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Preparation and Characterization of Potato Peel Starch-Based Bioplastic Using Different Starch and Gelatin Concentrations

Sarah Nur Amanah[1] Rachmah Nanda Kartika[1] And Yoga Putra Pratama[1]

[1] Department of Graphic Printing and 3D Engineering Technology, Politeknik Negeri Jakarta, Kampus Baru UI, Jl. Prof. Dr. G.A. Siwabessy, Kukusan, Beji, Depok 16425, West Java, Indonesia

Email : sarah.nur.amanah.tgp22@mhsw.pnj.ac.id

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Abstract

Conventional plastic packaging has contributed significantly to environmental pollution due to its non-biodegradable nature. One promising alternative is potato peel starch-based bioplastic, which utilizes agricultural waste as a renewable raw material for biodegradable packaging. This study aimed to produce and characterize potato peel starch-based bioplastic with different starch and gelatin concentrations by evaluating its thickness, water absorption, solubility, and moisture content. Bioplastics were prepared using the solution casting method with starch concentrations of 3, 5, and 7 g and gelatin concentrations of 0, 0.5, and 1 g. Other materials used included glycerol as a plasticizer, chitosan, acetic acid, distilled water, and peppermint oil. The resulting bioplastics were characterized by measuring thickness, water absorption, solubility, and moisture content. The results showed that the bioplastics had thickness values ranging from 0.182 to 0.542 mm, water absorption of 52.37-82.15%, solubility of 23.68-39.84%, and moisture content of 13.94-18.92%. In general, increasing the concentrations of starch and gelatin tended to reduce water absorption, solubility, and moisture content, indicating the formation of a denser and more stable polymer matrix. The P7G1 formulation (7 g starch and 1 g gelatin) exhibited the most favorable characteristics, with the lowest water absorption, solubility, and moisture content. Therefore, this formulation has the potential to be further developed as an environmentally friendly bioplastic packaging material.

Key words: *bioplastic, potato peel starch, gelatin, solution casting, characterization.*

INTRODUCTION

The increasing amount of plastic waste in Indonesia has become a serious environmental issue that requires immediate attention. According to the National Waste Management Information System (SIPSN) of the Indonesian Ministry of Environment and Forestry (KLHK) in 2024, the total municipal solid waste generation reached 33.79 million tons, of which approximately 19.64% (around 6.63 million tons) consisted of plastic waste. Conventional plastics derived from petroleum-based materials are highly resistant to natural degradation and may require hundreds of years to decompose completely, thereby posing significant threats to ecosystems. One promising approach to mitigating plastic pollution is the development of biodegradable and environmentally friendly bioplastics derived from renewable natural resources (Fadlilah & Udjiana, 2023).

Potato peel has considerable potential as a raw material for bioplastic production due to its high starch content (52.09%) and its abundant availability as an agricultural by-product (Rahmawati et al., 2023). Previous studies have demonstrated that potato peel starch-based bioplastics can be successfully produced and exhibit promising potential for further development; however, their physical and mechanical properties still require improvement (Putri et al., 2024). Nurlaila and Purnomo (2023) investigated the utilization of potato peel waste as a filler in biodegradable plastic production. Their study reported that the best visual quality was achieved using a chitosan-to-starch ratio of 5:5 with 5 mL of glycerol. The highest visual elasticity was obtained with 6 mL of glycerol and 2.5 g of carboxymethyl cellulose (CMC). The optimum biodegradation performance (29.23% within nine days) was achieved using 10 g of starch, 6 mL of glycerol, and 2.5 g of CMC. Furthermore, the fastest water solubility (12 s under stirring conditions) was obtained from a formulation containing 7 g of starch, 3 g of chitosan, and 6 mL of glycerol, whereas under static conditions the film dissolved within 1–2 h when supplemented with 2.5 g of CMC (Nurlaila & Purnomo, 2023).

