

Physical and Biodegradable Characteristics of Palm Wax-Coated Food Packaging Paper: Effect of Propylene Glycol

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ABSTRACT

Paper packaging is increasingly in demand by the food industry due to its eco-friendly nature, being made from cellulose fibers that are easily biodegradable. However, the current use of plastic coatings on paper packaging reduces its biodegradability. This study aims to evaluate the use of palm wax as a natural coating for paper packaging, utilizing several types of paper packaging and the addition of propylene glycol to improve the physical and biodegradable characteristics of the packaging. The study employed a completely randomized design with two factors: paper type (kraft, thin cardboard, and thick cardboard) and propylene glycol concentration (0%, 5%, 10%, 15%). The observed parameters included water absorption, oil absorption, thickness, tensile strength, elongation, and biodegradability. The results showed that paper type had a significant effect on oil absorption (0.05–1.58%), thickness (0.15–1.73 mm), and tensile strength (0.80–119.30 kN/m), but did not affect water absorption (0.07–0.58%) and elongation (5.69–32.13%). Propylene glycol concentration affected oil absorption, while the interaction between paper type and propylene glycol concentration influenced oil absorption, tensile strength, and biodegradability properties. This study provides new insights into the potential of palm wax as an environmentally friendly coating for food packaging.

KEYWORDS *Food packaging, paper, palm wax, propylene glycol, physical characteristics, biodegradation, eco-friendly.*



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INTRODUCTION

Packaging plays a crucial role in the food industry. According to Sulaiman (2021), packaging serves as a protective barrier and has additional functions, such as acting as a container and extending the shelf life of a product when packaged with the appropriate materials. Regulation No. 20 of 2019 issued by the Food and Drug Supervisory Agency states that food packaging materials must meet certain

requirements, including being non-toxic and leaving no residues on the packaged product, maintaining the product's shape, nutritional value, and cleanliness, not releasing toxic substances, and not polluting the environment.

There are four types of packaging based on the materials used: plastic, paper, glass, and cans (Putri, 2020). Paper packaging is one type of packaging that is now becoming a popular choice for the food industry (Deshwal et al., 2019). According to data from the Indonesia Packaging Federation, Indonesia's food packaging paper exports increased by 49.7% from 12,000 tons in 2021 to 18,000 tons in 2023.

The primary material used to make paper packaging is cellulose fiber, giving paper packaging the advantage of being naturally biodegradable and supporting sustainable efforts (Khansa et al., 2017). However, the paper packaging currently in circulation is coated with plastic, which serves as a barrier against oil, air, and water (Suma et al., 2023). This plastic coating reduces the packaging's ability to decompose naturally. This issue aligns with data from the Ministry of Environment and Forestry (*Kementerian Lingkungan Hidup dan Kehutanan, KLHK*), which reports that plastic waste accounted for 11.6 million tons in 2022. Therefore, there is a need to develop paper packaging with more environmentally friendly coatings.

There are several alternative materials that could potentially replace plastic-based coatings, such as natural wax (*biowax*) (Li et al., 2024). Generally, *biowax* is obtained from various sources, one of which is palm wax. Palm wax is a natural wax derived from palm oil that has been used in various industries. The use of natural wax-based coatings such as palm wax has become an innovative solution in the environmentally friendly food packaging industry.

The production of wax-based coatings requires the addition of a plasticizer to achieve good physical characteristics. In this study, *propylene glycol* was used as a plasticizer due to its ability to enhance the flexibility and mechanical strength of the samples. *Propylene glycol* is a dihydroxy alcohol that is soluble in water and other organic solvents, which is why it was chosen as the plasticizer in this study.

The type of paper used in the production of environmentally friendly food packaging affects its permeability, physical durability, and ability to biodegrade. Based on their level of protection, packaging can be divided into three types: primary packaging that comes into direct contact with the product, secondary packaging that groups several products into one container, and tertiary packaging used for transportation and distribution purposes (Widiati, 2019).

