Review Article

Exploring the Transformation of Food Waste into Bioplastic Materials: A Review

ABSTRACT

Plastics, commonly encountered in forms such as packaging, household items, office supplies, electronics, and more, are typically conventional plastics derived from petroleum synthesis. The environmental issues posed by conventional plastics, which do not naturally degrade, necessitate a solution. An effective approach to address this challenge involves substituting conventional plastics, synthesized from petroleum, with biodegradable plastics made from natural materials. This article employs a literature review methodology, exploring research journals that cover a spectrum of bioplastics topics, including definitions, applications, advantages, natural ingredients, and final bioplastic products. Bioplastics, crafted from natural materials, possess the ability to decompose through microbial action, rendering them more environmentally friendly. Utilizing agricultural and fishery waste as sources of natural materials, such as cassava peels, fruit seeds, seaweed, fish scales, starch and cellulose content for bioplastic production. Bioplastic applications extend across various sectors, encompassing packaging, catering, electronics, automotive, agriculture, horticulture, toys, textiles, and more.

Keywords: biodegradable, bioplastic, conventional plastics, natural materials

1. INTRODUCTION

Dealing with plastic waste poses a formidable challenge. According to data from the National Waste Management Information System of the Ministry of Environment and Forestry, Indonesia generated 36.08 million tons of waste in 2022, with food waste comprising 40.5% of this volume, placing it as the primary type of waste. Plastic waste, ranked fourth after wood/branches/leaves and paper/cardboard, constitutes 18.1% of the total waste [1]. The issues surrounding plastic waste, a critical concern given its ranking, could have severe consequences if not addressed properly. [2] note that mishandling plastic waste can lead to pollution in water, soil, rivers, and the air, particularly as discarded trash flows through rivers and eventually reaches the sea.

Plastics, encompassing packaging, household items, office supplies, and electronics, have become integral to modern living. The majority of these plastics are conventional, derived from petroleum synthesis and non-renewable. The drawbacks of conventional plastics, which do not possess natural degradation capabilities, result in persistent plastic waste causing pollution in water and soil [3].

To address the challenges posed by conventional plastics, one viable solution is transitioning to more eco-friendly alternatives, specifically biodegradable plastics. As outlined by [4], biodegradable plastics are designed to naturally break down into environmentally friendly compounds through microbial action. These plastics are crafted from natural polymers, including bacterial cellulose, chitin, chitosan, starch, and other materials found in plant and animal cells. This shift towards biodegradable plastics is crucial for mitigating the environmental impact of plastic waste.

2. MATERIALS AND METHODS

This article was developed through an extensive literature review, delving into research findings by various scholars that cover the spectrum of bioplastics, encompassing definitions, applications, advantages, natural ingredients employed in bioplastic production, and the final products derived from bioplastics.

Our literature search involved referencing articles published in both national and international journals dedicated to bioplastics. To facilitate this citation process, we utilized various tools, including searches in scientific journal databases and other relevant information sources, employing Google Classroom and navigating official websites via Google Chrome.

3. RESULTS AND DISCUSSIONS

Biodegradable plastics, commonly known as bioplastics, are plastics designed for conventional use but with the added feature of natural degradation. Derived from renewable sources, these materials typically include vegetable oils, various flours (such as corn, potato, jackfruit seed, tapioca, rice, and wheat gluten), cellulose, and polymers produced through microbial processes [3].

In essence, bioplastics represent a more environmentally friendly alternative to traditional plastics, as they can be broken down by microorganisms. This eco-friendly nature positions bioplastics as a suitable solution for promoting environmental sustainability [5]. Their inherent ability to return to nature classifies them as environmentally friendly plastics. Not only do bioplastics decompose rapidly, but their byproducts, when burned, avoid the release of harmful chemical compounds. The decomposition process by microorganisms yields carbon dioxide and water, enriching the soil and enhancing its quality [6].

3.1 NATURAL SOURCES OF BIOPLASTIC MATERIALS

An alternative to non-degradable conventional plastics involves the use of plastics crafted from materials with degradable properties. As indicated by [7], the raw materials for biodegradable plastics fall into two main categories. The first is the petrochemical raw material group, derived from non-renewable resources, complemented by additives from bio-active compounds that facilitate biodegradability. The second group comprises raw materials sourced from plant products, such as starch and cellulose, and from animals, including shells or microorganisms, all of which are renewable resources. For biodegradable plastics to be environmentally friendly, it is imperative that they are constructed from natural materials. This ensures that upon returning to nature, they do not impose adverse impacts.

