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Edible Coating Innovation Based on Taro Stem (*Colocasia esculenta L.*) and Used Waste Oil to Prevent Food Loss

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ABSTRACT

Food loss, especially in perishable items like fruits, is a critical global issue. This study introduces "ECOLA," an innovative edible coating made from taro stem starch (*Colocasia esculenta L.*) and natural glycerol derived from spent cooking oil. The research aimed to evaluate ECOLA's chemical properties (solubility and water vapor transmission rate), physical properties (density and tensile strength), and organoleptic characteristics. The coating was applied to extend the shelf life of fruits such as tomatoes, avocados, and mangoes. The optimal formulation, consisting of taro stem starch (2.5 g), CMC (2.5 g), glycerol (2.5 g), and water (175 g), demonstrated remarkable properties, including high tensile strength (47.834 MPa), balanced density (1.190 g/cm^3), and strong consumer approval. The coating significantly reduced water vapor transmission and extended fruit freshness by up to 14 days compared to untreated samples. ECOLA showcases tremendous potential for reducing food loss while promoting sustainability through the utilization of organic waste, such as spent cooking oil. By enhancing food preservation in an eco-friendly manner, ECOLA addresses critical challenges in food security and waste management. This study highlights ECOLA as a viable, sustainable, and environmentally friendly solution for the agricultural sector to mitigate food loss and achieve food security targets.

Keywords: edible coating, taro stems, cooking oil, tensile strength, food loss

1. INTRODUCTION

Global attention continues to focus on food security, particularly in light of the projected 9.8 billion global population by 2050. In Indonesia, food security has also become a significant priority as part of the government's efforts to ensure access to sufficient, healthy, and sustainable food. One key problem in this effort is food loss, which occurs frequently across the supply chain, from harvest to distribution. The Food and Agriculture Organization (FAO) reports that the loss or waste of approximately one-third of global food production occurs annually. This has an impact not just on food security but also on the environment because it wastes resources like water, soil, and energy [1].

The Zero Hunger goal of the Sustainable Development Goals (SDGs), which aims to eliminate hunger, achieve food security, enhance nutrition, and promote sustainable agriculture, has a strong connection to food security. Zero Hunger holds significant importance in Indonesia due to the persistent prevalence of hunger and malnutrition. Addressing the issue of Zero Hunger is crucial for achieving a country's welfare, as hunger problems can significantly impact a country's human resources, thereby hindering its progress [2].

To achieve the Zero Hunger goal, we must enhance food security by boosting agricultural output, promoting sustainable farming systems, expanding access to safe and nutritious food, and reducing food waste. Food loss is a reduction in the quality or quantity of food that occurs along the food supply chain, from manufacturing to consumption. Addressing food loss is crucial as it can lead to various losses, including environmental ones.

Fruits rank among the food classes with the highest rates of food waste, with the supply chain losing or discarding 20 to 50 percent of all produced fruits and vegetables before they reach the consumer stage [3]. Fruits are easily perishable due to their high water content, making damage the leading source of food loss. Therefore, it is crucial to reduce food loss in fruits, given their significant nutritional content and significant potential for value addition. In response to these challenges, the author developed an edible coating using taro stems (Colocasia esculenta L.) and cooking oil, with the aim of preventing food loss and enhancing food security by 2045.

Edible coating is a thin layer of edible components meant to coat food products and act as a protector or barrier against mass transfer (moisture, oxygen, light, lipids, and solutes) [4]. Research has shown that edible coatings can extend the shelf life of a variety of food products, such as fruits, vegetables, and processed foods. Previous research has demonstrated that we can use natural ingredients like starch, protein, and lipids as the foundation for edible coatings to create environmentally beneficial and safe-to-consume coatings [5]. However, the development of this technology in Indonesia remains limited, particularly in the use of available local materials. According to unupurwokerto.ac.id, starch-based food coatings have high cohesive characteristics and low gas and water vapor transmission rates. However, they have a weakness: low water vapor resistance. To address this shortcoming, a hydrophobic addition, stearic acid, is required [6]. Because of the inclusion of hydrophobic stearic acid, an emulsifier is required to stabilize the solution. You can use carboxymethyl cellulose as the emulsifier [7].

Given the potential and qualities of taro stem starch flour, using taro stems as waste from the taro plant will undoubtedly be more effective and useful. This is due to a shortage of individuals processing taro stems. In plants with rigid stems and a waxy coating, such as taro, pectin components dissolve in water. Pectin is a carbohydrate derivative; when exposed to acid and sugar, it forms a gel and absorbs water from its surroundings, lowering the product's moisture content [8].