Based on the background described above, this research is important because of the increasing demand for environmentally friendly packaging in response to the increasingly alarming issue of plastic pollution. Conventional plastics widely used in the food industry are often difficult to decompose and

contribute to microplastic pollution, which poses risks to human health and the environment. Therefore, the development of paper-based packaging coated with natural materials such as palm wax and *propylene glycol* could serve as a safer and more sustainable alternative solution. Furthermore, studies on the combination of paper types and natural coating concentrations are still limited, particularly in the Indonesian context, so this research is expected to provide relevant scientific data for the packaging industry and national policies. The use of coating materials from palm oil derivatives such as palm wax and *propylene glycol* also supports the principles of a circular economy, as they have the potential to be sourced from industrial waste. This research aims not only to evaluate the physical characteristics and biodegradability of packaging but also to ensure its safety for food use and compliance with food packaging standards. Thus, the results of this research are expected to support the development of green industries and contribute to reducing dependence on plastic-based packaging.

RESEARCH METHOD

Materials used were palm wax (SM 2000-PILAR SM742-CONTAINER), propylene glycol, distilled water, kraft paper, thin board, thick board, cooking oil (Sunco brand), soil, tissue paper, and polybags. This type of research is experimental research that carried out at LABTIAP (Laboratory of Agro-Industry and Biomedical Engineering Development), BRIN (National Research and Innovation Agency), Serpong, South Tangerang

Preparation of Palmwax Solution

Palmwax is heated using a hotplate at 150°C until all the palm wax melts, then add Propylene Glycol according to the treatment (0%, 5%, 10%, and 15%) gradually, while continuing to stir using a magnetic stirrer at a speed of 150 rpm until all ingredients are mixed.

Application on Paper

Place the paper on a flat surface, then pour 5 ml of palm wax solution onto the paper. Spread the solution evenly using a rolling pan until the palm wax solution is evenly distributed on the paper. Place the flattened paper on a tray and put it in an oven at 80°C for 15 minutes to ensure that the paper is coated with the palm wax solution. Remove the palm wax-coated paper from the oven and let it sit for 5 minutes until the palm wax solution dries naturally.

Oil Absorption Capacity

Oil absorption capacity is a test that determines the amount of oil solvent that can be absorbed by the sample matrix per unit of time. The principle of the test is to determine the amount of oil absorbed by the sample through the difference between the oil added and the amount of oil remaining by centrifuging the sample solution that has absorbed the oil.

$$\text{Oil absorption} = \left(\frac{W-W_0}{W_0} \right) \times 100\%$$

Water absorption (AOAC 1983).

Water absorption capacity is determined by cutting a 2 cm x 2 cm sample, weighing it initially (W_0), soaking it in water for 20 minutes, then drying it and weighing it again as the final weight (W). The water absorption capacity of a material that has been soaked in water for a certain period of time can be determined using the following equation:

$$\text{Water absorption} = \left(\frac{W-W_0}{W_0} \right) \times 100\%$$

The tensile strength

The tensile strength of paper packaging composites is tested using a Universal Testing Machine (UTM) by observing the maximum tensile force that the paper packaging can withstand before breaking or tearing. Determine the tensile speed in accordance with applicable standards, and clamp both ends of the sample tightly in the jaws of the tensile testing machine. Ensure the sample is aligned and not twisted to ensure the tensile force applied to the material is uniform. The tensile testing machine will slowly pull the sample and continuously increase the tensile force until the sample fails (breaks or tears). During the test, the machine will record the tensile force data and changes in sample length (elongation).

