UJEAS

UNIZIK JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 5(3), September (2025), 2664-2675
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Bio-plastic from Potato and Bambara Nut Shell Agro-Waste

Ogah Anselm Ogah[1*], Ojukwu Uju Pauline[1], Mbam Joseph Nwabueze[2], Ohoke Francis Okemini[3]
[1]Department of Polymer Engineering, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Nigeria
[2]Department of Chemical Engineering, Ebonyi State University, Abakaliki, Nigeria
[3]Department of Industrial Chemistry, Ebonyi State Unversity, Abakaliki, Nigeria
*Corresponding Author's E-mail: ao.ogah@unizik.edu.ng +2348061514134

Abstract
Plastic garbage has been deposited into the ecosystem as a result of anthropogenic activities. There is an urgent need to produce bio-plastics because plastics are not biodegradable and have a negative impact on the environment. One natural resource that can be utilized in the manufacturing of bio-plastics is starch. However, the brittleness of starch-based bio-plastics is a drawback. The study emphasizes the feasibility of utilizing cellulose derived from bambara nutshell agro-waste as an eco-friendly reinforcement in conjunction with potato starch for the synthesis of bio-plastic in order to overcome this constraint. It was studied how to produce and characterize bio-plastic from potato starch reinforced with 2.5, 5, 7.5, and 10 weight percentages of cellulose that was taken from agricultural waste manufactured from bambara nutshells. The main goal was to improve potato starch's mechanical qualities in order to overcome the drawbacks of pure starch materials. In order to create bio-plastic, cellulose was extracted from bambara nutshell fibers using 5% NaOH and combined to a potato starch matrix. Increases in cellulose loading were found to improve the mechanical properties of potato starch. When bambara nutshell cellulose was added to weight percentages, the bio-plastics' tensile, water-absorbing, and biodegradable qualities improved. Tensile strength increased significantly from 15 MPa to 50.25 MPa, elongation percentage dropped from 35% to 5%, Young's modulus rose from 50 MPa to 200 MPa, water absorption decreased from 15.93% to 11.48%, and biodegradability increased from 29.81% to 50.69%. By lowering reliance on non-renewable resources, the study has shown that bambara nutshell cellulose/potato-starch is a practical and sustainable method for producing bio-plastics, which offer an alternative to traditional plastics and promote environmental sustainability.

Keywords: Potato starch, Bambara nutshell, Agro-waste, Bio-plastic, Mechanical Properties, Biodegradability.

1. Introduction

The challenges related with traditional plastics have stimulated the conceptualization of manifold approaches to alleviate the huge effects discovered. These approaches comprise the evolution of novel plastics that can supplant the conventional ones or at the minimum lessen their employ in a few implementations (Jung et al 2023), the enhancement of brand design to reduce litter (Ingrao and Wojnarowska 2023), the design of modern and original replacements for plastics reuse (Chen and Hu 2024).Wholesome bio-plastics, such as films and coatings, constitute one of the advanced answer that have appeared, aiming to substitute conventional packaging methods in merchandize mostly masked by traditional plastics (Gaspar and Braga 2023). This replacement furnishes scientists and end users with an economical choice regarding palatability, performance, recyclability, and biodegradability, creating a remarkable benefaction to the food industry (Westlake et al 2023; Waluyo et al 2024). Similarly, biodegradable materials give a cutting-edge approach in food wrapping and health-related applications, stimulating, for example, injury healing and enhancing the standard of well-being of rehabilitants. Acquiring these compounds generates modern performance goods that permit the growth of new materials that are economical, harmless, very productive, and bioactive (Liu et al 2023). Bio-plastics are flexible and have permeated into diverse industries, such as clothing, farming/plants, locomotive and shipment, covering, bonding, building, end user devices, and plaything.

Food wrappings are their primary utilization, with about 43% of the 2.18 metric tons of bio-plastics produced in 2023 targeted to the packaging industry (Ghasemlou et al 2024; Zhao et al 2023). This industry is controlled by traditional plastics including polyethylene, propylene, polyester, polystyrene, nylon, and polycarbonate. Bio-plastics can possess identical or improved mechanical functionality compared to earlier mentioned plastics, permitting them to substitute hard food wrapping items including flatware, vessels, tubes, and swollen films (Ghasemlou et al 2024). Yet, bio-plastics encounter various limitations; extensive commercialization shows great manufacturing prices, and there are challenges with management and ignorance of product end-of-life therapy ((Ghasemlou et al 2024; Zhao et al 2023). The improvement of the attributes of a bio-plastic is connected to its preparation (kind of polymer, chemical adjustment, additives) and processing operation letting for advantages in both processing price and effects such as thermal, mechanical, oxygen and water barrier, optical characteristics, and biodegradability. This enhancement could accelerate the chances of substituting or eradicating traditional plastics (Zhao et al 2023).

The increasing global concern about plastic pollution and environmental sustainability has led to a growing interest in biodegradable plastics, also known as bio-plastics (Sharma et al 2019). Bio-plastics are derived from renewable resources such as plants, algae, or microorganisms, and can reduce dependence on fossil fuels and mitigate environmental pollution (Kumar et al 2020). Potato starch a biodegradable and renewable polysaccharide, has been widely used as a base material for bio-plastic production due to its abundance, low cost, and biodegradability (Afolabi et al 2020). However, potato starch bio-plastics have limitations, including poor mechanical properties, high water absorption rates, and low thermal stability (Ramasamy and Salim, 2022). To address these limitations, researchers have explored the use of natural reinforcement materials, such as cellulose, to enhance the properties of potato starch bio-plastics (Johnson and Adu, 2020). Cellulose, a natural polymer found in plant cell walls, has excellent mechanical properties, biodegradability, and thermal stability, making it an ideal reinforcement material for bio-plastics (Harajuwono and Suryanto 2020). Bambara nut shell, a waste product from food processing, is a potential source of cellulose for bio-plastic reinforcement (Afolabi 2020). The use of bambara nutshell agro-waste can reduce waste, promote sustainability, and improve the properties of potato starch bio-plastics. The potential applications of potato starch and bambara nutshell cellulose bio-plastics are vast. In the packaging industry, these materials create biodegradable films and containers that reduce the environmental impact of packaging waste. In agriculture, for mulch films and seedling pots that biodegrade in the soil, reducing plastic waste in farming practices.

