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Research Paper

Bioplastics from Avocado Seed Starch : Effects of Chitosan and PVA on Mechanical Properties, Water Resistance, and Biodegradability

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ABSTRACT: *A sustainable alternative to traditional petroleum-based plastics, bioplastics produced from avocado seed starch can help alleviate some of the environmental challenges presented by plastic waste. However, these products still need to improve their mechanical properties and water resistance for industrial use. The purpose of this study is to find out how changes in the amounts of chitosan and polyvinyl alcohol (PVA) affect the mechanical strength, water resistance, and biodegradability of bioplastics made from avocado seed starch. The solution-casting method prepared starch-based bioplastics using chitosan (2.5–4.5 g), PVA (2.5–5%) as filler, and glycerol as a plasticizer. This study found that adding more chitosan increased the tensile strength, reaching a maximum value of 30.696±0.106 N/mm*^{2} *in the SNI 7188.7:2016, which was higher than the tensile strength value of the N3 sample. The samples N1 and M1 demonstrated the highest elongation at break of 35.700±4.776% and the lowest water uptake of 5.167%, indicating a 94.833% water resistance. The plastics underwent complete biodegradation under soil conditions after 60 days. This led to valuable results, confirming that avocado seed starch-based bioplastics, as engineering materials for food packaging, have enormous potential for application in the industry. This research needs to increase the water resistance or scale it up for industrial production.*

Keywords*: avocado seed starch; bioplastics; chitosan; polyvinyl alcohol (PVA); mechanical properties*

1. INTRODUCTION

Concerns about plastic pollution in the world have elevated demands for the introduction of sustainable alternatives to conventional plastics. Plastics primarily composed of petroleum-based polymers, such as polypropylene, polycarbonate, polyethylene, and polystyrene, are widely used in both industrial and consumer applications due to their mechanical performance, which includes long-lasting properties, ductility, and affordability [1], [2]. Nevertheless, the non-biodegradable nature of the plastic mass is an environmental and health threat. Plastic waste accumulates in landfills and oceans, leaking toxins that disrupt ecosystems and harm animals. Furthermore, burning plastic waste releases toxic carcinogens, which add to air pollution and pose a public health danger [3], [4].

According to the Ministry of Environment and Forestry, approximately 18.6% of 19.56 million tons of waste generated in 2023 is plastic [5]. Indonesia is among the largest plastic waste contributors. Innovative solutions, such as the adoption of the 3R approach (Reduce, Reuse, Recycle) and the development of biodegradable materials like bioplastics, will be necessary to tackle this emerging challenge [6]. Bioplastics, produced using renewable resources, are environmentally sustainable alternatives due to their biodegradability

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and reduced ecological footprint [7]. Nonetheless, establishing their properties to obtain industrial standards for performance, i.e., mechanical strength and water resistance, remains a challenge [8].

Biodegradability and availability are well-known properties of starch-based bioplastics. Starch, a naturally occurring polysaccharide, has been of interest in literature due to its great film-forming ability, low cost, and non-toxic property [9], [10]. Traditionally, bioplastics are made from starch from food crops, such as cassava, corn, and potatoes. But food security is a crucial issue, as edible resources cannot be relied upon; therefore, alternative sources should be investigated [11], [12]. Avocado seeds, an agricultural waste, make a potential alternative due to the high starch content (30%) of the seeds and the availability of avocado waste, for example, in Indonesia with 2023 avocado production of 915,000 [13], [14]. Overall, this incident shows that avocado seeds are not just a waste of plastic; they can still be used, reminding us of the principles of a circular economy.

Though starch-based bioplastics have promising potential, various drawbacks, including low tensile strength, brittleness, and hydrophilicity, limit their functional lifespan and breakage and consequently reduce their application [15]. The need to improve these properties would make it necessary to incorporate reinforcing agents such as chitosan, polyvinyl alcohol (PVA), etc. Many people know that chitosan, a biopolymer made from chitin, can form hydrogen bonds with starch molecules [16], [17] and is very good at making films and killing microbes. Chitosan is widely used in bioplastics and is often lacking mechanical strength and flexibility; PVA is a synthetic biodegradable polymer that acts as an enhancer for the mentioned properties [18]. These materials have the potential to address the shortcomings of starch-based bioplastics, allowing them to be used for a wide range of applications, such as food packaging and agricultural films.

