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Critical Overview: Preparation of Bioplastics Using Different Reinforcement Fillers

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Abstract

The widespread use of synthetic plastics poses a significant threat to the environment due to their nonbiodegradable nature and reliance on nonrenewable petrochemical sources. Among these, single-use plastics are of particular concern as they are difficult to recycle efficiently. To mitigate this issue, bioplastics offer a promising alternative, as they are derived from renewable sources and are biodegradable. Bioplastics are produced using natural materials, such as plant, animal, and microbial sources. Various biomass resources have been explored for bioplastic production, including cellulose, the most abundant natural polymer, as well as starch extracted from sago, corn, and vegetable waste, including banana peels, potato peels, and orange peels. Additionally, the banana pseudostem has been studied as a potential raw material. Plasticizers, like glycerol, are commonly added to improve the flexibility and mechanical properties of bioplastics. Recent research has focused on studying and enhancing the strength and durability of bioplastic films by incorporating fillers. Bentonite, zinc oxide, saw dust, potato peel powder, calcium carbonate ($CaCO_3$), okra fibers, sugarcane bagasse cellulose fibers, and banana pseudostem fibers, are among the materials used to reinforce bioplastic films. The development and optimization of bioplastics using renewable biomass sources and effective fillers can contribute to a sustainable and eco-friendly solution to plastic waste. The study reveals that zinc oxide, $CaCO_3$, and banana pseudostem acts as promising fillers in increasing the tensile strength of biodegradable bioplastic.

Keywords: Natural polymers, cellulose, fillers, plasticizers, bioplastic, pseudostem

INTRODUCTION

Plastic is an essential component of modern life in every way. It has many advantages because it is lightweight, flexible, and less expensive, making it the best option for practically all household and industrial applications. However, excessive and impolite use of plastic damages the environment and has an adverse effect on the health of people and animals. It is currently a major environmental hazard, contributing to a significant portion of land pollution, which can make up as much as 25% of landfill volume [1]. The buildup of plastic debris does not exclude the oceans. The degradation of the marine ecosystem is caused by plastic trash, a poor waste management system, a low recycling rate, and harmful gas emissions from burning plastic. The buildup of plastic debris does not exclude the oceans. Drawbacks of plastics made from fossil fuel or coal tar include the destruction of the marine ecosystem caused by plastic waste, an insufficient waste management system, a low recycling percentage, toxic gas emissions from plastic incineration, plastic's nonbiodegradability, and the economic issue of rising fossil fuel prices.

Thermosetting and thermoplastic polymers are the precursors of plastic materials. Heat is used to

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fix or solidify thermosetting polymers. Conversely, thermoplastic is a type of plastic polymer that solidifies after cooling and becomes pliable at a particular elevated temperature. A sizable amount of plastic used in food pack ageing applications is thermoplastic. It may be affordably and swiftly framed into any desired shape to meet food packaging specifications.

It is especially conducive to recycling and the waste-to-energy paradigm. Vinyl, polyester, nylon, polycarbonate, polystyrene, and polyolefin (low- or high-thickness polyethylene, polypropylene, etc.) are the most common thermoplastic polymers used in food packaging. These polymers offer remarkable strength and mechanical dependability, which are essential for applications involving food packaging [2].

As a result, there is a great need for plastics made from renewable resources, or "bioplastic," to replace plastics made of synthetic polymers, particularly in the food packaging sector. These plastics are biodegradable and derived from natural resources. Because they are inexpensive, plentiful, easily accessible, and form continuous matrixes, sources, like potatoes, rice, maize, etc., are used to create bioplastics [3]. These sources include glucan-rich starch, which is mainly composed of two important basic components: amylose and amylopectin. There are numerous hydroxyl groups (O–H) in the starch chain, but one main O–H at C-6 and two subordinate O–H at C-2 and C-3 of all glucose excess are not connected. The starch becomes hydrophilic because of this process. Amylose is made up of linear glucose molecules joined by the α (1–4) link. Bifurcated molecules with α (1–6) bonds that connect branch units to the linear chain of α (1–4) glucose are found in amylopectin. In many plants that have seeds, tubers, and grains, starch functions as a semi-crystalline biopolymer that helps store carbohydrates. Moreover, starch is biodegradable and has outstanding heat conductivity [4].