Recent advances in bio-plastics include the development of composite materials that incorporate natural fibers or fillers, improving mechanical and thermal stability. Nanocellulose, in particular, has emerged as a promising additive due to its strength and reinforcing abilities (Adeyemi et al 2020). Canadian researchers, for example, have developed potato starch-based bio-plastics reinforced with nano-cellulose, which provides excellent mechanical performance (Singh and Verma 2022). In Europe, there is a growing interest in bio-polymer blends. In Germany, Fischer et al (2020) produced a blend of potato starch and PLA, which exhibited strong mechanical properties. Similarly, U.K. researchers have focused on potato starch-cellulose nanofiber composites as a means to produce more sustainable packaging materials (Turner and Brown 2019).

Bio-plastics derived from renewable resources such as starch and cellulose have a substantial global impact. According to the European Bio-plastics (2022), bio-plastics productions are to grow considerably, supported by consumer demand for eco-friendly products and government regulations to reduce plastic waste. The U.S. bio-plastics industry is projected to reach $5.9 billion by 2027, with starch-based materials making up a significant share (Shah et al 2020). In developing nations like Nigeria, bio-plastics offer substantial socio-economic benefits. Using locally available raw materials such as potato starch and bambara nut shell could foster local economic growth and provide job opportunities, aligning with national sustainability goals (Obi and Anyaoha 2021). Additionally, utilizing agricultural waste reduces environmental impact, offering a more sustainable waste management solution (Olusola et al., 2019). Countries such as Brazil and India have also embraced bio-plastic production, leveraging resources like sugarcane bagasse and rice husks to create sustainable packaging solutions (Santos and Lima 2020; Singh et al 2021).

The concentration of reinforcement materials such as bambara nutshell cellulose significantly influences the properties of bio-plastic composites. Research indicates that adjusting the cellulose concentration can greatly affect mechanical strength, thermal stability, and moisture resistance in starch-based bio-plastics. At lower concentrations, cellulose fibers may fail to provide adequate reinforcement resulting in composites with properties akin to those of pure starch bio-plastics. However, as the cellulose concentration increases the tensile strength and rigidity typically enhance due to improved interaction between the cellulose fibers and starch matrix. Modern study has been reported on bio-plastics to advance the recent drift in the bio-plastics market. The paramount donating components like starch, PLA, and PHA on bio-plastic production, give upcoming executing plans onto the market. Bio-plastics are preferred more in the food packaging market (Arif et al 2023; Khalid and Arif 2022). Conversely, excessively high concentrations can lead to fiber agglomeration, which may diminish reinforcement effectiveness and degrade the composite's overall properties. The water absorption and mechanical attributes should be juxtaposed to the quality plastic material to substitute it for utilizations like food packaging (Yang et al 2022). The composite bio-plastics possess various starch weight percentages, such as rice, corn, and tapioca. The cassava plant, which is widely available, cheap, and has properties such as inodorous and uncolored, is mainly applied to remove tapioca starch (Chowdhury et al 2023).

This study is significant because it investigates the potential of bambara nut shell agro-waste material as a sustainable reinforcement material for potato starch bio-plastics, contributing to the development of eco-friendly materials. It provides insights into the effects of cellulose concentration on the properties of bio-plastic composites, enabling the optimization of material performance. The study offers a comprehensive understanding of the mechanical properties, water absorption and biodegradability of bio-plastic composites, essential for their application in various areas of human application. Additionally, it contributes to the reduction of non-biodegradable plastic litters by developing biodegradable materials that can replace conventional plastics. The study also supports the utilization of agricultural waste (bambara nut shell) as a valuable resource, promoting a circular economy. Furthermore, it enhances the knowledge base on bio-plastic materials, informing future research and development in the field. The study has potential applications in packaging, agriculture, textiles, and medical domains, where biodegradable materials are in high demand. By carrying out this study, we can contribute to the advancement of sustainable materials science, reduce environmental pollution, and promote the use of renewable resources. In Nigeria, challenges in bio-plastic development include the lack of infrastructure and funding for large-scale production, though collaborations between research institutions and industry are underway to overcome these issues (Obi and Anyaoha, 2021; Ogah et al 2024).

Despite extensive research on starch-based bio-plastics significant knowledge gaps exist particularly regarding the integration of bambara nut shell cellulose as a reinforcement material. As an agricultural byproduct, bambara nut shell is often viewed as waste primarily used for animal feed or left to contribute to environmental issues. Although there are researches into agricultural residues in bio-plastics, the specific application of bambara nut shell cellulose in potato starch bio-plastics remains largely unexplored. This research gap underscores the need for studies focused on the compatibility, interaction, and effect of bambara nutshell cellulose as a reinforcement in starch-based bio-plastics. This study aims to investigate the effect of bambara nut shell agro-waste on the properties of potato starch bio-plastics, exploring the potential for sustainable bio-plastic production with improved mechanical properties, biodegradability and water resistance.

2.0 Materials and methods

In this study, the primary materials selected were chosen for their eco-friendly properties and availability. The raw materials used in this research includes: potato, bambara nut shell (locally known in Igbo as "*Okpa"*). Sodium hydroxide (NaOH) with acidimetric 99.0%, glycerol ($C_3H_8O_3$), and distilled water were also used.

2.1.1 Extraction of Potato Starch

The method of potato starch extraction was based on a study conducted by Natalia and Muryeti (2020). After peeling the potato's outer skin, clean tap water was used to wash it. A CookEX 4-in-1 blender was used to mash the potato until it was the consistency of porridge. After the cassava slurry has been carefully filtered, the starch is given time to settle, usually 24 hours at room temperature. The resulting cassava precipitate, which is mostly starch, is removed from the water after the precipitation time. After being separated, the starch is dried to eliminate any remaining moisture. A 100-mesh particle size is attained by filtering the dried starch precipitate.

2.1.1.1 Bambara Nut Shell Fiber Extraction

The Bambara nut shell, called Okpa in Igbo, was obtained locally from Eke Awka in Anambra State and first cleaned and washed to remove dirt and surface contaminants. The shells were then sun-dried to remove moisture and to lower the risk of microbial growth. The shells were then sieved to remove impurities like sand, stone, or any other material that could negatively affect the process. Finally, the thoroughly cleaned shells were ground into a fine powder using a mechanical grinder to reduce their size, and then sieved again with a 75µm mesh sieve to maintain a uniform particle size of 75 µm. To determine the real dry weight and eliminate any moisture or liquid content, the powdered bambara nut shell was baked on a tray at 100°C for 24 hours (Ogah et al 2024).