3.2 CASSAVA PEEL STARCH

Indonesia possesses a wealth of food resources, particularly tubers, such as cassava, sweet potato, potato, arrowroot, *gadung, kimpul, uwi,* taro, *gembili,* and *ganyong*, widely distributed across the country. Tubers, known for their high starch content, serve as a staple in various Southeast Asian cuisines [8]. However, the consumption of tubers inevitably generates waste, primarily from the peel. Hence, there is potential in repurposing tuber waste, particularly the underutilized peel, for the development of biodegradable plastics.

Among various tuber peels, cassava peels, often discarded as waste by some industries utilizing cassava, stand out as a prominent source for producing biodegradable plastics [9]. Regrettably, these peels are frequently underutilized, with many ending up as discarded waste or merely serving as animal feed. This underlines the need to harness cassava peels (Figure 1) for the production of bioplastics.

Fig. 1. Cassava peel

Several studies have explored different methods for extracting starch from cassava peels. In [10] research, 100 grams of cassava peels underwent a thorough cleaning process, followed by crushing with a blender using 100 ml of water to facilitate the process. The obtained cassava peel pulp underwent filtration and a 30-minute settling period, separating the precipitate from the water. The precipitate, dried at 70^{o}C for 30 minutes, yielded cassava peel starch for the production of biodegradable plastic films.

[11] employed a similar process for cassava peel starch preparation. Starting with washing the cassava peel, it was then crushed with water (1:4) and blended to produce wet cassava peel pulp. The pulp underwent squeezing and filtering with a cloth, and the resulting liquid, starch water, was left to settle for 12 hours to obtain starch sediment. After separation from the water, the starch sediment was dried to achieve a moisture content of 11%. The dried starch was then sieved through a 60-mesh sieve to obtain fine cassava peel starch.

[9] followed a slightly different procedure, involving the cleaning and blending of cassava peel with distilled water (1:2). The mixture was filtered, and the starch settled at the bottom over 3 hours. The separated starch underwent a second settling process with the addition of 500 ml of distilled water for 3 hours. This method aimed to isolate pure cassava peel starch from remaining impurities. The resulting clean cassava peel starch was sun-dried and ready for use as a component in environmentally friendly films.

3.3FRUIT SEEDS

Indonesia, with its tropical climate and fertile soil, provides an ideal environment for the abundant growth of various tropical fruits throughout the year [12]. Typically, when consuming fruits, only the pulp is utilized, leading to the generation of significant waste in the form of skin and seeds. Research by [13] indicates that approximately 25-30% of the total weight of fruits, such as jackfruit, mangosteen, and rambutan, is discarded as waste, comprising skin and seeds, totalling 50-70% by weight. Despite the substantial potential content in this waste, it often remains underutilized. Researchers have explored the application of fruit seeds in producing bioplastics, leveraging their starch content. Prominent examples include avocado seeds, jackfruit seeds, mango seeds, durian seeds, among others.

3.3.1 Avocado Seeds

[14] conducted research on avocado seeds (see Figure 2) containing 80.1% starch, making them a viable material for plastic production. The process involves peeling, washing, and cutting avocado seeds. The seed pieces are blended with distilled water, filtered using cloth, and left to stand for 24 hours. After discarding the precipitated water, the starch is washed, sun-dried, finely ground with a pestle and mortar, and sieved with a 100-mesh sieve. [15] employed a similar

approach, soaking avocado seed slices in a sodium metabisulfite solution, forming a slurry, and allowing it to stand before drying the precipitate for 6 hours at 50°C.

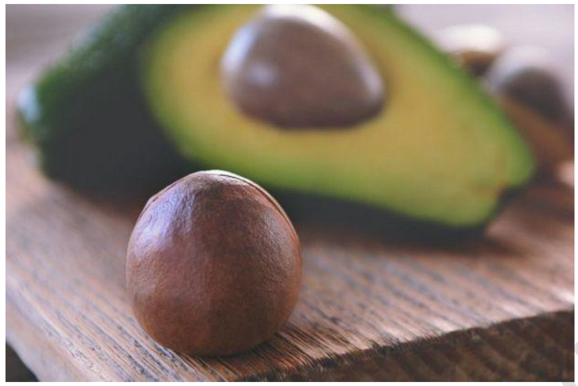

Fig. 2. Avocado Seeds

3.3.2 Jackfruit Seeds

Jackfruit seeds (see Figure 3), weighing 100 grams and containing 40-50% starch, can be harnessed for biodegradable plastics. Ripe jackfruit seeds are processed by peeling, blending with water, squeezing, and allowing the squeezed material to stand for 24 hours to obtain starch sediment, which is then sun-dried [4].

