence of marble dust (MD) waste, a byproduct of the marble brick cutting process, is a significant problem within the marble industry.

TABLE 5. Composition of White marble powder

Chemical Composition	CaCO3	Al 2O3	SiO2	Fe2 O3	MgO
Wt%	85 - 97	0.520	26.35	9.40	1.52

In this research [15] author reported use of marble dust particulates (MPs) having calcium-rich content as economic strengthening in biodegradable polypropylene (PP) to prepare ecological composites by using injection molding method. The method was optimized to develop high- strength, thermally insulated lightweight sustainable composites. After the experimental analysis carried out, created green composites were discovered to be low density, high strength, recyclable, energy-saving, thermally insulated, and water-resistant materials made from marble waste.

TABLE 6. Summary of Marble powder as a bio filler in Composites

Matrix	Method adopted	Testing parameters	Ref.
Polypropylene (PP)	Injection molding	Water absorption , Tensile, flexural strength, impact strength, thermal conductivity	[15]
Polyester resin	Molding method	Tensile test, compression test, and bending test	[16]
Epoxy	Manual hand layup technique	Tensile Strength(T.S), Flexural Strength (F.S),Tensile Modulus(T.M), Impact Strength (I.S), Compression Strength (C.S)	[17]
PLA	Melt blending	Mechanical, Wear resistance morphological, Thermal properties	[18]
Polyester	Mould casting	Strength and hardness, Microstructures	[19]

In this study [16] several composites (a mixture of matrix, marble powder, and Kenaf fibre) were made and tested in an effort to produce varied mechanical properties and achieve good tensile strength in sample specimens with varying compositions. Four compositions of matrix mix and marble powder were used to prepare test specimens: 50:50, 60:40, 70:30, and 80:20, with a fixed 2 gramme weight of kenaf fibre. The bonding abilities of the polyester resin used as a matrix to link the kenaf fibres as reinforcement will be reduced if the percentage of marble powder is increased. By manually hand-laying up [17] four compositions filled with marble powder (0wt%, 5wt%, 10wt%, and 15wt%),epoxy-based composites are created. There has been mechanical characterization, and when compared to other composites, 5wt% marble powder loaded epoxy composites have higher tensile strength and tensile modulus. This research has shown that unfilled epoxy has the highest flexural strength and compression strength. The findings suggest [18] that the inclusion of Marble dust (MD) in the PLA has significant relevance for industrial use. Most of the qualities examined in this study either became better or barely changed. Therefore, there are three benefits of using MD in PLA-based composites. First off, the cost of the biopolymer may be significantly reduced, which could aid in its global adoption, as a sizeable portion of PLA can be replaced by MD, which is basically free. Second, the environmental problems brought on by the disposed-of waste MD might be decreased. Thirdly, the improved PLA characteristics brought about by the addition of marble particles might expand the range of potential applications. In this work [19], polyester matrix composite material was created using varying amounts of marble dust, fly ash and polyester as the basis material, methyl ethyl keton peroxide as the hardener, and cobalt naphtanates as the accelerator. Investigations into the mechanical behavior of composite materials led to the identification of ideal values. Only the fly ash/marble dust ratio was altered during the initial stage of the production of composite material, leaving the proportions of hardener along with accelerator, and polyester unchanged. According to the experimental findings, increasing the fly ash/marble dust ratio by up to one-third boosted both the hardness and strength of the composite materials. Thus, highly durable and strong composite materials were created.