2.1.1.1.1 Extraction of Bambara nut shell cellulose

The technique used to extract cellulose was in accordance with Syafri et al. (2021). To remove the outer skin, potato tubers were chosen and peeled. After being peeled, the potato fibers were crushed until they became fibrous. A 5% NaOH solution was used to alkalize the fibers from the mashed potatoes. 5% NaOH is the optimum concentration used to avoid fiber degradation. A hotplate set at 80 °C was used to alkalize the potato fibers, and a magnetic stirrer was used to agitate the mixture for an hour at a speed of 200 revolutions per minute (rpm). Following the alkalization procedure, distilled water was used to clean the fibers until the fiber solution's pH was neutral. After being thoroughly cleaned, the fibers were dried to eliminate any remaining moisture. A particle size of 100 mesh was attained by mashing and filtering the dried fibers. Through this technique potato cellulose was separated making it available as a useful reinforcing element for enhancing bio-plastics made from potato starch.

2.1.1.1.1.1 Bio-plastic Film Production

Different concentrations of 2.5%, 5%, 7.5%, and 10% by weight of bambara nut shell cellulose was added to the formulation (Septiosari et al 2014). In a beaker with 200 milliliters of distilled water, 10 grams of potato starch and bambara nut shell cellulose were combined. Using a hot plate and a magnetic stirrer set to 200 revolutions per minute at 90°C, 2 mL of glycerol was added to this bio-plastic solution, and the mixture was agitated for around 15 minutes. One of the most important preparatory steps, gelatinization, occurs in the bio-plastic solution during this stirring phase. The solution was let to cool to room temperature for two to three hours following the completion of the gelatinization procedure. This cooling stage was crucial because it gives any air bubbles in the solution ample time to rise and escape, resulting in a more homogeneous and smoother bio-plastic layer. Once the gelatinized bio-plastic solution has reached room temperature, it was carefully poured into a mold with dimensions 60×60mm, ensuring that the thickness of the solution was regulated to precisely 3mm. To enable the film to harden and acquire the required qualities, the mold containing the bio-plastic solution was lastly put in an oven and dried for 20 hours at a constant temperature of 50°C.

2.2 Bio-plastic Film Characterization

2.2.1 Bio-plastics' Mechanical Properties

American Standard Testing and Materials (ASTM) standard D-882 is the basis for testing mechanical qualities. The test samples measure 8 cm in length, 10 cm in width, and less than 1 mm in thickness. A Universal Testing Machine (UTM) Zwick Roell type all round 250 kN is used to evaluate the mechanical properties of the bio-plastic samples at a speed of 8 mm min-1. Three parameters—tensile strength, elongation, and Young's modulus—were used to assess the mechanical characteristics of the bio-plastics. Equations were used to compute these parameters in accordance with the ASTM D5336 standard's instructions (Suparno and Danieli 2017).

The following formula can be used to get the resulting Tensile strength (Eq. 1), Elongation (Eq. 2), and Young's modulus (Eq. 3):

Tensile strength $$\partial = F\max / A \qquad (1)$$

Where δ was tensile strength (MPa), Fmax was maximum load force (N), and A was surface area (mm^2)

Elongation percentage $$\ell = \Delta L / Lo * 100 \qquad (2)$$

Where ΔL was long grain (mm) and Lo was the initial length (mm).

Young's modulus $$\delta = \partial / \varepsilon \qquad (3)$$

Where δ was tensile strength and ε is elongation

2.2.1.1 Absorption of Water

This test aids in figuring out how easily the bio-plastic absorbs moisture from the surroundings, which is crucial for evaluating how well it performs in different applications, especially when humidity levels may affect its characteristics. Usually measuring 2 × 2 cm the bio-plastic samples are chopped into tiny pieces. After that, these samples are dried in an oven set at a steady 50 °C till their weight doesn't change, and they are weighed until their weight stays constant (W1). In sealed containers filled with saturated salt solutions, the water vapor absorption test was carried out at 25°C with a constant relative humidity of 75±5%.

Water absorption (%) = $$W2 - W1 / W1 * 100 \qquad (4)$$

Where W_1 is the initial weight of the dried sample (grams) and W_2 was the final weight of the sample (grams) after exposure in a sealed container filled with salt solutions to controlled humidity conditions.

2.2.1.1.1 Biodegradability Test

The bio-plastic's biodegradability was assessed in accordance with Prachayawarakorn et al (2010). The soil used for the experiments had a clay loam texture. The test samples were cut into 2 × 5 cm pieces and then dried in an oven set to 50°C until they reached a consistent weight. These dried samples were subsequently placed in the soil for specified durations, including 5, 10, and 15 days. After a specified period, the samples were removed from the soil, and their degraded mass was determined. The extent of degradation was assessed in accordance with the ASTM D5336 standard. The samples were measured the initial and final weights using an analytical balance to determine the percentage of degradation using the following equation (Eq. 5):

Percentage of degradation (%) = $$M1 - M2 / M1 * 100 \qquad (5)$$

Where M_1 is the initial weight of the sample (grams) and M_2 was the final weight of the sample (grams) after degradation.

2.2.1.1.1.1 Analysis of Data

The study's experimental model was a straightforward, single-element, completely random depiction. When a control element without cellulose inclusion was introduced for analogy, the process used here needed bringing different loadings of cellulose from bambara nut shell, which are 2.5 wt%, 5 wt%, 7.5 wt%, and 10 wt%. IBM SPSS Statistics 26.0 was used to examine the investigative figures. To assess the impact of cellulose insertion on tensile strength and modulus, water absorption, and biodegradability, the figures were subjected to analysis of variance (ANOVA). Three samples were tested for each parameter. The Duncan's Multiple Range Test (DMRT) was then used to examine any differences in the mean values of the produced bio-plastic.