While starch-based bioplastics have been widely researched, there are still gaps in utilizing other starch sources based on agroinnovation and optimizing their formulations for industrial applications. The researchers [19] developed bioplastics from avocado seed starch but reported low tensile strength (4 MPa or N/mm^2) and elongation at break (54.50%) as well as high water absorption (10.32%). However, these values are still lower than those of the Indonesian National Standard (SNI 7188.7:2016) and should be improved. Chitosan is an important additive because it improves the mechanical properties of starch films through hydrogen bonding. Adding PVA makes the film resistant to water and makes it more flexible [20]. In addition, the addition of plasticizers such as glycerol reduces brittleness, offering a compromise between strength and flexibility [21], [22].

To get around these problems, the current study looked at what happens when the amounts of chitosan and PVA are changed. It looked at how these changes affect the mechanical strength, water resistance, and biodegradability of bioplastics made from avocado seed starch. This study aims to create biodegradable bioplastic products that are strong, flexible, and resistant to environmental influences as needed and specified in SNI 7188.7:2016 and Japanese Industrial Standards (JIS) No K 7130. This study supports bioplastics development with an untapped feedstock, which could contribute to solving both environmental as well as economic problems associated with developing sustainable materials.

2. METHODOLOGY

Materials and equipment. This research looks at sodium metabisulfite (to stop enzymes from turning the starch brown during the extraction process), distilled water, chitosan, glycerol, acetic acid, polyvinyl alcohol, and soil (for biodegradation analysis). The equipment used was an analytical balance, beakers, graduated cylinders, stirrers, thermometers, a magnetic stirrer (with a heating plate), a blender, a fine mesh (100 mesh), a drying oven, casting molds (23×26 cm), a tensile tester (Zwick Roell), a thickness gauge, and a humidity chamber.

Avocado seed starch preparation. Avocado seeds were the by-products of juice vendors around Karawang. The outer skin of the seeds was removed, and approximately 3 kg of cleaned seeds were rinsed thoroughly with distilled water. The seeds were pulverized and mixed with distilled water in a 1:2 ratio to yield a slurry. The mixture was passed through a fine cloth, which separated the starch-rich supernatant for easy collection from the fiber. After the starch settled for 24 hours, we decanted the supernatant and thoroughly washed the starch three times with distilled water to eliminate any contaminants. During the washing process, we added sodium metabisulfite (0.2%) to the starch to prevent browning due to the enzymatic reaction of polyphenol oxidase [1]. The starch was dried in a laboratory oven at a temperature 50–55°C for 8 hours, sieved through a 100-mesh sieve, and obtained fine, uniform starch powder.

Bioplastic film preparation. The solution–casting method was applied to prepare appropriate bioplastics. A homogeneous solution was prepared by dissolving chitosan in 1% acetic acid by stirring at room temperature. Simultaneously, we combined 10 g of starch avocado seed with 60 mL of distilled water and stirred it at 80°C. Depending on the formulation, PVA 2.5 and PVA 5% were separately dissolved in distilled water. Starch solution was plasticized using glycerol (2 mL) to increase flexibility [2].

The solutions were mixed by adding the chitosan–acetic acid solution to the starch dispersions and then the PVA solution. A magnetic stirrer thoroughly mixed the mixture at 80°C for 90 minutes to ensure complete blending. The viscous solution obtained was transferred to casting molds and evenly spread to prepare thin films. After 12 hours, we dried the films in an oven at 45–55°C and cooled them under controlled relative humidity (20–30%) for an additional 12 hours. This method provides constant film thickness and fewer cracks while drying [3].

Experimental design. This study carried out the experiment with different concentrations of chitosan (2.5, 3.5, and 4.5 g) with 2.5% PVA constant (M1, M2, and M3); then the same concentration of chitosan with 5% PVA constant (N1, N2, and N3, respectively). The testing sample included mechanical properties, water resistance, and biodegradability for each formulation. The researchers adapted the processing conditions and experimental setup values according to ASTM D 882-18 and Japanese Industrial Standards (JIS K 7130) [4], [5].

Characterization and testing. (a) Tensile strength and elongation at break. This study determined the tensile strength using a standardized tensile tester (Zwick Roell) in Equation 1, following the ASTM D 882-18 method. The research applied a uniaxial tensile load on rectangular bioplastic samples (15×6 cm) until they broke. Calculating the elongation at break (%) using Equation 2 to determine the ductility of the films.

$$TS = \frac{F_{max}}{A_0} \quad \text{.......... Eq. (1)}$$

$$\epsilon = \frac{\Delta L}{L_0} \times 100\% \quad \text{.......... Eq. (2)}$$

with F_{max} = the maximum force applied, A_0 = the initial cross-sectional area, ΔL = the change in length, and L_0 = the initial length.