Genalda and Udjiana (2023) evaluated the characteristics of potato peel starch-based bioplastics plasticized with sorbitol using calcium silicate and calcium carbonate as fillers. Their results indicated that the lowest water absorption value (38.27%) was achieved by incorporating 4% calcium carbonate, while the highest biodegradability (73.75%) was obtained with 6% calcium silicate. In addition, the maximum tensile strength of 2.61 MPa was observed in bioplastics containing 8% calcium silicate (Genalda & Udjiana, 2023). Similarly, Wening and Amalia (2023) investigated the utilization of bamboo sheath waste as a raw material for bioplastic production. The resulting bioplastic films exhibited a slightly rough surface texture, moderate elasticity, an average thickness of 0.38 mm, and good flexibility. Their preparation process involved cellulose extraction through delignification using 5% NaOH at 85°C for 60 min, followed by HCl treatment, bleaching, and bioplastic film formation with the addition of gelatin and glycerol (Wening & Amalia, 2023).

METHODS

The primary materials used in this study were potato peel starch and gelatin. Potato peel starch served as the main polymer matrix for bioplastic film formation, while gelatin was used as a binding agent to improve the structural integrity of the bioplastic (Pujiastuti et al., 2023). The concentrations of potato peel starch were 3%, 5%, and 7%, whereas the gelatin concentrations were 0%, 0.5%, and 1%. Additional materials included glycerol as a plasticizer, chitosan, acetic acid, distilled water (aquades), and peppermint oil.

a. Extraction of Potato Peel Starch
   Potato peel starch was extracted using the following procedure. Fresh potato peels (500 g) were thoroughly washed to remove adhering impurities and then cut into small pieces before blending. Distilled water was added at a potato peel-to-water ratio of 1:2 (w/v) (Yuniastuti et al., 2021). The mixture was blended twice and filtered after each blending process to obtain the starch suspension. The filtrate was subsequently allowed to settle to separate the starch from the liquid phase before being used in bioplastic preparation.
b. Preparation of Bioplastic Films
   Bioplastic films were prepared using the solution casting method. The required materials, including potato peel starch, gelatin, distilled water, glycerol, chitosan, acetic acid, and peppermint oil, were prepared before the experiment. Potato peel starch concentrations of 3%, 5%, and 7%, gelatin concentrations of 0%, 0.5%, and 1%, and chitosan at 1% were weighed using a digital balance. In the first stage, all components except potato peel starch were mixed and heated at 60–80°C while continuously stirred for 45 min to obtain a homogeneous solution. In the second stage, potato peel starch was gradually added to the mixture and stirred for an additional 15 min at 60°C until a homogeneous film-forming solution was obtained. The resulting solution was then poured into a 14 × 14 cm casting mold and dried in an oven at room-controlled conditions for 24 h. After drying, the bioplastic films were carefully removed from the mold and stored for subsequent characterization (Amanda et al., 2020).

RESULTS AND DISCUSSION

a. Bioplastic Thickness
   The thickness test was conducted to evaluate the effect of varying starch and gelatin concentrations on the physical dimensions of the produced bioplastic films. Thickness is one of the important physical properties because it influences the mechanical performance, barrier properties, and potential application of bioplastic films as packaging materials. The thickness measurement results are presented in Table 1.

Table 1 Thickness Data

Formulation	Starcth (gr)	Gelatine (gr)	Thickness (mm)
P3G0	3	0	0,266
P3G0.5	3	0	0,378
P3G1	3	0	0,182
P5G0	5	0.5	0,304
P5G0.5	5	0.5	0,347
P5G1	5	0.5	0,275
P7G0	7	1	0,542
P7G0.5	7	1	0,268
P7G1	7	1	0,275

The thickness measurement results showed that the bioplastic films had thickness values ranging from 0.182 to 0.542 mm. The highest thickness was obtained for the P7G0 formulation, whereas the lowest thickness was observed for P3G1. The variation in film thickness indicates that different starch and gelatin concentrations resulted in different amounts of total solids during the film-forming process. Higher solid content generally produced thicker films because more material remained after the drying process. In addition, gelatin acted as a film-forming agent, promoting the formation of a more cohesive polymer network through hydrogen-bond interactions with starch molecules, thereby contributing to the overall thickness of the bioplastic films.