3.0 Results and Discussion

3.1 Tensile Strength

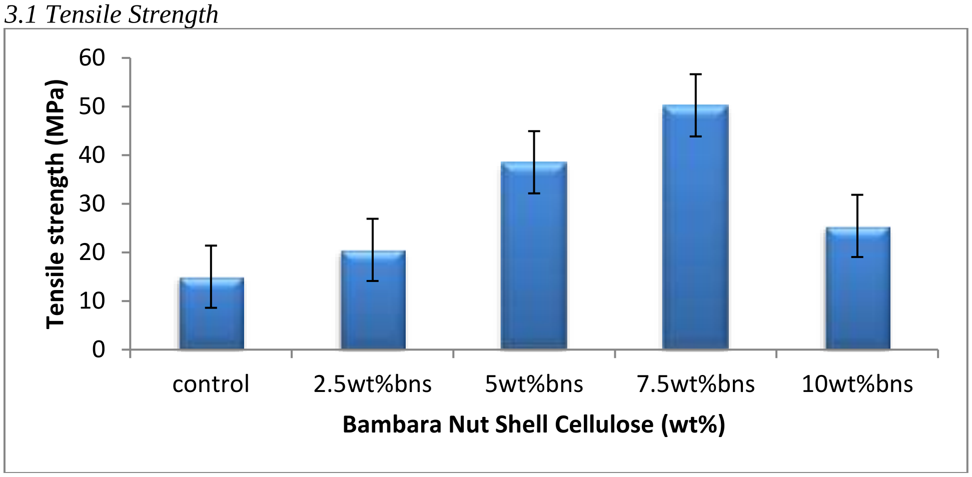

Figure 1: Effect of bambara nut shell cellulose on tensile strength of bio-plastic

The findings showed that under a loading of 7.5 weight percent bambara nut shell cellulose, the maximum tensile strength was 50.25 MPa. Compared to the control sample, which had a tensile strength of 15 MPa, this indicates a notable improvement. Strong intermolecular bonds between the BNS cellulose and the potato-starch matrix may have contributed to the improvement by forming a stronger and more cohesive bio-plastic structure. These results are in line with earlier studies that found that adding natural cellulose fillers to starch-based matrices as reinforcement resulted in comparable gains in tensile strength (Banik et al 2021; Zhao et al 2020). Because of the efficient load transmission between cellulose and starch, cellulose-reinforced starch films demonstrated increased tensile strength (Banik et al 2021). However, tensile strength dropped to 25.45 MPa at a 10% concentration. The reduction could be the result of cellulose particles clumping together with increased filler loading, which would cause incompatibility between the filler and matrix and create weak spots in the film. Zhao et al (2020) found that increasing filler loading can cause matrix homogeneity to be disrupted and tensile strength to decrease. The tensile strength was significantly impacted by the addition of cellulose, according to an ANOVA conducted with a significance level of α=0.05. According to the investigation, the tensile strength of the bio-plastics was significantly increased by the addition of cellulose, especially at the 7.5wt% loading. According to the DMRT data, bio-plastics that contain cellulose to a 7.5% degree differ significantly from those manufactured with potato starch.

3.2 Elongation at Break (%)

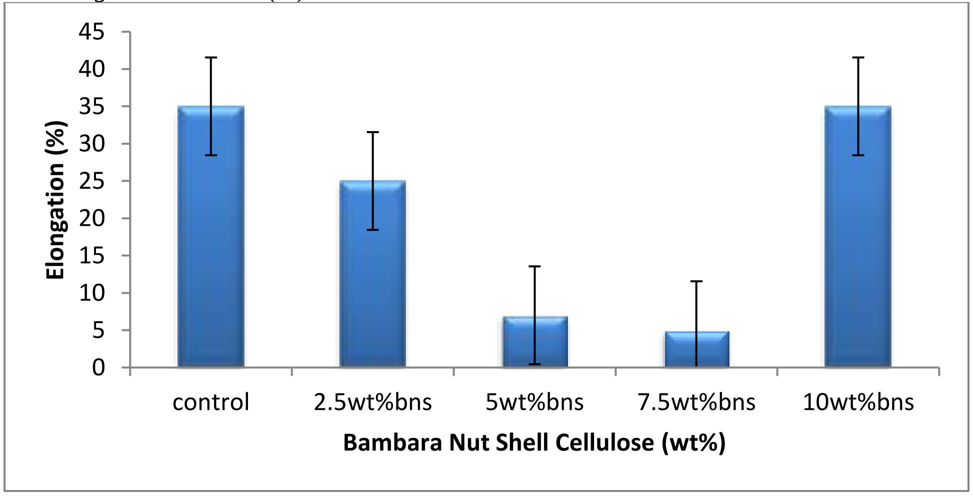

Figure 2: Effect of bambara nutshell cellulose on elongation at break of bio-plastic

The impact of bambara nutshell cellulose on the elongation at break (%) is depicted in figure 2. When bambara nutshell cellulose was added, the elongation value varied between 5 and 35%. When bio-plastics were elongated without cellulose (0%) added, the elongation value was 35%. The elongation value dropped to 25% when cellulose was added at a loading of 2.5 weight percent. This demonstrated that elongation values were significantly impacted by the presence of cellulose. The elongation values were statistically significantly affected by the addition of cellulose, as confirmed by the ANOVA (with α=0.05 significance level). The DMRT results showed that the bio-plastic containing 2.5 weight percent cellulose was distinct from the other bio-plastics. When cellulose was added at a loading of 7.5wt%, the elongation value dropped. Strong bonds that limit the overall strain value were formed as a result of the interaction between the carboxyl groups of cellulose and the hydroxyl groups of starch (Maulida et al 2016). Tensile strength and Young's modulus rose as a result of the bio-plastics' increased stiffness due to the addition of cellulose. But because the polymer matrix chains became less mobile as a result of the increased stiffness, elongation gradually decreased. The high degree of cellulose's flexibility may also be related to the decrease in elongation (Ogah et al 2024).