A different method of creating innocuous plastic is required to address this issue, and one appropriate method is to create bioplastic, which is a plastic that can break down when microorganisms operate on it [1]. Using bioplastic has the advantage of being able to decompose quickly without having any negative environmental effects. It is made of cheap raw resources and is an environmentally beneficial plastic. Furthermore, bioplastic is less expensive to manufacture than petroleum-based plastic [5].

In addition to lowering the environmental effects of using petroleum-based plastic, plastic materials were developed at the start of the 1990s, demonstrating that the biodegradation property would be an effective addition to short-term applications, like packaging, where it seems that long-lasting and durable plastics are not always suitable for this type of application [6]. Given that starch is a type of glucose-based polymer and is also inexpensive, readily available, and biodegradable, it presents an intriguing substitute for petroleum-based plastic [7]. Microorganisms in soil may readily break down starch without harming the environment. Because of these characteristics, starch is now the second most important raw material that the plastics industry may employ to make bioplastics.

BENEFITS OF BIOPLASTICS

Eco-Friendly

Petroleum-based plastic is reliant on fossil fuels, which are a non-renewable resource. The acquisition of fossil fuels causes significant environmental harm, and its use in the plastics industry raises greenhouse gas emissions, impeding global efforts to reduce the use of petroleum-based plastic in short-term applications, like packaging, where it seems that durable and long-lasting plastics aren't always appropriate for this kind of use [8].

Given that starch is a type of CO_2 emitter derived from glucose, it presents an intriguing substitute for petroleum-based plastic. However, bioplastics are manufactured from biomass, such as vegetables, trees, and even rubbish, and their production method is not as hazardous as it was in the past [9].

Less Time Is Needed for Decomposition

Plastics derived from petroleum require thousands of years to break down and decompose, and they end up in the environment – most notably on the ocean bottoms, where they cause years of severe harm

[10]. These plastics harm the ecology and slow down growth. On the other hand, bioplastics take much less time to break down, which eases the tremendous strain on our landfills [11].

Plasticisers must be introduced with fillers to reduce shrinkage, improve plastic's functionality, and reduce costs. When creating a wide range of bioplastics, the filler is crucial. Numerous studies have demonstrated that filler is utilized as reinforcement in thermoplastic materials to enhance the mechanical behavior of starch-based bioplastic films, which are often delicate and challenging to work with. The tensile strength (TS), elasticity modulus, and elongation capacity of bioplastic film are often impacted by the size of the filler particles [12].

Fillers, which function as reinforcing agents to improve the overall performance of the bioplastic without significantly compromising its biodegradable nature, are added during the bioplastic preparation process to improve the mechanical properties of the bioplastic, primarily by increasing its strength, stiffness, and occasionally barrier properties. This often lowers the material's cost by requiring less of the primary biopolymer to achieve the desired functionality.

IMPORTANT FACTS ABOUT FILLERS IN BIOPLASTICS INCLUDE

- *Improved mechanical properties:* The main function of fillers is to increase the bioplastic's TS , flexural modulus, and impact resistance, which makes it more appropriate for applications like packaging.
- *Cost reduction:* By adding fillers, a less costly biopolymer is required to achieve the desired properties, making the bioplastic more economical.
- *Functional enhancements:* Depending on the type of filler, the bioplastic may also have additional functionalities like improved barrier properties (against moisture and gases), flame retardancy, or even antimicrobial activity.