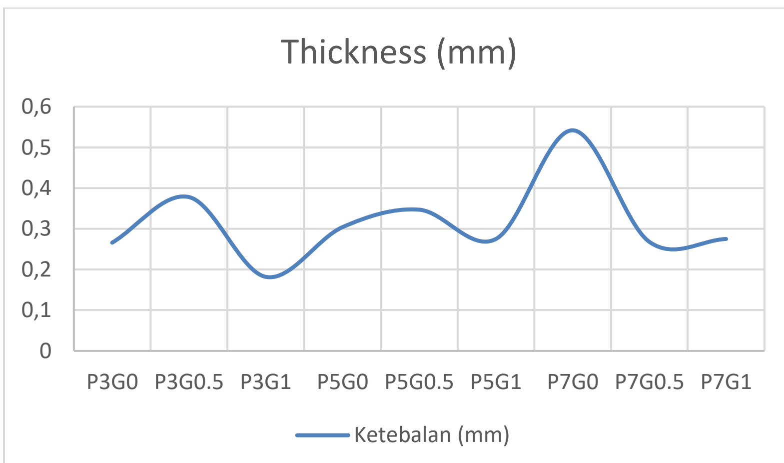

Figure 1 Thickness Graphic

Based on Figure 1, the thickness of the bioplastic films ranged from 0.182 to 0.542 mm. The highest thickness was obtained for the P7G0 formulation (0.542 mm), whereas the lowest thickness was observed for P3G1 (0.182 mm). The variation in film thickness among the formulations indicates that different starch and gelatin concentrations influenced the physical characteristics of the resulting bioplastic films. In general, increasing the starch concentration tended to produce thicker bioplastic films. This phenomenon can be attributed to the higher total solid content in the film-forming solution, which increased the amount of material remaining after the drying process. Consequently, a greater amount of solid residue resulted in the formation of thicker bioplastic films. Furthermore, gelatin contributed to film formation by acting as a film-forming agent. Through hydrogen-bond interactions with starch molecules, gelatin promoted the development of a more homogeneous and compact polymer matrix.

However, the increase in film thickness did not occur linearly across all formulations. This behavior may be attributed to variations in solution homogeneity, mixing efficiency, and material distribution during the solution casting process. Consequently, several formulations exhibited lower thickness values despite an increase in gelatin concentration. When compared with the Japanese Industrial Standard (JIS Z 1707), which specifies a maximum packaging film thickness of 0.25 mm, only the P3G1 formulation satisfied the standard requirement. The remaining formulations exhibited thickness values above the recommended limit, indicating that further optimization of the material composition and processing conditions is necessary to obtain bioplastic films with thicknesses more suitable for packaging applications.

b. Water Absorption

The water absorption test was conducted to evaluate the ability of the bioplastic films to absorb water during the immersion process. Water absorption reflects the moisture resistance of the bioplastic and is closely related to the hydrophilic nature of its constituent materials. Since starch and gelatin contain abundant hydroxyl groups, the water absorption capacity of the bioplastic is influenced by the interactions among these polymers and the compactness of the resulting polymer matrix. The results of the water absorption test are presented in Table 2.

Table 2 Water Absorption Data

Formulation	Starcth (gr)	Gelatine (gr)	Water Absorption (%)
P3G0	3	0	82,15
P3G0.5	3	0	75,36
P3G1	3	0	69,84
P5G0	5	0.5	74,28
P5G0.5	5	0.5	67,52
P5G1	5	0.5	61,85
P7G0	7	1	63,48
P7G0.5	7	1	57,94
P7G1	7	1	52,37

The water absorption values ranged from 52.37% to 82.15%. In general, increasing the concentrations of starch and gelatin resulted in a decrease in water absorption. This trend indicates the formation of a denser and more compact polymer matrix, which reduced the penetration of water into the bioplastic films. Gelatin formed hydrogen bonds with starch molecules, thereby strengthening the polymer network and improving the structural integrity of the films. In addition, increasing the starch concentration increased the total solid content, leading to a more compact matrix and consequently reducing the water absorption capacity of the bioplastic films.