(b) Thickness measurement. This research used a thickness gauge with an accuracy of approximately 0.001 mm to measure the thickness of the polymeric film. The study recorded an average of three measurements at various positions of each sample to ensure consistency [6].

(c) Water uptake. Water uptake was measured by immersing the bioplastic samples (2×2 cm) in distilled water at room temperature for 24 hours. Equation 3 computed the percentage water uptake (after - wet and before immersion - dry).

$$\text{Water uptake} = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100\% \quad \text{.......... Eq. (3)}$$

(d) Swelling degree. This study measured the degree of swelling for all the films to evaluate their ability to absorb water. One batch had samples submerged in water, with the weight change recorded. Swelling degree (%) was determined in Equation 4.

$$\text{Swelling degree} = \frac{L_{wet} - L_{dry}}{L_{dry}} \times 100\% \quad \text{……….. Eq. (4)}$$

(e) Biodegradability. Biodegradability was evaluated after burying bioplastic samples (5×5 cm) in soil at ambient conditions. The researchers monitored the samples for weight loss and physical degradation twice a day. All samples had completely degraded after 60 days, and the test lasted for 50 days [7].

3. RESULTS AND DISCUSSION

Biodegradable polymers were characterized according to their mechanical and water-related properties, biodegradation, and practicality. Parameters including tensile strength, elongation at break, and thickness inform the structural integrity of the materials; water resistance, water uptake, and swelling degree inform their functionality (Table 1 and Figure 1) in different environments (Figure 2). Biodegradability assessments are essential for aligning with sustainability goals, and comparisons with related studies underscore advancements made in this work. All these results together show the potential of chitosan-PVA bioplastics to fulfill the increasing demand for sustainable materials in packaging and more applications.

Mechanical Properties

1) Tensile strength

The bioplastics' tensile strength went up a lot as the concentrations of chitosan and PVA went up (Table 1). The N3 sample had the highest tensile strength, which was 30.696±0.106 MPa. The amino groups ($–NH_2$) of chitosan and the hydroxyl groups (–OH) of PVA form strong hydrogen bonds, which make the polymer matrix denser and more uniform. Also, unlike polyolefins, most plastic additives are made to work best at the glass transition temperature of the base plastic polymer. Because of this, they don't affect the glass transition temperature of the surface bioplastics [23], which makes the bioplastics stronger and better for industrial packaging uses. The resulting highest tensile strength value exceeds the minimum value specified in Indonesian National Standards (SNI 7818:2014), which can be used as an indication of the potential application of such a material.

Table 1. Mechanical properties chitosan-PVA bioplastics

Sample		Tensile Strength, N/mm^2	Elongation at Break, %	Thickness, µm
PVA, %	Chitosan, g			
2.5	2.5	9.168±0.809	32.270±1.850	238.000±12.909
2.5	3.5	14.482±1.285	2.970±0.904	204.667±13.683
2.5	4.5	18.081±0.113	2.540±1.033	213.000±11.385
5	2.5	11.895±0.176	35.700±4.776	234.667±10.040
5	3.5	25.862±1.873	14.180±2.754	264.667±2.869
5	4.5	30.696±0.106	4.477±0.201	265.665±11.475

The M1 sample showed a tensile strength of 9.168±0.809 N/mm^2, indicating a decrease but still acceptable for applications such as lightweight packaging. The balance of polymer concentrations and interactions at the molecular level makes it clear that any formulations need to be optimized in order to get the mechanical properties that are needed for the application [24].

2) Elongation at break

With increasing concentrations of chitosan (from 2.5 until 4.5 g), elongation at break decreased from 35.700±4.776% in the N1 group to 2.540±1.033% in the M3 group (Table 1). The decrease is due to the reinforcement effect of chitosan, which reduces the pliability of the polymeric matrix. Bioplastics with high elongation at break, such as N1, are ideal for flexible applications such as stretchable films [25]. Samples like M3 exhibit a decrease in elongation at break, indicating their suitability for more rigid packaging applications that prioritize mechanical strength over flexibility. This compromise shows the potential of these bioplastics to suit many industrial needs [26].