Important Considerations When Using Fillers

- *Size and distribution of filler particles:* The final characteristics of the bioplastic are greatly impacted by the size and distribution of filler particles. While larger particles may detract from the visual appeal, smaller particles can improve mechanical qualities and offer better dispersion.
- *Biopolymer compatibility:* To guarantee correct adhesion and avoid delamination, the filler needs to be compatible with the biopolymer matrix.
- *Processing considerations:* To get the best dispersion and bonding with the biopolymer, adding fillers may need modifying the processing parameters, such as temperature and pressure.
- *Variety filler materials:* Natural materials, including cellulose fibers, wood flour, rice husk, mineral fillers like calcium carbonate ($CaCO_3$), clay minerals (nanoclay), and even some forms of biochar, are frequently employed as fillers in bioplastics. In this study, we will evaluate how the TS of bioplastics is affected by reinforcing fillers like $CaCO_3$, bentonite, cellulose fiber from banana pseudostem, okra fiber, zinc oxide (ZnO), sawdust, potato peel powder, and natural fibers like hair, cotton, wool, and jute.

MATERIALS AND METHODOLOGY

Calcium Carbonate ($CaCO_3$)

Reinforcing additives, like $CaCO_3$, may improve the bioplastic's strength, resilience, and functionality. In the meantime, glycerol as a plasticiser increases the mobility rate of the polymer chains in the starch films by reducing intermolecular tensions and the material's glass transition, so providing flexibility in the polymer structure [13] to investigate how glycerol affects bioplastic that has a fixed quantity of $CaCO_3$. Optimising the plasticiser is crucial since it can make plastic softer and more flexible, which will aid in the plastics' breakdown [14].

Preparation of Cassava Peel Starch

Making Cassava Peel Starch

100 g of tiny cassava peel pieces were combined with 100 mL of distilled water, and the mixture was filtered through muslin cloth. After 30 minutes, the starch settled to the bottom of the beaker and

separated from the slurry. It was then cleaned with distilled water and dried in an oven set at 70°C for 40 minutes, until it was reduced to a fine powder [15].

For Bioplastic

The films are ready. After adding 5 g of cassava starch and 0.2 g of $CaCO_3$, the mixture was mixed, and then 70 mL of distilled water was added. It was then cooked for an hour at 60°C. The mixture was placed into an 8.5 cm × 2 cm x 0.3 cm petri dish, and varying amounts of glycerol were added before it was dried in an oven set at 60°C [16]. The percentage of the bioplastic's TS dropped as the glycerol concentration rose, according to the observation. Due to the hydrophilic nature of glycerol and starch, the bioplastic's TS decreased as its glycerol content increased.

In contrast, the tensile strain decreased at a rate as more glycerol was introduced, which was brought about by a decrease in the contact between the starch chains. As a result, the space between starch molecules increased, allowing glycerol to embed between the two [17].

Okra (Lady's Finger) Fibers

In fact, bast-extracted cellulosic fibers are the most used plant fibers in composites, suggesting that they are especially well-suited for polymer reinforcing applications. Herbaceous plant stalks can also be used for this purpose, albeit they are less commonly used for the classic retting method of fiber extraction, which is not necessarily simple or efficient [18]. The bark of the *Okra bahmia* plant, a member of the Malvaceae family and botanically known as Abelmoschus esculentus, which is widely distributed, for instance in North-East India, is used to remove the fibers of *okra* (lady's finger) [19].

The fresh plant was collected and then submerged to promote microbial deterioration. for fifteen to 20 days. After three rounds of washing with deionized water, the fibers were separated from the degraded leaves, tied with ropes, allowed to dry outside, and then stored in a moisture-proof container. Raw okra fiber was bleached for 90 minutes at 85–90°C using 0.4% $NaClO_9$, a 1:80 fiber liquid ratio, and a pH of 4. To neutralize the active chlorine, sodium meta-bisulphate was applied to the bleached fiber at a ratio of 1:20 fiber lacquer for a duration of 15 minutes.