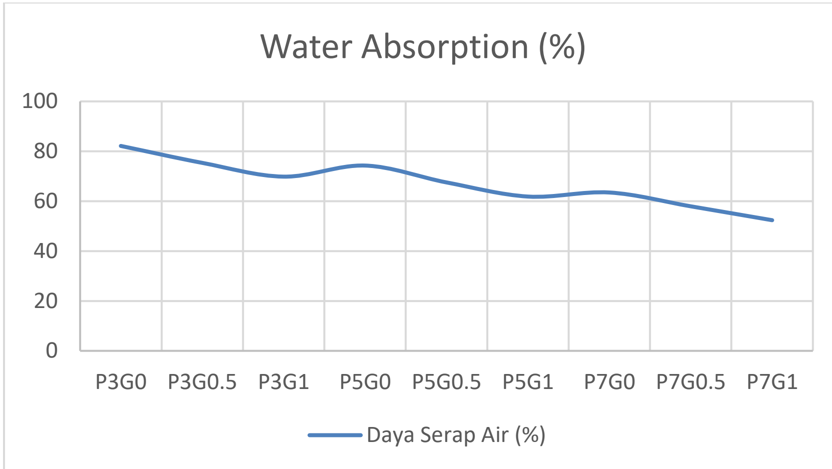

Figure 2 Water Absorption Graphic

Based on Figure 2, the water absorption values of the bioplastic films ranged from 52.37% to 82.15%. The highest water absorption value was obtained for the P3G0 formulation (82.15%), whereas the lowest value was observed for P7G1 (52.37%). In general, the graph shows a decreasing trend with increasing starch and gelatin concentrations, although slight increases were observed in the P5G0 and P7G0 formulations. The reduction in water absorption indicates that increasing the concentrations of starch and gelatin promoted the formation of a denser and more homogeneous polymer matrix. As the polymer network became more compact, the diffusion of water molecules into the bioplastic films was hindered, resulting in lower water absorption. Gelatin, acting as a film-forming agent, interacted with starch molecules through hydrogen bonding, thereby strengthening the polymer structure and reducing the free volume available for water penetration.

Slight increases in water absorption were observed in the P5G0 and P7G0 formulations compared with the preceding formulations. This phenomenon may be attributed to the non-uniform distribution of starch or the formation of microvoids during the solution casting and drying processes. Furthermore, the absence of gelatin in these formulations resulted in a less compact polymer network than those containing gelatin, allowing water molecules to penetrate the bioplastic matrix more easily. Overall, the P7G1 formulation exhibited the most favorable water resistance, as indicated by its lowest water absorption value. This result suggests that the combination of 7 g of potato peel starch and 1 g of gelatin produced the most compact polymer matrix among all formulations, thereby enhancing the water resistance of the bioplastic films. Lower water absorption is a desirable characteristic for packaging materials because it improves dimensional stability and maintains the integrity of the material under humid environmental conditions.

c. Solubillity

The solubility test was conducted to evaluate the water solubility of the bioplastic films. This parameter is important for assessing the stability of bioplastic films in aqueous environments and determining their suitability for specific applications, particularly as biodegradable packaging materials. The solubility of bioplastics is influenced by the interactions among polymer components and the compactness of the polymer matrix. The results of the solubility test are presented in Table 3.

Table 3 Solubillity Data

Formulation	Starcth (gr)	Gelatine (gr)	Water Absorption (%)
P3G0	3	0	39,84
P3G0.5	3	0	35,72

P3G1	3	0	32,18
P5G0	5	0.5	34,96
P5G0.5	5	0.5	31,47
P5G1	5	0.5	28,53
P7G0	7	1	29,85
P7G0.5	7	1	26,41
P7G1	7	1	23,68

The solubility test results showed that the bioplastic films exhibited solubility values ranging from 23.68% to 39.84%. A decrease in solubility was observed with increasing starch and gelatin concentrations, indicating that the bioplastic films became more stable in aqueous environments. The interaction between starch and gelatin molecules promoted the formation of a denser and more cohesive polymer network through hydrogen bonding. As a result, the structural components of the bioplastic films were more firmly bound within the polymer matrix, reducing their tendency to dissolve during the immersion process.