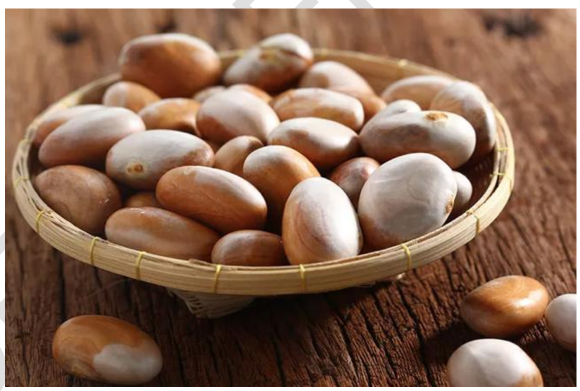

Fig. 3. Jackfruit Seeds

3.3.3 Mango Seeds

Unused mango seed waste (refer to Figure 4), an underexplored resource, possesses a substantial starch content of 70.76%. To harness this potential, the process of extracting mango seed starch involves several steps. Initially, the seeds are meticulously peeled and cleaned, then finely cut into small pieces. Subsequently, these mango seed pieces are mashed and immersed in hot water at a temperature ranging between 80-90°C for 30 minutes. Following the soaking process, the mixture is carefully squeezed and filtered, after which it is left undisturbed for 24 hours. The sediment, rich in phytate, is separated and subjected to drying in an oven set at 30°C for a duration of 12 hours [16]. This comprehensive procedure ensures the efficient extraction of starch from mango seeds, establishing a viable source for the production of bioplastics.

Fig. 4. Mango Seeds

3.3.4 Durian Seeds

Abundant durian seed waste (refer to Figure 5), comprising approximately 43.6% starch, stands out as a promising material for crafting biodegradable plastic films. The production process unfolds in several stages[17]:

1) **Hulling:** Initially, the husk is separated from the durian seed kernel.
2) **Cutting:** The durian seed core is then precisely cut to a thickness of 2-3 mm.
3) **Soaking:** The cleaned durian seed kernel undergoes a soaking process in lime water for one hour, aimed at removing any attached mucus.
4) **Drying:** Subsequently, the cleaned and soaked durian seed kernel is dried using an oven set at 100°C.
5) **Pounding:** The dried seed kernel is pounded thoroughly with a lumping-hammer.
6) **Sieving:** In the final stage, the refined seed core is sieved through a 150 mesh sieve, resulting in durian seed flour

This detailed process ensures the extraction of valuable starch content from durian seeds, laying the foundation for the production of high-quality biodegradable plastic films.

Fig. 5. Durian Seeds

3.3.5 Dregs Waste

Dregs are typically discarded by-products, often overlooked and underutilized materials. This residue becomes waste if not repurposed, encompassing commonly discarded items like coffee grounds, tea grounds, shredded coconut pulp, and more. Several studies have harnessed these dregs to create valuable materials, with a notable application being their use in bioplastic production. Various types of pulp, including coconut pulp, sago pulp, sugarcane bagasse, and tofu pulp, have been explored for this purpose.

1) Coconut Dregs

The remnants from processed coconut, which are obtained after extracting coconut milk, result in coconut pulp (Figure 6). As [18] stated, coconut pulp waste contains galactomannan, constituting 61%, making it a promising raw material for bioplastics. The extraction process involves washing the coconut pulp to remove any remaining coconut milk. Subsequently, the pulp is sun-dried, ground to sizes of 80 and 100 mesh, and subjected to extraction.

The extraction is carried out with two variables. In the independent variable of mesh size (80 and 100), 300 ml distilled water is put into the extractor and heated to 50°C. After the temperature is reached, 100 mesh coconut pulp is added, and the extraction temperature is maintained at 50°C with magnetic bar stirring speed scale 6. After 5 hours of extraction, the solution is filtered using a filter cloth to separate it from coconut pulp. The solution is then put into a glass cup, and methanol is added to separate galactomannan from water. After forming two layers, they are separated using a separating funnel. The galactomannan obtained is dried with an oven at 60°C. The dried galactomannan is weighed to determine the optimal mesh size.