Okra fibers, both raw and bleached, were cut into 50-cm lengths and soaked in chemical solutions (10% NaOH, 10% Na_2SO_4, or 10% CH_3COOH) at 30°C while keeping the liquor ratio at 1:50. For 2 hours, the fibers were submerged in the alkali solution. After neutralising the fiber surface with a diluted acetic acid solution, distilled water was used to wash it once more. After 48 hours of room temperature drying, the fibers were oven-dried for 6 hours at 100°C [20]. The first attempt at creating a composite is the extraction of okra fibers using a low-cost chemical treatment and a polymer matrix that is similarly accessible and affordable. This method worked well for adding plant fibers, like Bakelite (phenol-formaldehyde) resin, to the composite [21].

Bakelite and native *okra* fiber were used to create the composites, which were then partially dried out over the course of 7 days. The fiber was employed without a coupling agent, either scoured or bleached. To manufacture the laminates, several processes were used. First, okra fibers were trimmed to a length of 2–3 mm. Next, the fibers were mixed with casting resin by hand to minimize their dispersion.

After that, it was cured in a closed matching mould at 80°C for 2 hours and at 170°C for 3 hours using a pressure of 0.5 MPa. It was then cooled and post-cured for 18 hours.

Bentonite

This work used bentonite as a reinforcing filler and yam starch to create a unique bioplastic film. Physiochemical, mechanical, biological, and biodegradable effects of filler content were described [22]. The biofilms were created using the solvent casting process and strengthened with varying amounts of bentonite (0.5, 1, 1.5% w/w). Ten species of stapled yam are among the 600 species of yam (Dioscorea).

About 30% of yams contain amylase, which has a high potential for film formation. Starch was extracted from fresh yam root tubers.

Bioplastic films were prepared by using 3% (w/w) starch powder, glycerol (plasticizer) of about 1.5% (w/w), and with three different proportions of bentonite (filler) powder (0.5%, 1%, and 1.5% w/w) in 100 mL of distilled water [23, 24].

Using a magnetic stirrer, batches of distilled water, yam starch, and plasticiser were combined directly and allowed to sit at room temperature for 15 minutes. After mixing the bentonite powder into the normalized solution at 400 rpm, the liquid was heated to 85°C until gelation took place. A circular Petriplate was promptly covered with gelatinized suspension starch, which was then left to dry for 24 hours at 40 ˚C in a vented hot air oven. All experiments were conducted in triplicate, and this procedure was repeated for all bentonite powder amounts. A UTM was used to examine how the concentration of bentonite reinforced filler affected the TS of the starch-based bioplastic sheets.

Using a magnetic stirrer, distilled water and yam starch and plasticizer were combined at room temperature for 15 minutes. Then, the bentonite powder was added to the normalized solution at 400 rpm, and the mixture was heated to 85°C until gelation took place. The gelatinized suspension starch was immediately placed on a circular Petriplate and allowed to dry in a ventilated hot air oven at 40°C for 24 hours. This procedure was repeated for all different amounts of bentonite powder.

Sugarcane Bagasse Fiber

Cellulose from sugarcane bagasse fiber is isolated and delignified in this work. To achieve the desired particle size, the fibers are first dried, then ground and filtered using an 80 µm sieve. A 0.7% (w/v) sodium chlorite ($NaClO_2$) solution (fiber to liquid ratio of 1:50) at pH 4 was used to bleach (100 g of SCB) initially. The pH was then altered using acetic acid to acidify the $NaClO_2$ solution. The fiber was cooked in the solution for 2 hours at 75˚C in a water bath to extract all the lignin and some of the hemicellulose. Four or five bleaching cycles were performed until the fiber turned white, after which it was filtered.