3.3 Young's Modulus

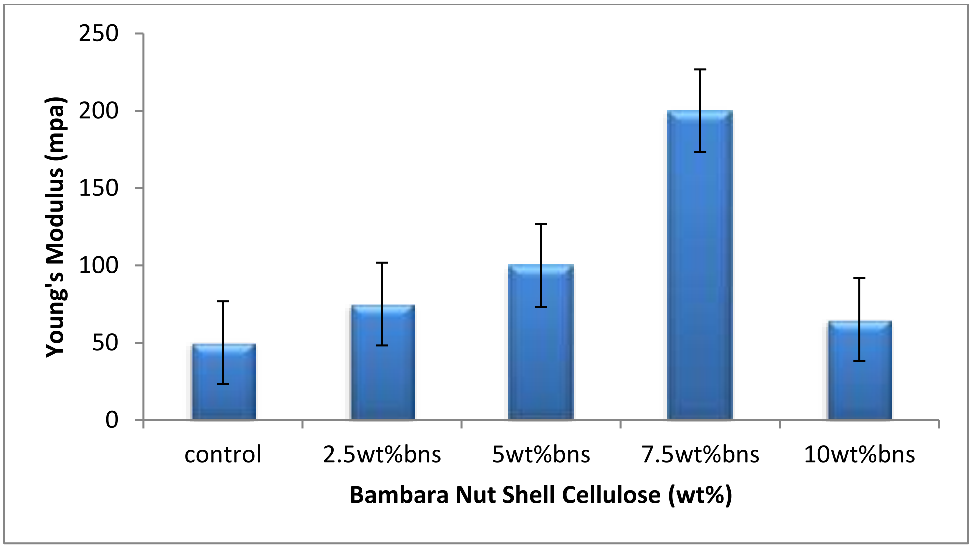

Figure 3: Effect of bambara nut shell cellulose on Young's modulus of bio-plastic

The bambara nut shell cellulose potato starch bio-plastic's Young's modulus is displayed in figure 3. The Young's modulus value of bio-plastics without cellulose (0%) added was 50 MPa. When cellulose is added, the Young's modulus value varies between 75 and 200 MPa. ANOVA (with a significance level of α=0.05) confirmed that the addition of cellulose significantly affected the Young's modulus values. The addition of 7.5% cellulose resulted in the highest Young's modulus value, reaching 200 MPa. The 7.5% cellulose bio-plastics were distinct from the other bio-plastics, according to the DMRT data. The high Young's modulus value indicates that the bio-plastics' stiffness and rigidity were greatly enhanced by the inclusion of cellulose from bambara nut shell. According to earlier studies, the inclusion of cellulose up to 7.5 weight percent increased the Young's modulus value (Jumaidin et al 2021). According to Edhirej et al (2017), the interaction between cellulose and the starch matrix was responsible for the increase in Young's modulus, which produced stronger and more rigid material characteristics. The bio-plastic is strengthened by the addition of cellulose, which reduces its vulnerability to deformation under stress. However, because of structural alterations in the starch matrix that occur at greater cellulose concentrations, the 10% cellulose addition reduced the value of Young's modulus (Edhirej et al 2017). A less homogeneous structure results from the cellulose's unequal distribution and aggregation inside the matrix. The uneven distribution of cellulose disrupts the material's homogeneity which is essential for maintaining the desired material.

3.4 Water Absorption (%)

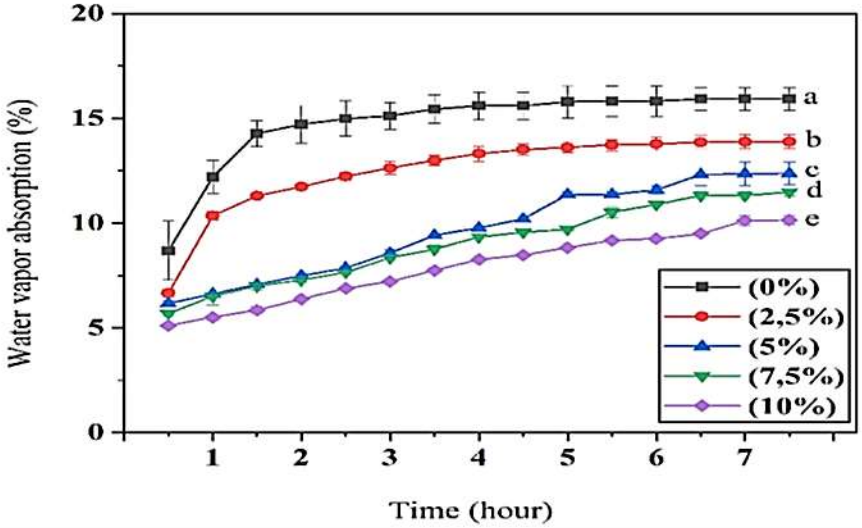

Figure 4: Effect of bambara nutshell cellulose on water absorption of bio-plastic

The impact of bambara nut shell cellulose on the water absorption of bio-plastic is depicted in figure 4. The process of water absorption is used to assess how well bio-plastics can absorb environmental water. Figure 4 shows the water absorption of the bio-plastic following 7.5 hours of addition. The water absorption value that results falls between 10.14 and 15.93%. The highest water absorption value of 15.93% was obtained from bio-plastics that had a cellulose addition of 0wt%. This pattern demonstrated the high-water affinity of bio-plastics that do not contain cellulose. At 10 weight percent cellulose addition, the lowest water absorption value was 10.14%. This demonstrated how adding cellulose can increase the bio-plastics' resilience to reducing the rate of water absorption. ANOVA (α=0.05) showed that the water absorption value was significantly impacted by the addition of cellulose. The water absorption value is significantly altered by the addition of cellulose.

According to the DMRT results, bio-plastics created with cellulose added up to 10 weight percent differ from those made with potato starch. When 10 weight percent cellulose is added the water absorption value can drop from 15.93% to 10.14%. This suggests that the cellulose found in bambara nut shells may enhance the starch's water affinity characteristics. According to similar earlier research, cellulose can decrease the absorption of water vapor (Asyrofi et al 2018; Mahardika et al 2019). The water resistance of the bio-plastic is significantly impacted by the inclusion of cellulose because cellulose chains do not prefer water as much as starch molecules do. Water molecules cannot enter the starch matrix because cellulose acts as a barrier (Liu et al 2005). The strong link between the matrix and the filler, such as cellulose, limits the passage of water molecules into the bio-plastics, which is why Mahardika et al (2018) also showed a decrease in water vapor absorption. Additionally, the presence of cellulose in the starch matrix limits the accessibility of empty space, which contributes to the decrease in the rate of water absorption. As a result, water molecules face challenges when trying to permeate the bio-plastics. One advantage of bio-plastics with lower water absorption is that they preserve the quality and state of the goods they enclose or package (Mahardika et al 2021). They are therefore appropriate for uses where controlling water absorption is crucial.