Meanwhile, the variable volume of distilled water solvent (250 ml, 300 ml, 350 ml) is put into the extractor and heated to 50°C. After the temperature is reached, 100 mesh coconut pulp (the best result before) is added and extracted at 50°C with a magnetic bar stirring speed scale 6. After 5 hours of extraction, the solution is filtered using a filter cloth to separate it from coconut pulp. The solution is then put into a glass cup, and methanol is added to separate the galactomannan from water. After forming two layers, they are separated using a separating funnel. The galactomannan obtained is dried with an oven at 60°C. The dried galactomannan is weighed to determine the best solvent volume [8].

Fig. 6. Grated coconut pulp

2) Sago Dregs

Sago bagasse waste (Figure 7) is one of the renewable materials that is abundant in existence and contains starch which has high potential as a biodegradable plastic raw material. The plant with the name Metroxylon has a starch content in the pith of the sago stem that varies according to age, type, and environment where it grows. The starch content will be greater the older the plant is, and will decrease at a certain age. Making starch from sago pulp can be done by cutting and grating the sago pith. Store in a container and add enough water. After that, filtering is done twice with different sieve sizes. Then precipitation, washing, and drying are carried out. Then cut into pieces, crushed and sieved with a size of 60 mesh, then 80 mesh. The results were weighed and put in a container [19].

Fig. 7. Sago dregs

3) Bagasse

Bagasse, comprising 35% of the total sugarcane, is extensively utilized in the sugar industry as boiler fuel, filling material for paper production, and for bioethanol. Additionally, bagasse, especially from the fifth grinding process (Figure 8), can serve as a valuable raw material for producing bioplastics due to its cellulose content [20].

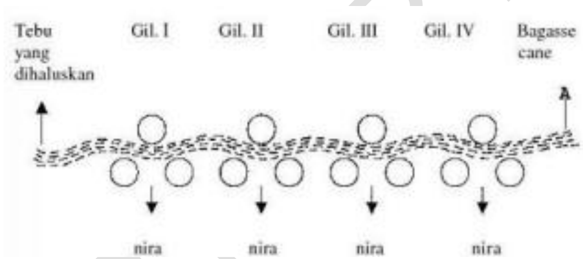

Fig. 8. Sugarcane Milling Process
(Source: [20])

The method for preparing cellulose from bagasse involves cutting it into 1 cm pieces, thorough washing, and rinsing with distilled water. Subsequently, the bagasse is sun-dried for 12 hours and then oven-dried at 85°C for 16 hours. The dried bagasse is finely blended and dried again at 100°C for 6 hours. Twenty grams of fine bagasse is placed into a 3000 ml beaker glass, and 1000 ml of 15% NaOH (1:20) is added. The mixture is stirred and heated at 110°C for 4 hours. The resulting fusion is filtered, and the precipitate is washed and dried at 100°C. The residue is hydrolyzed using 0.1 M HCl (200 ml) and heated at 105°C for 1 hour (1:10 ratio), then washed until neutral. The precipitate is dried once more [20].

4) Tofu Dregs

Tofu pulp (Figure 9), a by-product of tofu production, is rich in protein content, with dry tofu pulp containing 23.39% wt. of protein. Given its amino acid composition, soy protein from tofu dregs is an excellent choice for a bioplastic base material. The protein extraction process involves preparing dry tofu pulp, adding water (1:2), and using a strong base (2 N NaOH) for extraction for 1 hour. The extracted protein is then filtered twice to separate it from the residue.

Fig. 9. Tofu Dregs

To separate the NaOH content from the extracted protein, precipitation is induced by a strong acid (HCl) to reach a pH of 4.5 for ≥ 15 hours. The subsequent separation based on specific gravity employs a 4000 rpm centrifuge for 10 minutes. The resulting precipitate, consisting of protein, and the residue (whey) are separated. The protein precipitate is washed with distilled water, subjected to another centrifugation under the same conditions, and then dried in an oven for ≥ 24 hours at 50°C. The dried protein concentrate is left to stand at room temperature [20].