Banana bio waste: In this study [20], banana fibers—natural fibers from the bark of banana trees are recycled to reinforce the composite material. The fibers are taken from banana peels, processed with 5% NaOH, and then cut in to pieces of an average length of 30 mm. For epoxy resin Epikote 240, banana fiber is reinforced with mass percentages of 10 weight %, 15 weight %, 20 weight %, and 25 weight %. Thermal, mechanical, fire-resistance, and structural morphological (SEM) qualities were used to assess the results. As per the experimental results, biosynthetic materials have up to 20% greater tensile, impact and compressive strengths by weight than epoxy neat. 20 weight percent banana fiber provides a limiting oxygen index of 20.8% and adequate thermal stability, maintaining both flame retardant and thermal characteristics. Water absorption experiments were performed on banana fiber reinforced IPN laminate in this study [21] to examine how water absorption affects the material's physical characteristics. The specimens were immersed in a de- ionized water bath that was kept at 45°C, 55°C, and 65°C for varying periods of time (7 days) in order to undergo the accelerated hygrothermal examination. Following the immersion test, a study of their tensile, flexural, and impact strengths was conducted to verify their mechanical strength. It was discovered throughout the test that the natural (banana) fiber reinforced IPNs' water absorption properties consistently had a negative impact on the specimens' strength. Additionally, it was a regular occurrence for the specimen's strength to deteriorate at high temperatures. Banana plant powder particles are affixed to the polylactic acid (PLA) employed in this experiment [22]. Dried banana fiber from Chennai was used to make the banana particles. This study examines PLA 3D printed composite samples reinforced with varying weight percentages of banana natural powder. These banana fiber composite samples had high mechanical strength in all three dimensions (tensile, flexural, and impact) when compared to the raw PLA composites. With PLA-based composites, the hardness values of the natural banana powder have reached a significant strength. The percentages of banana powder range from 2.5 to 7.5 to 10%. Three distinct processing methods Extrusion injection molding (EIM), Direct injection molding (DIM) and extrusion compression molding (ECM)—were used in the current experimental study [23] to create biocomposites created on short banana fiber (20 weight percent) and polylactic acid. To comprehend and compare the performance of the produced biocomposites, dynamic mechanical analysis, thermal characterization, and mechanical characterization have all been carried out. The biocomposites made by EIM showed notable improvements in their tensile and flexural properties, dynamic mechanical (loss modulus, storage modulus and tan delta), and crystallinity characteristics. In this research work [24], the melt blending method was used to create polylactic acid (PLA)/banana fiber (BF) composites. Consequently, the addition of BF significantly improved the PLA's mechanical and thermal stability. Mechanical testing demonstrated that the fiber content significantly boosted the composites' tensile and flexural strengths, which reached 78.6 and 65.4 MPa when strengthened with 40 phr fiber—roughly 2 and 1.66 times greater than those formed by pristine PLA. However, the higher fiber content of composites results in a slight drop in their impact strengths. The HDT of pure PLA improved by around 122% when 40 phr BF was added to the composite, rising from 62 °C to 139 °C.

TABLE 7. Composition of Banana peel biowaste

Chemical Composition	Water	Carbohydrates	Magnesium	Phosphorus	Potassium
Wt%	74.91	22.84	8	3	8

TABLE 8. Summary of Banana bio waste as a bio filler in Composites

Matrix	Method adopted	Testing parameters	Ref
Poly-lactic acid (PLA)	Extrusion and 3D printing	Hardness, Absorbance behavior	[20]
Interpenetrating polymer network (IPN)	Laminates fabrication method	Tensile, flexural and impact strength, Water absorption	[21]
Epikote 240 epoxy (E 240)	Hydraulic press using mould	Structural morphology (SEM),fire resistance, and thermal properties. tensile, compressive, impact strengths	[22]
Poly-lactic acid (PLA)	Direct injection, Extrusion injection, Extrusion compression Molding	XRD analysis,Thermal and mechanical characterization	[23]
Poly-lactic acid (PLA)	Melt-blending technique	Tensile and flexural properties, impact strength	[24]

Papaya bio filler composites: This work [25] creates natural fiber and biochar with epoxy composites, which were intended for the preparation and characterisation of sustainable materials, using chopped areca fiber and papaya slice biochar as reinforcing elements. Mechanical testing revealed a 50 percent increase in flexural capabilities and a 62 percent improvement in tensile qualities. The 2% papaya slice biochar that was added to the mixture is what caused this improvement. An efficient network with a heat conductivity of 0.426W/mk is demonstrated using thermal conductivity in an epoxy matrix. The dielectric properties were steadily improved by the epoxy matrix's reinforcement addition. This research work [26] mainly dedicated for papaya bast short fibre polypropylene composites and comparison with wood plastic composites. Two types of papaya fibres were used one is papaya plantation and other is papaya greenhouse type. The composites were produced by injection moulding and young modulus was highest with 4093.1 Mpa in case of papaya greenhouse polypropylene composites compared to wood polypropylene composites having young modulus of 3224.8 Mpa. Similarly tensile strength papaya greenhouse polypropylene composites was observed higher compared to wood polypropylene composites. Fibrous laminas make up the papaya phloem, [27] which envelops and strengthens the plant's stem. Papaya-mixed epoxy composites are made by hand lay-up and tested in two full-factorial designs for configurations with and without holes, dependent on the fiber-to-load direction, in longitudinal (0°) as well as transverse (90°) circumstances. In addition to the initial experiment, composites composed of short fibers oriented randomly are also assessed. Its potential as a structural material is evaluated by comparing its tensile and flexural characteristics to those of other materials found in the literature. According to the findings, layers of papaya bast fiber may be a potential reinforcement for polymeric composites.