Thickness Test

The tool used was a caliper, and the test was based on ASTM 1983. The test began by cutting the bioplastic into pieces measuring 12.5 cm x 2.5 cm. The thickness of the bioplastic was then measured using calipers at three different points on the surface of the bioplastic. The average of all measurements was calculated using the following equation.

$$\text{Thickness} = (\text{point 1} + \text{point 2} + \text{point 3}) / 3$$

Biodegradation Test

The decomposition rate was determined in vitro in an environmental medium. The decomposition parameter observed was the visual appearance of the tested packaging after being buried (Soil Burial Test) in the ground for a certain period of time (12 days) and then observing the changes that occurred.

RESULT AND DISCUSSION

This study aims to examine the effect of paper type (factor A) and concentration of Propylene Glycol (PROPYLENE GLYCOL) (factor B) as plasticizer on the physical characteristics of paper packaging coated with palm wax. The test results include thickness, water absorption, oil absorption, tensile strength, and elongation, which collectively reflect the potential performance of this packaging

Table 1. Physical Analysis Results of Samples

Physical and Biodegradable Characteristics of Palm Wax Coated Food Packaging Paper:
Effect of Propylene Glycol Concentration And Paper Type

No	Kode	Water Absorbency	Oil Absorbency	Thickness	Tensile Strength	Elongation
1	A1B1	0.225	0.188	0.160	0.65	24.89
2	A1B2	0.163	0.163	0.245	1.85	15.62
3	A1B3	0.225	0.300	0.190	3.05	12.18
4	A1B4	0.113	0.150	0.152	1.40	19.67
5	A2B1	0.138	0.150	0.402	8.15	11.50
6	A2B2	0.238	0.138	0.463	8.17	21.53
7	A2B3	0.1	0.087	0.492	2.25	20.34
8	A2B4	0.1	0.050	0.450	39.60	13.96
9	A3B1	0.238	0.288	1.668	5.70	16.65
10	A3B2	0.2	1.250	1.672	0.80	18.10
11	A3B3	0.363	1.563	1.723	24.60	13.27
12	A3B4	0.2	1.250	1.562	21.00	8.62

Thickness

The data shows that the thickness of paper packaging is greatly influenced by the type of paper used. A3 paper has the highest thickness, ranging from 1.562 to 1.723 mm, followed by A2 paper, which ranges from 0.402 to 0.492 mm, while A1 paper has the lowest thickness, ranging from 0.15 to 0.245 mm. These differences indicate that the initial thickness or base thickness of each type of paper significantly contributes to the final thickness after coating. Variations in propylene glycol concentration did not show a significant effect on packaging thickness, whether on A1, A2, or A3 paper. This is due to differences in the internal structure and fiber characteristics of each paper type, which affect how well the coating adheres to and penetrates the paper surface. Hernández García et al. (2024) state that the final dimensions of the coated material are highly dependent on the thickness and texture of the initial substrate. Additionally, palm wax and propylene glycol coatings at low concentrations ($\leq 15\%$) generally form thin layers that do not significantly increase the total thickness. According to research by Singh and Patel (2020), coating materials such as plant-based waxes tend to form thin surface layers that function more as moisture barriers than structural enhancers. In the context of water absorption, Chatterjee and Singh (2014) explain that water is absorbed by paper through capillary action, i.e., the penetration of water through microscopic pores in the paper walls. Therefore, paper with smaller pores and a smoother surface—such as A3 paper—tends to have lower water absorption. This finding reinforces the importance of considering the physical structure of paper in determining the final performance of packaging, particularly in terms of thickness and barrier properties.