3.5 Biodegradability Test

The bio-plastics' deterioration is depicted in figure 5. Bio-plastics that were treated to five days of deterioration showed degradation values ranging from 16.10% to 22.72%, those that were submitted to ten days from 22.13% to 28.64%, and those that were subjected to fifteen days from 29.81% to 50.6%. The analysis of variance data (α=0.05) confirmed that the degradation values were significantly impacted by the addition of cellulose. The degradation value of bio-plastics is significantly altered by the addition of cellulose. After 15 days of deterioration, the highest degradation value 50.6% was observed when 2.5% cellulose was added. On the other hand, bio-plastics without cellulose addition showed the lowest degradation value over the same 15-day degradation period, at 29.81%. The DMRT results demonstrated that bio-plastics made with a 2.5% cellulose addition differ from other bio-plastics. According to the findings, adding 2.5% cellulose from bambara nutshells can enhance the breakdown of bio-plastics.

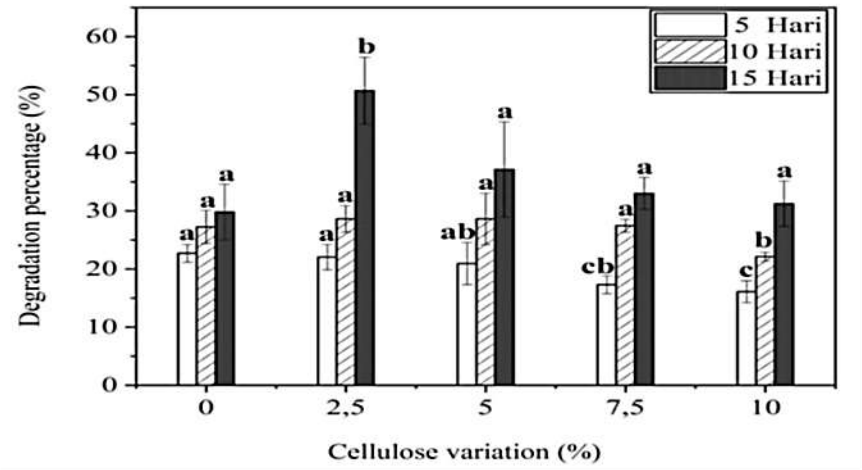

Figure 5: Effect of bambara nut shell cellulose on biodegradability of bio-plastic

Figure 6 depicted the breakdown of bio-plastics at 5, 10, and 15-day intervals. By day 15, the bio-plastics containing 2.5% cellulose had degraded the most. Adding 2.5% cellulose caused the bio-plastic to literally break down into tiny fragments. Cellulose insertion can quicken the bio-plastics' rate of deterioration. According to other research, adding cellulose could speed up the breakdown of bio-plastics because it is a biological substance that breaks down readily by microbes (Mahardika et al 2019; Behjat et al 2009; Panjaitan et al 2017). Bio-plastics should totally degrade (100%) in 60 days if the ASTM D5336 standard, which specifies protocols for the amount of time needed for plastic to entirely breakdown, is followed. The ASTM D5336 standard was reached by the degradation findings for bio-plastics containing 2.5% cellulose which achieved a 50.6% breakdown rate in 15 days. Temperature, soil pH, humidity and presence of microorganisms in the soil could influence the biodegradation process in real-world conditions.

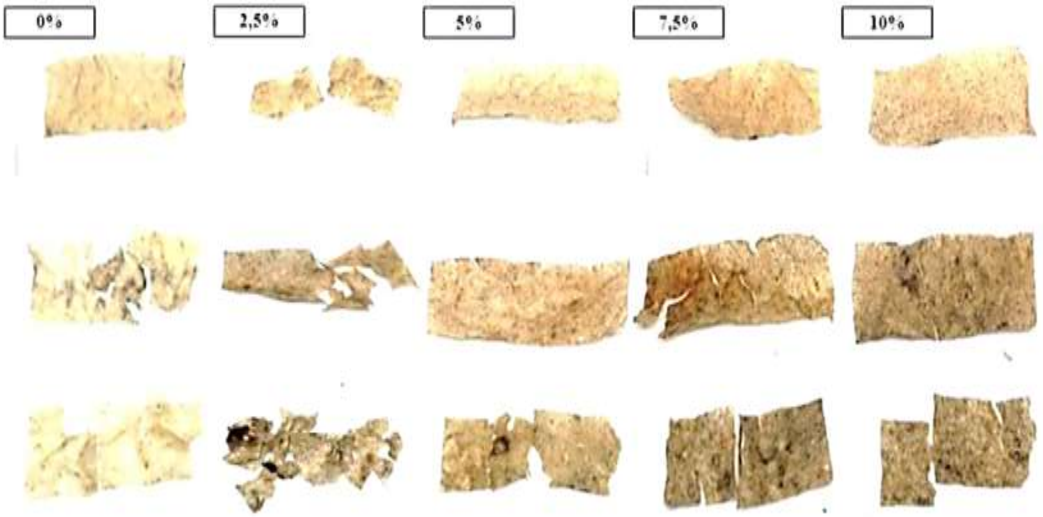

Figure 6: Degradation of bio-plastic after soil burial for 5, 10, and 15 days

4.0. Conclusion

In this study, the cellulose from bambara nut shells and potato starch were successfully used to produce bio-plastic. The tensile strength and Young's modulus of the potato-starch bio-plastic were enhanced by the addition of bambara nutshell cellulose up to a loading of 7.5%. At 7.5% loading, the insertion of cellulose into potato-starch bio-plastics was optimized. Tensile strength increased from 15 MPa to 50.25 MPa, elongation decreased from 35% to 5%, Young's modulus increased from 50 MPa to 200 MPa, water absorption rate decreased from 15.93 to 11.48%, and biodegradability increased from 29.81 to 50.69% when cellulose was added at a loading of 7.5%. The extensive usage of synthetic plastics has led to a serious environmental problem, particularly with regard to plastic trash. It can take more than a century for plastic garbage to fully break down. Thus, a trend toward the use of eco-friendly alternatives, like bio-plastics, is a workable way to address these issues. One kind of eco-friendly plastic that breaks down spontaneously is called bio-plastic. A vital raw element for the manufacturing of bio-plastics is starch obtained from foods like cereals and tubers. Because starch is an environmentally beneficial material that microorganisms can readily break down, it is employed in the creation of bio-plastics. It is also a renewable resource, abundant, and reasonably priced. However, hygroscopicity, low mechanical qualities (brittleness), and excessive moisture absorption are some of the drawbacks of starch-based bio-plastics. Cellulose is a reinforcing substance that can be used to overcome these restrictions.