TABLE 9. Composition of papaya fruit bio waste

Chemical Composition	Water	Carbohydrates	protein	fat	Ash
Wt%	85-90	7.98	0.79	0.24	0.29

TABLE 10. Summary of papya bio waste as a bio filler in Composites

Matrix	Method adopted	Testing parameters	Ref.
Epoxy Bisphenol-A	hand layup process	Tensile and flexural properties, Thermal conductivity, Izod impact, Elongation	[25]
Polypropelyne PP Moplen HP501L	Injection moulding machine	Elongation, Young ‘s modulus, Tensile strength	[26]
Epoxy RenLam M resin	hand layup process	Tensile and flexural properties, Morphology	[27]

Coconut Shell bio waste: In this research work, The effects of the coupling agent 3- aminopropyltriethoxysilane (3-APE), filler content and the on the mechanical, thermal properties, and morphologies of polylactic acid (PLA) blended with coconut shell powder (CSP) bio composites were investigated [28]. It was concluded that increasing the CSP amount reduced the tensile strengths, elongations at break of the PLA/CSP bio composites. Though, combining CSP shown rise in modulus of elasticity. The modulus of elasticity, tensile strengths of the PLA/CSP bio-composites were enhanced due the addition of 3-APE, which can be recognized to a stronger filler–matrix interaction.

TABLE 11. Composition of coconut shell bio-waste

Chemical Composition	water	Lignin	Cellulose	Hemicellulose	Ash
Wt%	14.00	33.30	30.44	26.70	0.56

TABLE 12. Summary of Coconut waste as a bio filler in Composites

Matrix	Method adopted	Testing parameters	Ref.
Polylactic acid (PLA)/	Compression molding	Tensile strengths, modulus of elasticity and elongations at break, Thermogravimetric analysis (TGA), FTIR, Morphology	[28]
Epoxy resin	Hand lay-Up process	Flexural strength, Impact strength	[29]
Recycled Polypropylene	Hand lay-up process	Tensile strength, Hardness, Impact energy, Water absorption	[30]
Natural rubber	Compression molding	Tensile strength, Thermal stability, modulus of elasticity, Tear strength	[31]

Various other Bio waste fillers

Coconut shell and palm fruit particulate composites: In this research work [32], particles of the coconut shell and 95g, 90g, 85g, 80g, 75g and 70g corresponding weight of polyester resin were added to palm fruit reinforcement with various weight fractions (5, 10, 15, 20, 25 and 30) wt. %. Test samples were prepared by mould casting and the analysis of mechanical properties of the developed composites was done. Results displays that ultimate tensile strength of palm fruit particulate polyester composite was less and 62.5MPa and 70MPa was attained for the coconut shell particulate polyester composite, the highest impact strength for coconut shell particulate polyester composite was 4.76J, the highest hardness value was 208 BHN for coconut shell particulate polyester composite and 182.30 BHN while that of palm fruit particulate polyester composite. They are prospective materials for interior applications such as gear cams, dashboard, car seat, and car interior for decorative uses. Pineapple leaf fiber: In this review analysis [33] design and analysis of industrial safety helmet was done for utilization of pineapple leaf fiber, hand layup method was used for fabrication of industrial safety helmet by using pineapple leaf fiber and analysis is carried out for mechanical properties of industrial safety helmet.
Sugar cane bagasse fiber (SCBF): Sugar cane bagasse fiber (SCBF) used [34] as reinforcing (blending) element in manufacture of Polymer composite. Hand lay-up techniques are frequently utilised in the manufacture of polymer composites. Moreover, several researchers used moulding techniques like extrusion and centrifugal moulding. A wide range of industries, including aerospace, automotive, construction, decking, etc., use reinforced composite materials with natural fillers. SCB dust particles have never been employed, as per the survey of natural filler reinforced, in the making and application of low-priced epoxy-based composites.