3) Thickness

The bioplastic was between 204.667±13.683 µm in M2 and 265.665±11.475 µm in N3 (Table 1). On the other hand, thicker films, like the ones noticed in N3, have better mechanical stability, which can be favorable for crucial applications requiring durability [27]. The composition and concentration of film-forming agents influence the variations in thickness. Uniformity is crucial for mechanical properties, as required by industrial standards such as the Japanese Industrial Standard (JIS) for bioplastic packaging [28], which mandate a uniform film thickness.

4) Water resistance

The resistance to water was better when the concentration of chitosan increased (Figure 1), while water resistance was highest in M1 (94.833%). Chitosan forms a hydrophobic barrier that makes it harder for water to pass through. This makes the material better for use in places with a lot of humidity [29]. On the other hand, precisely balancing hydrophobic and hydrophilic components becomes an important approach for adjusting bioplastics under specific environmental conditions or packagings, as samples with a higher PVA content showed a slight decrease in water resistance [30].

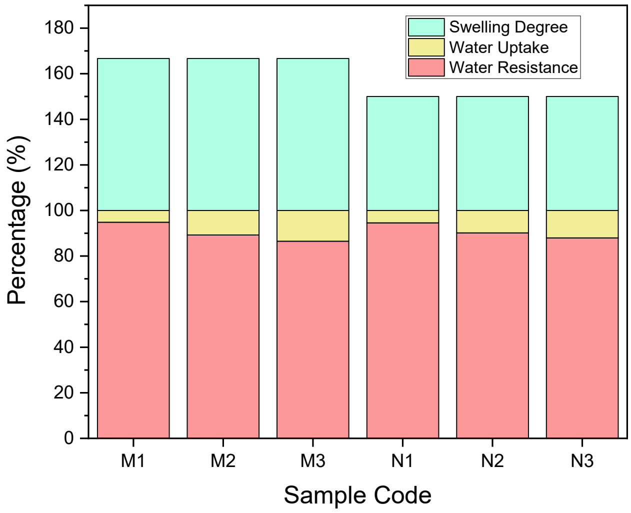

Figure 1. Characterization of chitosan-PVA bioplastics in terms of water-related properties

5) Water uptake

The results of water absorption varied between M1 (5.167%) and N3 (12.056%) and showed the opposite relationship with the water resistance (Figure 1). In N3, the hydrophilic property of PVA resulted in a substantial increase in water absorption that could meet the application needs for moisture control [31]. When using bioplastics for food packaging or biomedical applications, it's crucial to determine the ideal PVA-to-chitosan ratio to achieve the necessary properties for water uptake and water resistance [32].

6) Swelling degree

The swelling degree was 66.667% for M-series samples and decreased to 50.000% for N-series samples (Figure 1). This decrease is linked to the higher polymer density in N-series samples, which stops water from getting in and limits matrix expansion [33]. A lower degree of swelling makes these bioplastics more stable in size, which makes them good for uses that need to last and be resistant to changes in the environment, like agricultural films or industrial liners [34].

Biodegradability

All bioplastic samples degraded within 60 days and met SNI standards for biodegradable materials (Figure 2). The samples that were tested broke down faster when they had more PVA in them. This is likely because the polymers lost their integrity as they broke apart into molecules [35]. Consequently, this biodegradability renders the material an environmentally friendly substitute for conventional plastics used in single-use products, including but not limited to disposable cutlery and food packaging, to counter environmental pollutants [36].