Water Absorbency

Water absorption data showed complex variations between treatment combinations. A2 paper samples tended to have lower water absorption levels (0.100–0.238), with treatments A2B3 and A2B4 recording the lowest values of 0.100. This indicates that A2 paper has good resistance to water, which is likely enhanced by the presence of a hydrophobic palm wax layer. The hydrophobic nature of palm wax can form a barrier

against water penetration, although the thickness of this layer depends on the absorbency and porosity of the paper surface (Mikkonen et al., 2011). In contrast, A3 paper showed more varied water absorption values (0.200–0.363), with A3B3 as the highest combination at 0.363. Although palm wax functions as a water barrier, its effectiveness can be influenced by the internal structure of the paper, including fiber distribution, porosity level, and interaction with additives such as propylene glycol. In thicker papers like A3, there are likely more pores and microscopic gaps that can absorb water before the surface is fully covered by the coating. Ardiani et al. (2020) state that high-grammage papers tend to have greater water absorption compared to low-grammage papers due to their higher fiber density and surface area, which allows water to be retained. Additionally, the addition of propylene glycol as an additive in the protective coating can enhance water resistance due to its hygroscopic nature and ability to form hydrogen bonds with the coating material (Chinga-Carrasco et al., 2018). This indicates that the combination of paper type and coating material plays a crucial role in determining the water barrier capability of paper-based packaging.

Oil Absorbency

The pattern of oil absorption in packaging paper shows interesting and varied trends. A2 paper consistently shows the lowest oil absorption values (0.050–0.150), with the A2B4 combination reaching a minimum value of 0.050. These findings indicate the great potential of A2 paper for use as food packaging that requires good oil barrier properties. The low oil absorption values in A2 paper are likely due to a combination of a smoother surface, low porosity, and optimal interaction between the paper substrate and the palm wax layer. In contrast, A3 paper, especially in combination with propylene glycol concentrations B2, B3, and B4, showed very high oil absorption (1.250–1.563). This may be attributed to the thicker physical structure of A3 paper, which may have larger pores, allowing oil to be more easily trapped through capillary action. This effect becomes more significant as propylene glycol concentration increases, as this additive can modify the microscopic structure of the coating layer and increase flexibility, but reduce the compactness of the wax film (Nurul et al., 2020).

According to Liu et al. (2019), the surface characteristics and porosity of the substrate play a crucial role in the effectiveness of the coating layer in preventing water and oil penetration. The more open and larger the pores of the paper, the higher the potential for oil to be absorbed into the structure. Additionally, palm wax, which should function as an oil barrier, when combined with propylene glycol at certain concentrations, can become less effective due to changes in the coating layer structure from dense to more flexible and permeable. Previous research by Mikkonen et al. (2011) also noted that modifying the structure of lipid- or wax-based films by adding plasticizers such as propylene glycol reduces their barrier properties against non-polar substances like oil.

Tensile Strength

Tensile strength showed significant variation, indicating a strong interaction effect between paper type and propylene glycol concentration. The highest tensile strength value was recorded in treatment A2B4 at 39.60 MPa, indicating that the combination of paper

type A2 with propylene glycol concentration B4 was able to produce packaging with superior tensile strength. The A3B3 combination also showed high tensile strength (24.60 MPa), but differed significantly from other treatments. Conversely, very low tensile strength values were recorded in A1B1 (0.65 MPa) and A3B2 (0.80 MPa), indicating that not all treatment combinations are effective in strengthening the paper structure.

These findings suggest that the use of palm wax contributes to the enhancement of the mechanical strength of paper packaging through the formation of a protective layer and fiber bonding. However, the role of propylene glycol as a plasticizer or softener exhibits complex and contextual properties. At certain concentrations, propylene glycol can enhance the flexibility of the coating layer and facilitate even stress distribution, thereby strengthening the tensile strength of the material (Sanyang et al., 2016). However, if used at too high a concentration or incompatible with the type of paper substrate, this softener can reduce inter-fiber cohesion and disrupt the coating film structure, thereby negatively impacting tensile strength (Abeywickrema et al., 2021). Additionally, the hydrophilic nature of propylene glycol can affect interactions with cellulose fibers and cause excessive moisture, ultimately reducing the material's mechanical integrity (López et al., 2017). Therefore, optimizing the concentration of propylene glycol and selecting the appropriate type of paper are key factors in producing paper packaging that is not only environmentally friendly but also has sufficient mechanical strength for food applications.