The holocellulose thus obtained was boiled with 250 mL 17.5% (w/v) sodium hydroxide solution for 5 hours to remove the hemicelluloses. Corn starch and cellulose fiber are used to make bioplastic. By combining the starch (10 g) with 200 mL of distilled water, a film-forming dispersion was created. The dispersion was manually swirled for 15 minutes at the same speed on a magnetic stirrer set at 70–80°C until it became gelatinized. Glycerol (3.6 mL) was then added, and for 10 minutes, it was agitated. After that, cellulose fiber was added at dry basis at 0.00, 0.50, 1.00, and 1.5 g based on the weight of the starch. Before being cast onto a non-stick pan, each mixture was allowed to cool to 75 °C after being mixed to ensure homogeneity and strong gelatin.

To dry the film, the dishes will be placed in an oven set at 50°C, 40°C, and 30°C. The drying temperature and the amount of fiber in starch-based blends are the factors under examination. TS was examined in relation to the concentration of cellulose fiber and 15 weight percent) was added to a specific gram of maize starch (5 g).

Banana Pseudostem

The banana (Musa acuminata) plant's pseudostem provided the cellulose employed in this investigation. The main waste product of banana plants that is chopped off, left on the plantation, allowed to rot, or burned after the fruits have been picked is banana pseudostem.

Cellulose is the main organic material present in plant cell walls. Large amounts of cellulose can be found in banana pseudostem fiber, cotton, and wood. The glucose molecules in cellulose are joined by glycosidic bonds. Because of the hydrogen bonds that form between successive glucose units within and between adjacent strands, cellulose is a more durable fiber than glycogen or starch. Cellulose acts as a reinforcing element in bioplastics as a result [25–27].

The pseudostem of a banana (Musa acuminata) plant provided the cellulose employed in this investigation. After the fruits are harvested, the pseudostem – the main waste product from banana plants – is either cut off, left on the farm, allowed to rot, or burned. Although banana pseudostem fiber is underutilized, it is quite rich in cellulose, which is one of its main elements [28]. Banana pseudostem has an average cellulose content of 49.33% [29].

The usage of banana pseudostem fiber in the creation of fiber or polymer composites has been documented in several research publications [30]. The peel and cellulose from banana pseudostem are used to strengthen starch-based bioplastics with cellulose or cellulose derivatives to enhance their mechanical qualities, thermal stability, and gas and water barriers according to their intended uses. As explained by [31], potato peel starch was obtained. The entire banana tree's trunk, or pseudostem, was chopped into chips, allowed to air dry, and then preserved for examination. To eliminate pectin and sugar, 50 g of the dried sample was boiled for 2 hours in a sulphuric acid solution (2 g/L) [32].

Excess water was used to thoroughly wash the pulp until it was neutral. To get rid of lignin and other extractibles, the neutral pulp was also cooked for 3 hours in a 20% NaOH solution. After cooling, the material was crushed to create paste and rinsed until neutral. An amount of 200 mL of 3.5% w/v sodium hypochlorite (NaOCl) was used to bleach the pulp, and it was left to stand for 12 hours [33]. After being cleaned with more water until it turned white, the cellulose was dried in an oven set at 102°C for 2 hours. For packaging purposes, the dry cellulose was crushed into a powder and then sieved through a 0.2 mm screen to ensure uniform particle size.

Alkali delignification and bleaching were used to extract cellulose from dried banana pseudostem. Two grams of glycerol were added to each blend of cellulose powder and potato peel starch powder at 0, 5, 10, 20, and 30%. To gelatinize each blend, 100 g of distilled water was added, and the mixture was then heated to 90°C while being stirred constantly for 20 minutes. After being cast on a polypropylene plate, the gelatinized starch was placed in an oven set to 50°C for 12 hours to dry. The gelatinized mixture of potato peel starch, BPC, and glycerol (plasticiser) was cast and oven-dried at a consistent weight in each film. Before being characterized, the dried films were stored in a desiccator after peeling off the plate.