3.4 Seaweed

Certain types of seaweed serve as promising base materials for bioplastics, notably*Sargassum* sp. (Figure 10) and *Kappaphycusalvarezii* (Figure 11). These varieties are rich in hydrocolloid polysaccharides like alginate, agar, and carrageenan, making them ideal for producing robust, biodegradable, and eco-friendly bioplastics. *Sargassum* sp., for instance, can yield alginate through extraction [21]. In contrast, *Kappaphycusalvarezii* produces carrageenan, specifically in the κ-carrageenan fraction, which, when dissolved in hot water, forms a gel due to its hydrolytic polymer nature, showcasing its potential for bioplastic formation [22].

Fig. 10. *Sargassum* sp.

To prepare these seaweeds, dry *Sargassum* sp. and *K. alvarezii* are soaked in fresh water for 24 hours, washed with running water to eliminate salt and impurities, and sun-dried for approximately 3 days. The dried seaweed is then packed in plastic and stored in a dry place to prevent mold growth [21].

Fig. 11. *Kappaphycusalvarezii*

For alginate extraction from Sargassum sp., 100 grams of samples are soaked in 1% HCL for 1 hour, washed with fresh water until the pH is neutral, and then extracted with a 3% Na_2CO_3 solvent (3 liters, 1:30 w/v) at 60^oC-70^oC for 2 hours. The filtrate is treated with 4% NaOCl (1 liter, 1:2 v/v) to induce alginate gel formation. Alginic acid conversion is achieved by adding 5% HCl while stirring until alginate gel forms. The resulting alginate fibers are filtered, washed with 1% NaOH until neutral pH, and then immersed in 3 liters of isopropyl alcohol (1:3 v/v) to create alginate fibers, which are then sun-dried and blended into powder [21].

Carrageenan extraction from *K. alvarezii* involves soaking 50 g of dry seaweed in 350 ml of distilled water for 30 minutes, followed by filtration and soaking in 5% KOH for 24 hours. After thorough washing, the seaweed is boiled in 2 liters of distilled water at 90ºC for 3 hours. The extraction results are filtered, poured into isopropyl alcohol (1:3 v/v) to form fibers, then filtered, sun-dried, and finally blended into powder [22].

3.5Chitosan

Chitosan (Figure 12), a biopolymer derived from the deacetylation process of chitin, is typically sourced from crustacean shells like crabs and shrimps, as well as from the cuticles of insects, fungi, and fish scales [23]. Chitosan acts as a reinforcement, enhancing tensile strength and elongation at break [24].

Fig. 12. Chitosan

Primarily used as an additive in bioplastic production, chitosan enhances various characteristics. Its hydrophobic, non-toxic, and biodegradable properties contribute to stronger bioplastics with improved water resistance. The incorporation of chitosan increases the number of hydrogen bonds in bioplastics, further reinforcing their structural integrity [23].

Chitosan extraction from fish scales (Figure 13) involves drying the waste until it becomes brittle for ease of processing into a fine powder (50 mesh) using a flouring machine. The chitin isolation process includes deproteinization, conducted by stirring fish scale powder in a 3.5% NaOH solution (fish scales to NaOH ratio of 1:10, m/v) at $100^{o}C$ for 2 hours. The deproteinized results are filtered, washed, and dried. Subsequently, demineralization is achieved by reacting the deproteinized product in a 1 N HCl solution (1:6, m/v) at room temperature for 30 minutes. The demineralized product is filtered, washed, and dried.Chitosan preparation involves breaking the acetyl group in the chitin extract by deacetylation. Chitin is dissolved in 50% NaOH for 1 hour at $100^{o}C$ (1:10, m/v). The resulting mixture is filtered, washed, and dried [25].

Fig. 13. Fish Scales

3.6 Bioplastic Finished Products

Bioplastics are gaining widespread use across various industries, including packaging, catering, electronics, automotive, agriculture/horticulture, toys, textiles, and more. Packaging remains the dominant market segment, constituting 48 percent (nearly 1.1 million tons) of the total bioplastics market in 2022. Other segments, such as automotive & transportation and building and construction, are continually diversifying as functional polymer capacities as constituent materials increase [26].

6. CONCLUSION

The rise of bioplastics presents a promising alternative to address the issues associated with conventional plastics, which pose environmental challenges and economic hurdles linked to petroleum-based counterparts. Bioplastics, sourced from degradable biopolymer materials like starch, cellulose, and protein, tap into natural reservoirs for the production of environmentally-friendly biodegradable plastics. It is advisable to harness these natural resources, focusing on agricultural waste and by-products from both plant and animal sources. The objective is to reduce unused waste to a minimum and cultivate economic value for the future.

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