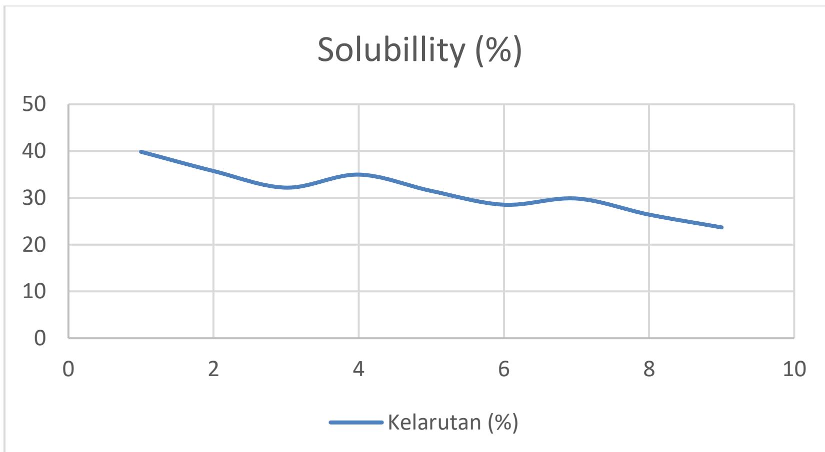

Figure 3 Solubillity Graphic

Based on Figure 3, the solubility of the bioplastic films ranged from 23.68% to 39.84%. The highest solubility value was obtained for the P3G0 formulation (39.84%), whereas the lowest value was observed for P7G1 (23.68%). In general, the graph exhibited a decreasing trend with increasing starch and gelatin concentrations, although slight increases were observed in the P5G0 and P7G0 formulations. The decrease in solubility indicates that higher starch and gelatin concentrations promoted the formation of a more compact and stable polymer matrix. As the starch concentration increased, a greater number of amylose and amylopectin molecules interacted to form a stronger polymer network. In addition, gelatin enhanced the cohesion of the matrix through hydrogen-bond interactions with starch molecules, thereby reducing the dissolution of the bioplastic components in water. The slight increase in solubility observed in the P5G0 and P7G0 formulations may be attributed to the absence of gelatin, which resulted in less effective intermolecular interactions and a less compact polymer network. Furthermore, the mixing and drying processes may have caused the formation of microvoids or non-uniform material distribution, allowing water to penetrate the bioplastic matrix more easily and dissolve part of its polymer components. Among all formulations, P7G1 exhibited the lowest solubility, indicating that the combination of 7 g of potato peel starch and 1 g of gelatin produced the most water-stable polymer structure. Low solubility is a desirable characteristic for biodegradable packaging materials because it improves resistance to water exposure and enhances the structural integrity of the bioplastic films under humid environmental conditions (Plasticizer, 2026).

d. Moisture Content

The moisture content test was conducted to determine the amount of residual water retained in the bioplastic films after the drying process. Moisture content is an important parameter because it influences the storage stability, physical properties, and overall quality of bioplastic films. The amount of residual moisture depends on the interactions among the polymer components and the effectiveness of the drying process. The results of the moisture content test are presented in Table 4.

Table 4 Moisture Content

Formulation	Starcth (gr)	Gelatine (gr)	Water Absorption (%)
P3G0	3	0	18,92
P3G0.5	3	0	17,84
P3G1	3	0	16,75
P5G0	5	0.5	17,28
P5G0.5	5	0.5	16,42
P5G1	5	0.5	15,38
P7G0	7	1	15,72
P7G0.5	7	1	14,81
P7G1	7	1	13,94

The moisture content of the bioplastic films ranged from 13.94% to 18.92%. Formulations with higher starch and gelatin concentrations exhibited lower moisture content. This finding suggests that increasing the concentrations of these polymers promoted the formation of a denser and more compact polymer matrix, thereby reducing the free volume available for retaining water molecules. Consequently, less residual moisture remained within the bioplastic films after the drying process. In general, lower moisture content is considered a desirable characteristic because it enhances storage stability, minimizes the risk of microbial growth, and reduces changes in the physical properties of the bioplastic films during storage.