Zinc Oxide (ZnO) Nanofiller

ZnO-reinforced composite biopolymeric films based on bioplastic cassava starch films were made using the casting technique. ZnO concentrations in the bioplastic films ranged from 0.2% to 1.0% (w/w) by weight of starch. Using a scanning electron microscope, the surface morphologies of the composite bioplastic films were investigated.

According to the results, adding ZnO considerably increased the TS.

The preparation of bioplastic packaging films and the casting were based on [34] with some modifications. Initially, 0.2–1.0% (w/w) of the total starch was used to disperse ZnO nanoparticles in a distilled water solution. The mixture was then swirled for an hour and ultrasonically agitated for 30 minutes. For gelatinization, the solution was then heated to 85 ± 5ºC and maintained there for 15 minutes. The plasticized addition of glycerol is then performed with concentration variations of 25, 30, and 35%, and it is stirred until it is uniform. The uniform solution is then poured over a 2.0 mm thick plate. Additionally, drying is done in an oven set at 60°C for 5 hours.

Prior to measurements, the dry bioplastic films were taken out of the oven and kept in a controlled environment at 25°C and 75% relative humidity for at least 48 hours. Additionally, control films were made without the addition of nanoparticles. After drying, the films were peeled and trimmed to an average size of 7 cm by 5 cm. Additionally, samples were used, and the thickness was measured. TS is examined in relation to the concentration of ZnO filler. According to ultimate TS, which is the highest tension before breaking, TS is the capacity to withstand load or strain without causing damage to the composite or breaking it.

The relative comparison of the reinforcement materials and matrix in composite materials, specifically the amount of ZnO added to the polymer matrix in contrast to composite materials, can have an impact on the TS of the composite material.

Saw Dust and Banana Peel Powder

The primary goal of this effort is to develop bioplastics by using renewable waste from natural agricultural sources, such as banana peels, and a combination of rice, corn, and banana peel starch. By using readily available, abundant, biodegradable, and renewable natural waste as reinforcing fillers, the hazards and issues associated with conventional plastics can be greatly decreased, and their mechanical qualities can be enhanced. Three types of starch – banana peels, rice, and maize – were utilized. As fillers for reinforcement, leftover materials, like sawdust and powdered potato peel, were employed.

To pretreat the fillers, two slightly modified methods of [35–37] were used: the potato peels and wood shavings were chopped into smaller pieces with scissors, dried in an oven at 90°C for 5–6 hours, and then ground into a powder in a blender. The resulting powder was then sieved through a 63 µm sieve to achieve a consistent powder size. Ethanol, analytical grade 5ml glacial acetic acid, sorbitol, and glycerol were used thoroughly.

Bioplastics From Banana Peel Starch (BPP)

Banana peel bioplastic (BPP) was made by slightly altering the techniques of [5] and [38]. Banana peels were cleaned, cut into the appropriate size with scissors, and then boiled in water for 30 minutes. The peels were then allowed to dry before being turned into paste. To create the bioplastic samples, 5 ml of aqueous acetic acid (5%) solution, 5 ml/5 g of plasticizer, and the necessary amount of reinforcement filler were added to a beaker and thoroughly stirred.

After 15 minutes of constant stirring at 220°C, the mixture was spread out onto a petri dish lined with aluminium foil and left to dry at room temperature for 24 hours. It was then heated again in an oven at 85°C for 2 hours, and the bioplastic was once more allowed to cool completely before being removed from the foil.

Bioplastics Made from Rice Starch, Cornflour, and Banana Peel Composite (COM)

Using significantly altered techniques from [39, 40] bioplastics were created using a mixture of rice starch, cornflour, and banana peel (Composite as COM). To create the bioplastic samples, banana peel paste, cornflour solution (20% w/v), and rice starch solution were prepared. Then, in a beaker, the necessary amount of composite starch solution, 5 ml of aqueous acetic acid (5%) solution, 5 ml/5 g of plasticizer, and the necessary amount of reinforcement filler were added, and everything was thoroughly stirred. The mixture was boiled for 15 minutes at 220°C while being constantly stirred. The cooked mixture was then spread out into a petri dish lined with aluminium foil and left to dry at room temperature for 24 hours. It was then heated again in an oven at 85°C for 2 hours. A Universal testing machine was used to test the TS of the different bioplastics produced in the study.