ECOLA (Edible Coating based on taro stems and used cooking oil) is an innovation that offers a strategic solution to utilize organic waste as a raw material for edible coating. Taro stems (Colocasia esculenta L.) possess significant potential as a starch source, and used cooking oil, often regarded as waste, can transform into lipid components that enhance the hydrophobic properties of the edible coating. This combination not only supports efforts to reduce food loss but also contributes to the sustainable management of organic waste.

Thus, the purpose of this research is to investigate the possibility of ECOLA as an innovative option for ensuring Indonesia's food security by 2045. The discussion will include an examination of raw material properties, formulation methods, and the usefulness of ECOLA in prolonging the shelf life of food products, with the goal of becoming a valuable resource for the future development of sustainable food technologies.

2. MATERIALS AND METHODS

The researcher conducted this research from February 15, 2024, to March 9, 2024, at Jln Kartini no.212 Denpasar Utara, where they prepared the research paper and made the edible fruit coating. They also tested the tensile strength of ECOLA at the Metallurgy Laboratory of the Mechanical Engineering Department at UNUD.

2.1 Materials

Taro Stalks, Salt, Sodium Bicarbonate, Cooking Oil, 96% Alcohol, Aquades, CMC.

2.2 Methods

Research Procedure

2.2.1 Making Sago Starch

Collect any waste taro stems that are still in good shape. Prepare a large plastic container to store the taro pieces. Peel the taro stalks until just the white tubers remain. Grate the taro stem with an electric grater. Next, boil the taro stem for 20 minutes in 300 mL of water per 100 grams of taro stem. Stir the taro stem slurry until it blends thoroughly, then filter it to obtain the starch liquid. We allow the starch liquid to settle in a bucket for six hours. We remove the residual liquid from the sedimentation process and then dry the starch sediment on trays under direct sunshine. We soften and sieve the dried starch to produce artificial taro starch powder [9].

2.2.2 Production of Natural Glycerol from Used Cooking Oil

Filter the cooking oil with filter paper. Then collect the filtered oil and place it in a beaker. Mix the oil with 96% alcohol in a ratio of 1:3 (v/v). Heat the mixture at a temperature of 70 degrees Celsius for approximately 1 hour. Stir the mixture until two distinct phases are visible. Glycerol, the lower part of the mixture, serves as a natural plasticizer in the edible coating. The next step is to separate the mixture using a pipette and a test tube through distillation.

2.2.3 Making Edible Coating

Heat Aquades to a temperature of 70 degrees Celsius. Add taro stem starch to the mixture and stir for 5 minutes. Dissolve CMC in the heated Aquades water and stir for 6 minutes. Then add glycerol to obtain an elastic layer. Next, we bake the edible coating to create an edible film for testing. The edible coating is then molded using plastic molds, dried in an oven at a specific temperature of 60°C for 24 hours, and the edible film is ready for testing. All the ingredients are mixed with the following composition.

Table 1 Fully Randomized Design

Material	Experimental Treatment		
	P1	P2	P3
CMC	2.5 gr	2.5 gr	2.5 gr
Aquadest	175 gr	175 gr	175 gr
Glyserol	2 ml	2,5 ml	3 ml
Taro Stem	3 gr	2,5 gr	2 gr

2.2.4 Density Analysis

We conducted the density test by cutting the edible coating into 3x3 cm pieces, which we had compacted by baking the edible coating liquid until it transformed into thin sheets. We then measured the resulting pieces using a digital scale.

2.2.5 Tensile Strength Test

We conduct a tensile strength test using a universal testing machine based on the ASTM D638-02 test standard. We measure each treatment at length, width, and thickness of 3 cm, 3 cm, and 0.30 mm.

2.2.6 Organoleptis test

This organoleptis test is conducted using a questionnaire that will be administered to 50 panelists randomly selected from 10th-grade students at SMA Negeri 4 Denpasar. Panelists will answer the questionnaire questions on paper by marking a linear scale ranging from 1 to 5. The higher the score, the better the evaluation. The obtained scores will be averaged. The range of the average score is categorized as follows.

Table 2 Value Category

No	Range of Values	Category
1	0 – 1.00	Critical
2	1.10 – 2.00	Needs Improvement
3	2.10 – 3.00	Adequate
4	3.10 – 4.00	Above Average
5	4.10 – 5.00	Excellent

2.2.7 Solubility Test

This test was conducted using an edible coating procedure modified into edible film and dissolved in water for 24 hours. The edible film was made by oven-drying the edible coating samples until the coating formed thin sheets. The edible film to be used in the solubility test included each treatment cut into 3x3 cm pieces. The edible film was initially weighed and then dissolved in water over a 24-hour period in a beaker. After 24 hours, the solubility of the sample in water was recorded.