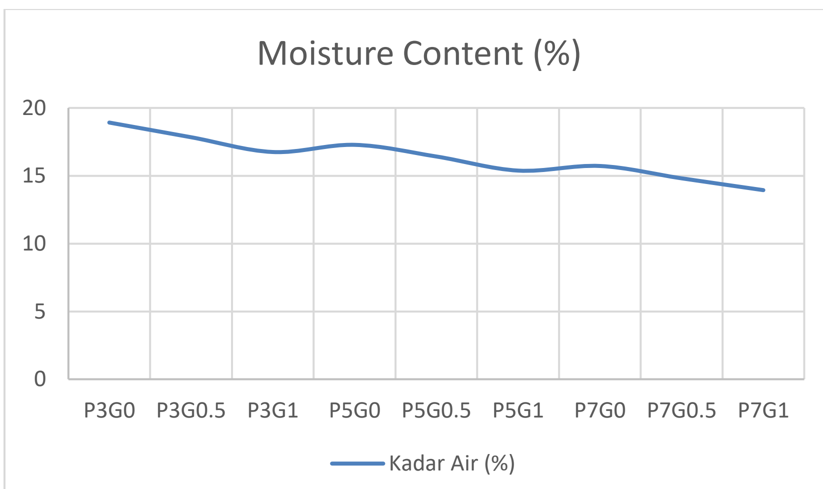

Figure 4 Moisture Graphic

Based on Figure 4, the moisture content of the bioplastic films ranged from 14.00% to 18.80%. The highest moisture content was obtained for the P3G0 formulation (18.80%), whereas the lowest value was observed for P7G1 (14.00%). In general, the graph exhibited a decreasing trend with increasing starch and gelatin concentrations, although slight increases were observed in the P5G0 and P7G0 formulations. The reduction in moisture content indicates that increasing the concentrations of starch and gelatin promoted the formation of a denser and more compact polymer matrix. As the starch concentration increased, stronger interactions occurred among the polymer chains, thereby reducing the free volume within the bioplastic matrix and limiting the amount of residual water retained after drying.

Furthermore, gelatin contributed to the formation of hydrogen bonds with starch molecules, resulting in a more cohesive polymer network that reduced the ability of the bioplastic films to retain moisture. The slight increase in moisture content observed in the P5G0 and P7G0 formulations may be attributed to the absence of gelatin, which limited the formation of strong intermolecular interactions within the polymer matrix. In addition, non-uniform material distribution during the mixing and drying processes may have led to the formation of microvoids, allowing moisture to become trapped within the bioplastic structure and resulting in slightly higher moisture content (Elektronik & Cokroaminoto, n.d.). Among all formulations, P7G1 exhibited the lowest moisture content, indicating that the combination of 7 g of potato peel starch and 1 g of gelatin produced the most compact polymer matrix. Low moisture content is a desirable characteristic for packaging materials because it enhances storage stability, reduces the risk of microbial growth, and helps maintain the mechanical properties and durability of bioplastic films during storage and use.

CONCLUSION

Potato peel starch-based bioplastic films were successfully prepared using the solution casting method with varying starch and gelatin concentrations. The characterization results demonstrated that each formulation exhibited different physical properties. The thickness of the bioplastic films ranged from 0.182 to 0.542 mm, with the highest thickness observed in the P7G0 formulation (0.542 mm) and the lowest in P3G1 (0.182 mm). The water absorption, solubility, and moisture content values ranged from 52.37% to 82.15%, 23.68% to 39.84%, and 13.94% to 18.92%, respectively. In general, increasing the concentrations of starch and gelatin tended to reduce water absorption, solubility, and moisture content. These findings indicate that the combination of starch and gelatin promoted the formation of a denser and more compact polymer matrix, thereby improving the water resistance and stability of the bioplastic films (Fatmawati & Nurani, 2025). Among all formulations, P7G1 (7 g potato peel starch and 1 g gelatin) exhibited the most favorable characteristics, as indicated by the lowest water absorption, solubility, and moisture content values. Therefore, this formulation has the potential to be further developed as an environmentally friendly bioplastic material for sustainable packaging applications.

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