Elongation

Elongation reflects a material's ability to stretch before breaking, which is closely related to the flexibility and elasticity of the material. Based on the data, type A1 paper exhibits higher elongation values (12.185–24.887%) compared to A2 (11.502–21.533%) and A3 (8.621–18.099%). The high elongation value of A1 paper indicates that this material is more flexible and capable of withstanding strain before structural damage occurs. Conversely, A3 paper consistently shows lower elongation values, particularly in the A3B4 combination (8.621%), indicating that this material tends to be stiffer and more brittle.

The role of propylene glycol as a plasticizer or softener is generally aimed at enhancing flexibility by reducing intermolecular forces within the coating matrix. However, the plasticizing effect is highly dependent on its interaction with the material's underlying structure. In thicker papers like A3, which have higher fiber density and rigid structural characteristics, the softening effect of propylene glycol may be less optimal or even counterproductive. Under such conditions, an inappropriate plasticizer concentration can lead to inhomogeneity in the protective layer, creating weak points that accelerate cracking when subjected to stress (Chen et al., 2019).

According to Eichhorn et al. (2018), mechanical properties such as elongation in cellulose-based materials are primarily determined by the microstructure of the fibers and the strength of intermolecular bonds within the network, which tend to be stable against external modifications as long as they do not exceed the material's tolerance limits. Additionally, the use of plasticizers has a saturation effect, where increasing the concentration beyond the optimal limit no longer enhances flexibility and may even compromise the structural integrity of the material (Müller et al., 2012). Therefore,

selecting the appropriate type of paper and determining the optimal concentration of propylene glycol are critical factors in controlling the elongation properties of packaging materials.

Biodegradable

Based on the qualitative biodegradability test data obtained, observations of changes in shape, color, and texture of paper samples from day 1 (H1) to day 12 (H12) showed a clear visual degradation pattern. Almost all samples (A1B1 to A3B4) consistently experienced decreased strength and color changes as the observation time increased. As shown in Figure 1, material degradation on day 12 was clearly visible, marked by changes in the structure and color of the samples. These visual changes reflect the active biodegradation process taking place in the test environment. Degradation of shape and texture indicates a decrease in the structural integrity of the material, while color changes can be caused by the growth of microorganisms or oxidative reactions that occur during the decomposition process (Shogren et al., 2019). Paper, as a cellulose-based material, is known to be very susceptible to degradation by microorganisms such as bacteria and fungi, which produce cellulase enzymes to break down glycosidic bonds in cellulose (Li et al., 2020).