Reinforcing Fiber (Hair, Wool, Jute, and Cotton)

The impact of fiber reinforcing on the mechanical characteristics of starch-based bioplastics is discussed in this work. To conduct the experiment, four different kinds of bio-composites were made using thermoplastic starch as a biodegradable polymer matrix and natural fibers – cotton, jute, hair, and wool – as reinforcement. A biopolymer (corn starch), glycerol, deionized water, a 5% acetic acid solution, and natural fibers, like cotton, jute, wool, and hair, were the materials employed in the experiment.

Commercial starch solution was combined with 30 mL of water, 2 mL of glycerol, and 2 mL of acetic acid. Natural fibers of various kinds were added in different amounts to the solutions (2%, 4%, 6%, 8%, and 10%). A glass rod was then used to agitate the solution continuously while it was heated to 150°C on a hot plate for 15 minutes. The solution was spread out on an aluminium sheet to dry at room temperature after it became clear once again after being taken off the hot plate. TS tests were performed on each sample once their weight stabilized over time. It was determined the average thickness of each bioplastic sample reinforced with various natural fiber kinds.

Each sample was then sliced to a size of 6 cm by 1.5 cm and placed on a tensiometer with predetermined load, extension, and speed ranges. The findings demonstrate that adding different natural fibers, like cotton, jute, hair, and wool to bioplastics, can boost their strength [41].

RESULT AND DISCUSSION

TS of bioplastics with the addition of $CaCO_3$, bentonite, cellulose fiber of banana pseudostem, Okra fiber, ZnO, sawdust, potato peel powder, natural fiber such as hair, cotton, wool, and jute. Each filler's TS is given in Table 1 has a different value.

- *$CaCO_3$:* The findings demonstrated that the presence of cellulose in this instance raises the molecular attractive forces, resulting in the formation of a thin layer [42]. This disorder is brought on by hydroxyl groups creating hydrogen and intermolecular connections.
- *Okra (Lady's Finger) Fibers:* Average TS of composites made with raw or bleached okra fibers with varying fiber contents in comparison to the TS of the pure matrix. marginally enhance the qualities, except for sodium sulphate treatment. Only a very small volume (a few percent) of reinforcement showed some potential for this initial attempt to introduce okra fibers in a polymer matrix. Due to the technical fiber's varied geometry, a higher volume of reinforcement would make resin impregnation more challenging. This problem may be resolved with the right chemical treatment, but only fiber bleaching has demonstrated a noticeable improvement; in other instances, the decreased void content, when it was achieved, did not result in improved mechanical qualities. This suggests a more thorough examination and comparison of the potential effects of chemical treatment on these fibers, which may need varying chemical concentrations.
- *Bentonite:* It was found that both the TS and Young's modulus rose as the bentonite concentration rose. The concentration of bentonite enhances the mechanical characteristics of bioplastic sheets. The uniform dispersion of bentonite in the bioplastic composite sheet could be the cause. Because of the aggregation of clay particles and consequent decrease in the mechanical strength of the bioplastic film, the concentration of bentonite cannot be raised above a certain point [7].
- *Sugarcane Bagasse Fiber:* As the proportion of glycerol in the bioplastic grew, the percentage of TS, Young's modulus, and tensile stresses of the bioplastic declined. This is because the hydrophilic nature of glycerol and starch caused the bioplastic to lose strength. These are caused by the hydrophilic hydroxyl group in cassava, which forms hydrogen bonds. As a result, it improves the bioplastics' water solubility while decreasing their mechanical qualities [24]. According to the results, starch composites supplemented with cellulose fiber from sugar cane bagasse may find use in biodegradable packaging and biocomposite medicine.
- *Banana Pseudostem:* The films' thermal characteristics were ascertained. The film with 10% BPC (Banana Pseudostem composite) has the best mechanical qualities (modulus of 188.93 MPa, TS of 9.20 MPa) and the lowest moisture content (18%). In compliance with ASTM D 88-02 (2002), the mechanical properties were assessed using a Universal Testing Machine (Instron Machine-Serires 3369). The highest TS, 12.80 MPa, is found in film containing 5% BPC. In films with 5% BPC, the young modulus increased to 108.84 MPa; in films with 10% BPC, it increased to 188.98 MPa; and in films with 20% BPC, it drastically decreased [30].
- *ZnO Nanofiller:* The relative comparison of the reinforcement materials and matrix in composite materials, specifically the amount of ZnO added to the polymer matrix in contrast to composite materials, can have an impact on the TS of the composite material. TS and break elongation results were examined [39]. With a ZnO concentration of 0.6% and a plasticizer concentration of 25%, the ideal formulation composition has a TSvalue of 218.688 MPa.
- *Saw dust and Banana peel powder:* Plasticizers were found to have the same effect on both types of bioplastics. The study shows that samples with sorbitol and glycerol as plasticizers had the highest values for Youngs modulus and TS, while samples with a combination of sorbitol and glycerol as plasticizers had results in between the two. Because glycerol has a lesser molar mass