5.0 Recommendation

The utilization of single-use-plastic (bio-plastics) produced from potato starch reinforced bambara nut cellulose will go a long way in giving economic relevance to waste in Nigeria. It can also provide cost effective options for developing bio-plastics by manufacturing industries. It will help reduce the problem of unnecessary waste in the environment and also serve to reduce environmental hazards caused by fossil-based plastics material; as the bio-plastics produced from this study will be environmentally friendly, and will have no negative impact on the environment. Moreover, the Lagos State Government intends to introduce single-use-plastic by banning sachet water by the year 2025. The actualization of this study will boost the application of single-use-plastics (SUP) and local raw materials in Nigeria.

Acknowledgements

The authors would like to thank their individual universities for creating the favorable conditions that allowed this study to be conducted.

References

Adeyemi, M. O., Nwafor, I., and Akinyele, D. 2020. Cellulose extraction from agricultural wastes for bio-plastics reinforcement. International Journal of Agricultural Waste Management, 9(2):55-70.

Afolabi, A. A., Akinpelu, S. O., and Yusuff, A. O. 2020. Biodegradability and mechanical properties of starch-based bio-plastics from sweet potato and bamboo fibers. Journal of Polymers and the Environment, 28(3):815-823.

Arif, Z.U.; Khalid, M.Y.; Noroozi, R.; Hossain, M.; Shi, H.H.; Tariq, A.; Ramakrishna, S.; Umer, R. (2023). Additive manufacturing of sustainable biomaterials for biomedical applications. Asian J. Pharm. Sci., 18, 100812.

Asyrofi M, Abral H, Kasim A, Pratoto A, Mahardika M, et al., 2018.Characterization of the sonicated yam bean starch bionanocomposites reinforced by nanocellulose water hyacinth fiber (WHF): the effect of various fiber loading. *Journal of Engineering Science and Technology* **13** 27002715.

Banik, S., Alam, M. S., Hossain, M. M., and Islam, M. N. 2021. Effect of cellulose and starch on the mechanical properties of biodegradable composites: A review. *Materials Science and Engineering*, 55(3), 234-245. doi: 10.1016/j.msea.2021.120912.

Behjat T et al., 2009. Effect of PEG on the biodegradability studies of Kenaf cellulose –polyethylene composites *International Food Research Journal* **16** 243247.

Chen, S.; Hu, Y.H. 2024. Advancements and future directions in waste plastics recycling: From mechanical methods to innovative chemical processes. Chem. Eng. J., 493, 152727. Gaspar, M.C.; Braga, M.E.M. (2023). Edible films and coatings based on agrifood residues: A new trend in the food packaging research. Curr. Opin. Food Sci., 50, 101006.

Chowdhury, M.A.; Hossain, N.; Badrudduza, M.D.; Rana, M.M. 2023. Development and Characterization of Natural Sourced Bioplastic for Food Packaging Applications. Heliyon 9, E13538.

Edhirej A et al. 2017. Tensile, barrier, dynamic mechanical, and biodegradation properties of cassava/sugar palm fiber reinforced cassava starch hybrid composites *BioResources***12**71457160.

European Bio-plastics 2022. Bio-plastics Market Data. Retrieved from https://www.european-bioplastics.org

Fischer, R., Müller, S., and Wagner, T. 2020. Enhancing the thermal stability of potato starch-based bio-plastics through glycerol plasticization. Materials Science Journal, 45(6):78-89.

Ghasemlou, M.; Barrow, C.J.; Adhikari, B. 2024.The future of bio-plastics in food packaging: An industrial perspective. Food Packag. Shelf Life, 43, 101279.

Harsojuwono, B. A., and Suryanto, D. 2020. Characteristics of bio-plastics reinforced with modified cassava starch and konjacglucomannan: Effects on mechanical properties and biodegradability. International Journal of Pharmaceutical Research, 13(2):1502-1510.

Ingrao, C.;Wojnarowska, M. 2023.Findings from a streamlined life cycle assessment of PET-bottles for beverage-packaging applications, in the context of circular economy. Sci. Total Environ. 892, 164805.

Johnson, L., and Adu, A. 2020. Global trends in bio-plastic development and application. Renewable Materials Research, 15(1):34-45. *Journal of Physics: Conf. Ser.* **710** 012012.

Jumaidin R et al., 2021. Processing and characterization of banana leaf fiber reinforced thermoplastic cassava starch composites. *Polymers* **13.**

Jung, H.; Shin, G.; Kwak, H.; Hao, L.T.; Jegal, J.; Kim, H.J.; Jeon, H.; Park, J.; Oh, D.X. (2023). Review of polymer technologies for improving the recycling and upcycling efficiency of plastic waste. Chemosphere, 320, 138089.

Khalid, M.Y.; Arif, Z.U. 2022. Novel Biopolymer-Based Sustainable Composites for Food Packaging Applications: A Narrative Review. Food Packag. Shelf Life, 33, 100892.

Kumar, A., Sharma, S., and Singh, R. 2020. Development and characterization of potato starch-based bio-plastics with enhanced mechanical properties. *Journal of Polymer Science*, 58(4):567-579. https://doi.org/10.1002/pol.2020.

Liu W et al., 2005. Green composites from soy-based plastic and pineapple leaf fiber: fabrication and properties evaluation. *Polymer* **46** 27102721.

Liu, Z.; de Souza, T.S.P.; Holland, B.; Dunshea, F.; Barrow, C.; Suleria, H.A.R. 2023.Valorization of Food Waste to Produce Value-Added Products Based on Its Bioactive Compounds. Processes, 11, 840.

Mahardika M et al., 2018. Ftir and moisture absorption of yam bean starch biocomposites with bam bean (*Pachyrhizuserosus*) bagasse fibers as reinforcement. *Jurnal ILMU DASAR* **19** 9398.

Mahardika M et al., 2019. Properties of cellulose nanofiber/bengkoang starch bionanocomposites: Effect of fiber loading. *Food Science and Technology* **116.**

Mahardika M et al., 2021. Tensile strength and moisture resistance properties of biocomposite films based on polyvinyl alcohol (PVA) with cellulose as reinforcement from durian peel fibers on *E3S Web of Conferences* **302** 02001.