FIGURE 3. Various other bio waste filler for development of polymer composites

Basalt fibre: This investigation [35] focuses on the fiber orientation of basalt fibre, effect of fibre content on mechanical properties of the newly developed composites. In this analysis the fabrication is done by hand lay-up process and different fiber orientations are taken, Uni directional basalt fiber is used throughout the experiment. The specimens for orientation of 90° give conservative result as compared to the specimens for orientation of 0° for each layer.
Flax fibres: The development of ecological composites [36] made of PHA was focuses on (Polyhydroxyalkanoate) matrix and with a reinforcement of flax nonwoven fabrics. The properties of both constituents work together to generate a solution that is biodegradable, stiff, and exhibits good regularity and lightweight during the foaming process, opening the door to the replacement of other less environmentally friendly materials in automotive, construction, and other sectors.
Bamboo fibre, Banana fibre and Linen fibre : The paper [37] deals with the detailed study of banana fibre, bamboo fibre and linen fibre cut into pieces of 2-4 mm of length having random orientations with epoxy resin. Various tests like Fourier Transform Infra-Red (FTIR) test, Impact test (IZOD and CHARPY test), and Rockwell Testing of hardness were conducted on 10 test specimens of bamboo–banana (90/5/5) epoxy resin composite, bamboo epoxy resin composite (90/10), and bamboo-linen (90/5/5) epoxy resin composite.
Human hair: The objective of this work [38] was to assess the human hair reinforced epoxy composites mechanical properties. The impact of length and fiber loading on mechanical properties like flexural strength, tensile strength impact strength and hardness of composites is examined. Trials were directed on polymer composites with different contents of human hair fiber i.e. 0%, 10%, 20%, 30% and with shifting length of human hair i.e. 0.5, 1,1.5 and 2 cm. It has been observed that there is significant influence on the mechanical behavior of composites due to human hair reinforcement.
Corn stalk husks: The study involved the use of volumetric fractions of 10%, 20%, and 30% of corn stalk husks. The composites were exposed to representation using the Charpy,Izod impact tests. The results got discovered superior

performance in relative to the epoxy matrix, with a gradual inclination to increase resistance proportional to the increase in volume fraction.

TABLE 13. Summary of Combination of various bio fillers in hybrid Composites

Filler and Matrix	Method	Testing parameters	Ref.
Filler: Coconut shell and palm fruit **Matrix:** polyester resin	Mould casting	Ultimate tensile strength, Impact strength, hardness	[32]
Filler: Pineapple leaf fiber **Matrix:**Epoxy resin	Hand layup	Ultimate tensile strength, Impact strength, hardness	[33]
Filler: Sugar cane bagasse **Matrix:**Epoxy resin	Hand layup	Ultimate tensile strength, Impact strength, Flexural strength	[34]
Filler: Basalt fiber **Matrix:**Epoxy resin	Hand layup	Ultimate Stress, Ultimate Load, Young's Modulus	[35]
Filler: Flax fibres **Matrix:**Polyhydroxyalkanoate PHA)	Extrusion foaming	Tensile, Impact strength, compression, water absorption	[36]
Filler: Bamboo,Banana/linen fibre **Matrix:** Polylactic Acid (PLA)	Injection moulding	Tensile, flexural, Impact and Hardness, SEM analysis	[37]
Filler: Human hair **Matrix:**Epoxy resin	Hand layup	Tensile strength, Flexural strength, Impact strength, Hardness	[38]
Filler: Corn stalk **Matrix:**Epoxy resin	Compression Moulding	Charpy and Izod impact tests	[39]
Filler: Household tea wastes **Matrix:**Poly (lactic acid) (PLA)	Hand layup	Tensile testing, Scanning electron microscopy, X-ray diffraction	[40]

3.GIST OF LITERATURE REVIEW

Types of Polymer matrix: As per review conducted for various types of polymer matrix used for many researchers following types of polymer base or matrix were suitable for making polymer composites.

a. **Polypropelyne:** It is a thermoplastic type of polymer used in various types of composites. It is mostly suitable for plastic packaging, machinery parts, fibers and textile applications. It has main merits include cheaper for manufacturing cost, superior chemical, electrical, heat resistance, and light weight. As per review it can be easily blended with walnut shell, egg shell powder, marble powder and papaya powder. It can be processed by injection moulding, hot and cold press, extrusion process.

b. **Epoxy resin:** It is a thermosetting polymer which has excellent adhesion, chemical resistance, corrosion resistance ideally suitable for coating, adhesives, hardware components, composite matrix due to high tensile strength, high stiffness. As per review, it can be easily blended with marble powder, banana fibres/powder, papaya fruit powder, coconut shell powder, basalt fibre, sugarcane baggase, Pineapple leaf fiber, Human hair, corn stalk,etc. It can be processed by injection moulding, hand lay-up method, Hydarulic press machines.

c. **Polylactic Acid PLA):** PLA is a thermoplastic polymer and its main element is lactic acid that is come from corn starch and it would be a favour economical polyester resin of the profiles using natural fibres with the economical process. As per review, it can be easily blended with egg shell, marble powder, banana bio waste, coconut waste, Bamboo, Banana/linen fibre, Household tea wastes. It can be processed by Single barrel extruder, Film casting, Hand layup, Injection moulding methods easily.