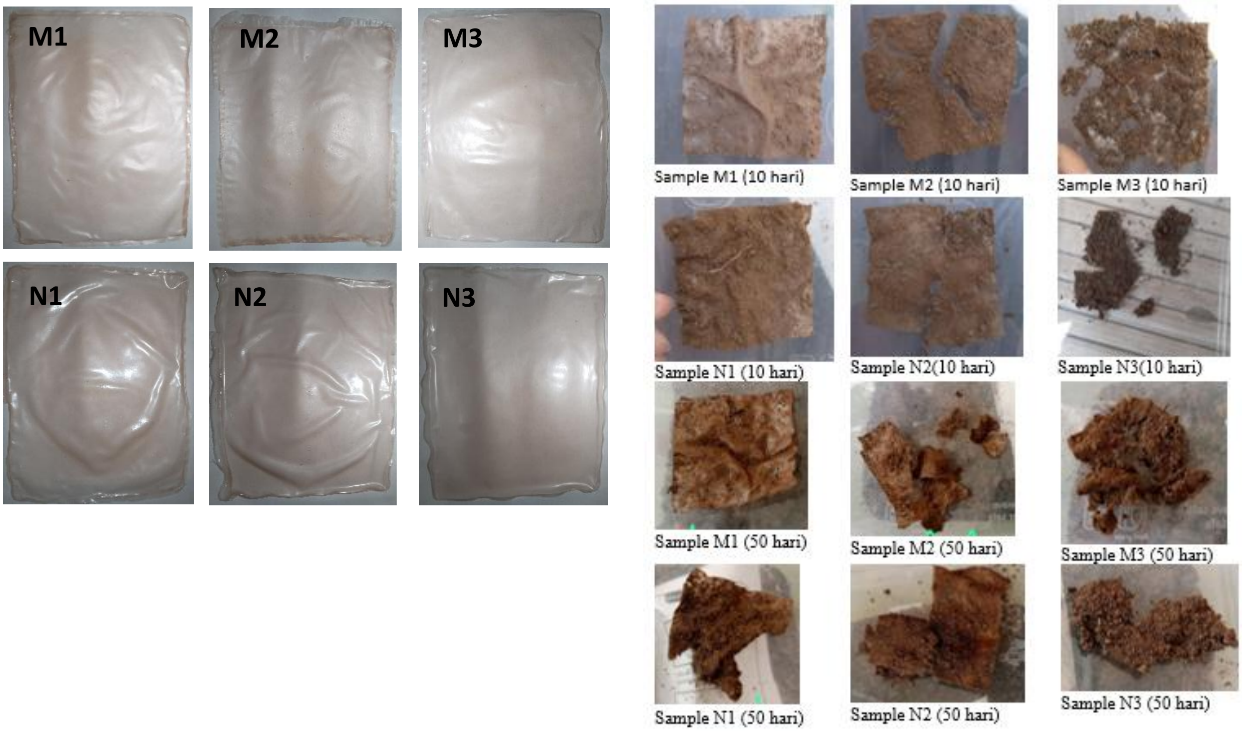

Figure 2. Bioplastic product appearance and post-degraded product appearance

Comparison with Previous Studies

N3 has a tensile strength of 30.69±0.106 N/mm^2 (Table 1) which is higher than other bioplastics like films made from cassava (3.68–3.80 N/mm^2) but about the same as very hard starch-PVA composites (24.7–302 MPa) [37]. The results for water resistance and biodegradability are also in line with what was said about chitosan-starch blends [38], which shows that the material performed well enough to be used in industry. This work demonstrates significant advances that will be useful for comparison with future developments in biopolymers based on renewable feedstocks [34].

Applications and Future Directions

These bioplastics (Table 1 and Figure 1-2), with their improved mechanical properties, water resistance, and biodegradability, offer improved alternatives for various applications such as food packaging, agricultural films, and disposable products. Furthermore, we can incorporate additives such as nanofillers or essential oils to enhance their functional attributes, including antimicrobial action and barrier properties [39]. Future studies need to include scaling up the production process, integrating with renewable energy sources, and advanced technology, such as hot-melt extrusion, to enable commercial use. These strategies have the potential to significantly expand the use of bioplastics, thereby igniting the spark of sustainable development in various sectors [40].

4. CONCLUSION

The study demonstrates that when reinforced with chitosan and PVA, avocado seed starch-based bioplastics can serve as a promising and sustainable replacement for plastic products commonly used in Indonesia. Given that the country produced 18.6% of plastic waste in 2023, adopting natural biomaterials from local agricultural waste is the only viable solution. The best bioplastic was made with 4.5 grams of chitosan and 5% PVA. It had a tensile strength of 30.696±0.106 N/mm^2, which was the same as what the Indonesian National Standard (SNI 7188.7:2016) called for. N1 had high flexibility with an elongation break of 35.700±4.776%, and M1 had the best water resistance (94.833%). Furthermore, the complete biodegradation of all bioplastics within 60 days aligns with environmental sustainability objectives. By using avocado seed waste, abundant in Indonesia but generally rejected due to its high starch content, this research contributes to reducing plastic pollution and encouraging the implementation of a circular economy. The food packaging industry, which requires flexible, strong, and biodegradable materials, could benefit from the results, according to the researchers. Further studies are required to increase the resistance against water for applications in wet environments, scale up for industrial production, and optimize the economic viability for widespread application in Indonesia. This research contributes to integrating Indonesia to achieve the sustainability target, reduce the dependency on petroleum-based plastic, and overcome the challenges in the environmental sector.

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