Maulida, Siagian M. and Tarigan P. 2016. Production of starch-based bio-plastic from cassava peel reinforced with microcrystalline cellluloseavicel PH101 using sorbitol as plasticizer.

Murevanhema, Y. Y., and Jideani, V. A. 2013. Potential of bambara groundnut (Vignasubterranea (L.) Verdc) pilk as a probiotic beverage—A review. Critical Reviews in Food Science and Nutrition, 53(9):954-967.

Natalia, E. V. and Muryeti 2020. Pembuatanplastik biodegradable daripatisingkongdankitosanelza. *Jurnal Printing and Packaging Technology* **1** 5768.

Obi, C., and Anyaoha, C. 2021.Exploring the potential of bio-plastics in Nigeria: A review. Journal of Nigerian Environmental Research, 21(1): 45-57.

Ogah, A, O., Archibong, F.N., Ojukwu, U.P., Mbam, N.J., Yudhanto, F. 2024. Investigating natural fiber reinforced polymer composites, biocomposites, bionanocomposites thermo-Mechanical attributes emerging implementations. Journal of Fibers and Polymer Composites, 3(2): 119-157. https://doi.org/10.55043/jfpc.v3i2.136.

Ogah, A.O., Archibong, F, N., Allen, M.A., Nlemedim, P.U., Ime, J.U., Chima, M.O., Igberi, C.O. 2024. Evaluation of physical, mechanical and thermal properties of epoxy composites filled with bio-fiber derived from bambara nut shell filler, Polymer Bulletin, 1-19. https://doi.org/10.1007/s00289-024-05227-8..

Olusola, F., Adebola, K., and Ogunbiyi, J. 2019. Water absorption challenges in starch-based bio-plastics. Nigerian Journal of Chemical Engineering, 12(3):250-267.

Panjaitan R. M, Irdoni, and Bahruddin 2017. Pengaruhkadardanukuranselulosaberbasis batangpisangterhadapsifatdanmorfologibioplastikberbahanpatiumbitalas. *Jom FTEKNIK* **4** 17

Prachayawarakorn J, Sangnitidej P. and Boonpasith P. 2010. Properties of thermoplastic rice starch composites reinforced by cotton fiber or low-density polyethylene. *Carbohydrate Polymers* **81** 425433

Ramasamy, M., and Salim, M. 2022. Impact of nano-cellulose on the mechanical properties of starch-based bio-plastics. Materials Today: Proceedings, 51:2357-2362.

Santos, P., and Lima, M. 2020. Bio-plastic production from sugarcane bagasse in Brazil. Brazilian Journal of Agricultural Science, 9(8):125-134.

Septiosari A., Letifah and Kusumastuti E. 2014. Pembuatandankarakterisasibioplastiklimbahbijimanggadenganpenambahanselulosadangliserol. *Indonesian Journal of ChemicalScience* **3** 157162.

Shah, P., Chang, T., and Wu, Y. 2020. Biodegradable packaging solutions in the U.S.: A focus on starch-based bio-plastics. American Journal of Green Technology, 15(3), 95-110.

Sharma, S., Chandel, A., and Thakur, V. 2019. Bio-plastics: towards sustainable development. *Environmental Chemistry Letters*, 17(2):629-643. https://doi.org/10.1007/s10311-019-00862-5

Shen, L., Haufe, J., and Patel, M. K. 2010. Product overview and market projection of emerging bio-based plastics. *PRO-BIP 2009* Report, Utrecht University, the Netherlands.

Singh, R., Sharma, M., and Kumar, P. 2021. Agricultural by-products as cellulose sources for bio-plastics reinforcement. Journal of Environmental Biotechnology, 16(2): 45-58.

Singh, V., and Verma, P. 2022. Biodegradable composites based on starch and cellulose nanofibers: Mechanical and thermal properties. International Journal of Biological Macromolecules, 206: 1160-1167.

Suparno O. and Danieli R. 2017. Penghilanganhemiselulosaseratbambusecaraenzimatikuntukpembuatanserat bamboo. *JurnalTeknologiIndustriPertanian***27** 8995.

Syafri Edi, Sandra Melly, Irwan Anas, Angga Defrian, Sdirman Umar and Melba Mahardika 2021. Extraction and characterization of agave gigantean fibers with alkali treatment as reinforcement for composites. Journal of natural fibers, 19(14): 1-10. https://doi.org/10.1080/15440478.2021.1964124

Turner, L., and Brown, K. 2019. Enhancing mechanical properties of bio-plastics using cellulose nanofibers. European Journal of Polymer Science, 28(5), 210-225.

Waluyo, J.; Purba, I.T.; Sani, K.Q.; Sayekti, N.; Ramadhani, S.S.; Pranolo, S.H.; Margono; Kaavessina, M. (2024). Bio-plastic from empty fruit bunch cellulose/chitosan/starch: Optimization through box-Behnken design to enhance the mechanical properties. J. Plast. Film. Sheeting, 40, 259–282.

Westlake, J.R.; Tran, M.W.; Jiang, Y.; Zhang, X.; Burrows, A.D.; Xie, M. 2023. Biodegradable biopolymers for active packaging: demand, development and directions. Sustain. Food Technol., 1, 50–72.

Yang, J.; Dong, X.; Wang, J.; Ching, Y.C.; Liu, J.; Chunhui, L.; Baikeli, Y.; Li, Z.; Mohammed Al-Hada, N.; Xu, S. 2022. Synthesis and Properties of Bio-plastics from Corn Starch and Citric Acid-Epoxidized Soybean Oil Oligomers. J. Mater. Res. Technol., 20,373–380.

Zhao, H., Wu, Q., Zhang, C., and Xie, J. 2020. Impact of cellulose fillers on the performance of bio-plastics: Insights into structural homogeneity and tensile strength. *Journal of Applied Polymer Science*, 137(32): 48832. doi:10.1002/app.48832.

Zhao, X.; Wang, Y.; Chen, X.; Yu, X.; Li, W.; Zhang, S.; Meng, X.; Zhao, Z.-M.; Dong, T.; Anderson, A.; et al. 2023.Sustainable bio-plastics derived from renewable natural resources for food packaging. Matter, 6, 97–127.