TABLE 14. Summary of types of polymer matrix

Polymer matrix	Fabrication Method	Reference
Polypropylene (PP)	Injection moulding, Twin-screw extruder, hot press and cold press	[1],[5],[10],[15],[26],[30]
Epoxy resin	hand layup, Hydraulic press using mould	[17],[22],[25],[27],[29],[33],[34],[35],[38],[39]
Polylactic Acid PLA)	Single barrel extruder, Film casting, Hand layup, Injection moulding	[12],[13],[18],[20],[23],[24],[28],[37],[40]
Natural rubber	Moulding method	[9],[11]

Effect of reinforcement of Bio fillers on properties of polymer matrix: According to the review done, following table highlights the effect of reinforcement of various bio fillers along with respective polymer matrix. It was observed that addition of bio fillers changed/improved mechanical properties like tensile, flexural strength, hardness, thermal behavior, modification in microstructure of newly developed composites. The bio fillers successfully blended with various polymer resins and shown modification/changes in characteristics compared to polymer without fillers. The bio waste fillers may be the element which can enhance the properties composites to eliminate the some limitations of various polymer matrixes.

TABLE 15. Summary of Effect of bio fillers on characteristics of composites

Type of Composite	Effect on characteristics of composites	Ref.
Polypropylene + walnut shell powder composites	Reduction in flexural strength, tensile strength, elongation at break, with rise in walnut shell filler contents	[1]
Walnut shell and fibers of wood and resin of urea formaldehyde	Improvement in resistance to water but fall in flexural strength and strength of internal bonds	[3]
Polypropylene + egg shell powder composites	Tensile stress and strain, thermal stability has been improved	[10]
Poly(lactic acid)/Egg shell powder (PLA/ESP) composite films	Composite films' tensile strength and modulus were discovered to be higher than PLA	[13]
Epoxy marble powder composites	5wt% marble powder loaded epoxy composites have higher tensile strength and tensile modulus	[17]
Epoxy banana peel fibres composites	20% greater tensile, compressive, and impact strength than epoxy.	[20]
PLA/banana fiber (BF) composites	Tensile and flexural strengths, reached 78.6 and 65.4 MPa, HDT of pure PLA improved by around 122%	[24]
Papaya bast short fibre polypropylene composites	Young modulus was highest with 4093.1 Mpa compared to wood polypropylene composites 3224.8 Mpa. Similarly tensile strength was observed higher than wood polypropylene composites.	[26]

4.CHALLENGES AND OPPORTUNITIES IN DEVELOPMENT OF ECOFRIENDLY POLYMER COMPOSITES

- Recyclability of the composites will lead to the cost efficient products as well as the options for the increased amount of waste materials. Recyclability of the composites is one of the main difficulties for development of eco-friendly materials. Green or ecofriendly composites can substitute all harmful and waste-producing materials.
- Life cycle analysis should be done for biodegradability for all newly developed composite materials. This will help to replace traditional polymers and select eco-friendly and acceptable materials.
- Micro/nano fibrillar composites created a lot of interest, their characteristics and applications are to be considered because of their innovative properties and applications.

- Composite materials having long-term durability, sustainability for latest emerged applications are desirable and cost-effective.
- Since the interface interactions has a significant role in property enhancement and exist between fiber and matrix, new characterization techniques for interface will bring new prospects.
- Attention of researchers needs online monitoring of morphology of composites during processing is another area.

5.CONCLUSION

Abundant quantity of bio waste was generated through many sources like agricultural by- products after post processing like banana peels, stem, papaya fruit peels, corn husk, wastage generated by food sector like walnut shell, coconut shells, sugarcane bagasse, etc. After review of various papers, it can conclude that there is a large potential to make of these bio waste materials for development of new improved polymer composites which can be ecofriendly and may replace traditional polymer composites which may not be ecological and causing pollution. The researchers may contribute for development of superior and strong composites by selecting proper bio filler along with polymer resin or matrix.

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