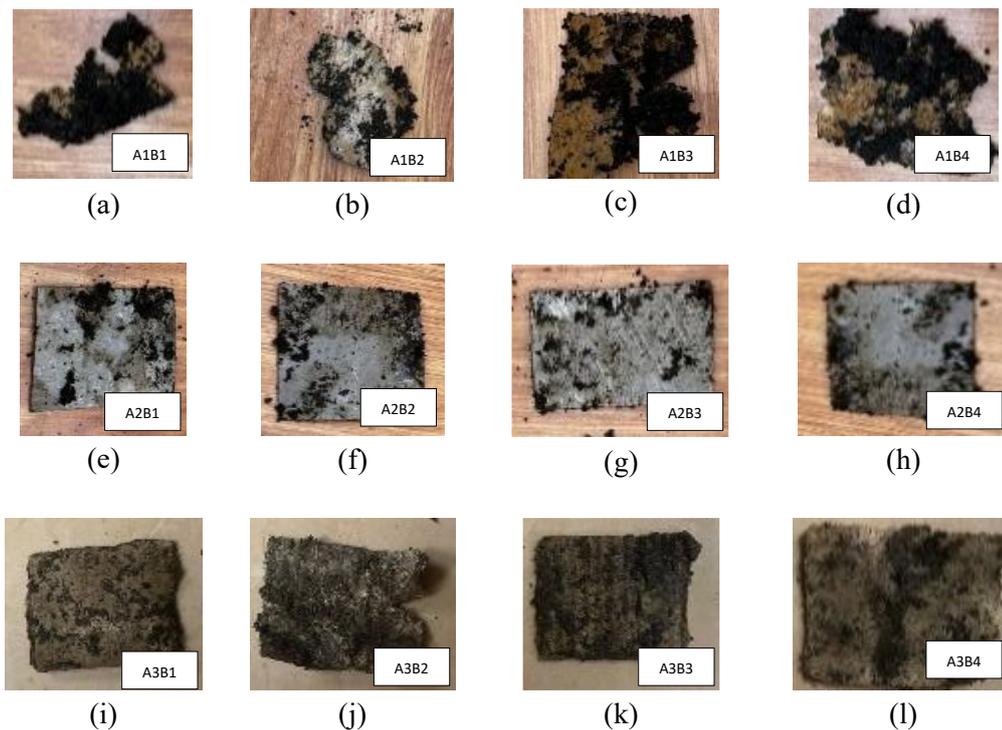


Figure 1. Biodegradable Sample Test

Source: Personal

From the observation results, the main findings of this study indicate that the type of paper (factor A) is the main determinant of basic physical properties such as thickness, and has a strong influence, both directly and in interactions, on barrier properties (water and oil

absorption) and mechanical properties (tensile strength and elongation). On the other hand, the concentration of propylene glycol (factor B) does not always have a single linear effect, but rather acts as a modulator that can strengthen or weaken certain physical properties, depending on the type of paper used. These results are in line with the study of Wang et al. (2021), which emphasized that the nature of the substrate greatly determines the performance of the protective layer in biopolymer-based packaging systems.

Palm wax coating makes an important contribution to the hydrophobic properties and increases the mechanical strength of the paper. However, its effectiveness is greatly influenced by the surface morphology and porosity of the base paper. Wax forms a water and oil barrier layer, but its performance is highly dependent on the ability of the coating to evenly close the pores (Mikkonen et al., 2011). The addition of propylene glycol as a plasticizer can change the structure and flexibility of the coating film, as well as increase the homogeneity and cohesion between layers if used in the right concentration. Previous studies have shown that plasticizers can fill intermolecular spaces and increase film flexibility, but at excessive concentrations they can create micropores and reduce cohesion, leading to decreased mechanical strength or increased permeability (Sanyang et al., 2016; Chen et al., 2019).

The complex role of propylene glycol is also reinforced by the findings of Sari et al. (2023) and Purba et al. (2019), which show that selecting the optimal plasticizer concentration is key to obtaining the best barrier and mechanical properties in starch or cellulose-based bioplastics. Therefore, formulation optimization not only involves selecting the additive concentration, but must also consider the synergy between the coating material and the paper substrate used.

Overall, this study provides important insights into how paper type and propylene glycol concentration interact to determine the performance of palm wax-coated packaging. These results emphasize the importance of a specific formulation-based approach to achieving optimal packaging properties, which are in accordance with functional and sustainable needs in food applications.

CONCLUSION

The research concludes that palm wax-coated paper packaging demonstrates promising physical properties—including water and oil absorption, thickness, tensile strength, and elongation—making it a viable, environmentally friendly alternative to conventional food packaging, as supported by biodegradability tests that show clear visual degradation. The hydrophobic and strengthening effects of palm wax are influenced by the pore structure and surface morphology of the base paper, while the addition of *propylene glycol* as a plasticizer can enhance coating homogeneity, flexibility, and interfacial bonding at optimal concentrations. However, excessive *propylene glycol* or poor interactions may increase microporosity and reduce mechanical strength. Future research should focus on optimizing the formulation and processing conditions of palm wax and *propylene glycol* coatings for different paper substrates to maximize both barrier properties and biodegradability, as well as evaluating their safety and performance in real food packaging applications.

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