(almost half) than sorbitol, its molecules may interact with starch more effectively, which explains why glycerol has a better capacity for plasticization than sorbitol. However, when both plasticizers are introduced to a sample, they influence the bioplastic's TS and Youngs modulus at the same time [31]. As a result, natural fillers improve water absorption, biodegradation, and oxidation [22].

- *Reinforcing fiber (Hair, Wool, Jute, Cotton):* The findings demonstrate that utilising different natural fibers, including cotton, jute, hair, and wool, can boost the strength of bioplastics [42]. The amount of fiber reinforced in bioplastics determines their TS, which rises as the number of fibers increase to a certain point, after which it falls, possibly because of a drop in the binding material, or biopolymer.

Different bioplastics with different types of natural fibers and varied percentages of fibers have variable TSs.

TS values are listed below in Table 1.

Table 1. Tensile strength of various bioplastic prepared using different fillers.

S.N.	**Name of the Fillers**	**Tensile Strength (MPa)**
1	Calcium Carbonate ($CaCO_3$)	99.79
2	Bentonite	4.18
3	Banana Pseudostem Cellulose fiber	9.20
4	Okra fiber (Bleached) 5% content	19.00
5	Sugarcane bagasse	24.45
6	Zinc Oxide (ZnO) (Nano Filler)	218.688
7	Potato Peel Powder	0.094
8	Sawdust	0.085
9	Natural Fiber (Hair)	2.397
10	Natural Fiber (Wool)	2.529
11	Natural Fiber (Jute)	1.573
12	Natural Fiber (Cotton)	2.511

CONCLUSIONS

The manufacture of bioplastics frequently uses starch-based bioplastics. However, fillers are utilized to boost the strength of bioplastics due to their poorer tensile characteristics compared to traditional plastics. Fillers are used to improve TS and hardness, lower the cost of plastic, and minimize shrinking during the setting process. Consequently, this review reports on the TS of a number of starch-based biodegradable plastics that contain $CaCO_3$, bentonite, cellulose fiber from banana pseudostem, okra fiber, ZnO, sawdust, potato peel powder, and natural fibers like hair, cotton, wool, and jute as fillers. The review states that ZnO, $CaCO_3$, and banana pseudostem function as promoting fillers to raise the biodegradable bioplastic's TS. These qualities can be enhanced by adding a filler material without the need for expensive or specialized equipment.

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