2.2.8 Water Vapor Transmission Rate Test

WVTR (water vapor transmission rate) is the rate at which water vapor will penetrate a film layer under specific temperature and relative humidity conditions. US standard units express the value as g/100 in 2/24 hours, while metric units express it as g/m/24 hours. (atau SI). To test the edible coating, we cut the compacted edible coating sheet into a 3x3 cm square shape. Then, we placed the cut piece over the mouth of a test tube containing 20 ml of water and put it into a desiccator for 1 day. (24 jam).

2.2.9 Coating Test

In the coating test, we used three types of fruit: avocados, mangoes, and tomatoes. These fruits were chosen based on the reason of their rapid ripening and as a representative form of different types of fruit skins. We selected avocado as a fruit with rough skin, mango as a fruit with medium skin, and tomato as a fruit with thin skin. These three fruits were monitored for 14 days to observe the condition of each fruit with treatments 1, 2, 3, and a negative control.

3. RESULTS AND DISCUSSION

3.1 Density Analysis

Density is one of the important parameters in the development of edible coating products because it affects the layer thickness, adhesion, and effectiveness of protection for food products. In this study, the density test results of ECOLA based on taro stems and used cooking oil are shown in the **Figure 1.**

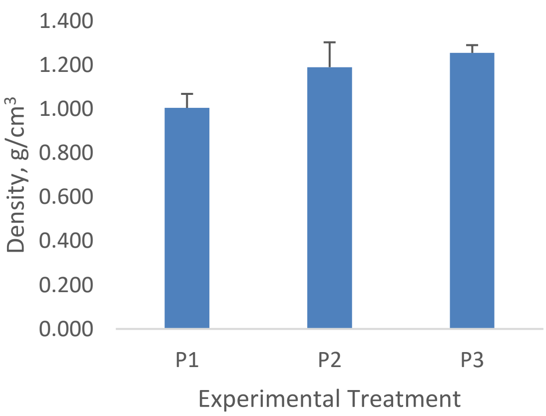

Figure 1. Result of Density

From the density test results, P1 has the highest taro stem starch content (3 grams), but the resulting density value is the lowest at 1.005 g/cm³. This is due to the high starch concentration, which makes the layer structure denser but less flexible. As a result, the coating layer matrix experiences micro-cracks, leading to a decrease in density. P2 with a taro stem starch content of 2.5 grams showed a significant increase in density to 1.190 g/cm³. The decrease in starch content is offset by an increase in glycerol (2.5 ml), which acts as a plasticizer. Glycerol helps increase the flexibility of the layer, reduce porosity, and make the structure more compact [10]. P3 has the lowest taro stem starch content (2 grams) and the highest glycerol content (3 ml). The density value of P3 is 1.255 g/cm³, slightly higher than P2. The decrease in starch content may reduce structural density, but the increase in glycerol enhances the layer's elasticity, keeping the structure compact without micro-cracks.

Glycerol significantly influences the physical characteristics of edible coatings. By improving flexibility, the higher glycerol concentration in P2 and P3 contributes to the stabilization of the layer structure and raises the layer density. Plasticizers like glycerol can lessen stress in the polymer matrix, increasing the layer's density and elasticity [11].

Test results indicate that changes in the percentage of taro stems and used cooking oil impact the ECOLA density value. While unused cooking oil helps generate a more elastic and flexible structure, the taro stems' natural fiber and starch content create an opaque coating matrix. The ideal density in ECOLA influences the coating layer's ability to effectively protect food products' surfaces. Higher density values typically produce a more compact coating layer by slowing the velocity at which oxygen, water vapor, and other degrading gases disperse. Thus, in keeping with the objective of preventing food loss, a high density in ECOLA contributes to the extension of food products' shelf life.

Higher densities in treatments P2 and P3 indicate a more compact and closely packed coating layer. The capacity to stop the movement of gas and water vapor is generally better in a layer with the ideal density. Density influences the permeability of edible coatings; a layer with a high density can better protect food items from oxidative or microbiological degradation [11]. The lack of significant differences between P2 and P3 indicates that we have reached the ideal point. P2 and P3, high-density edible coating layers, have a greater chance of extending food goods'shelf lives. ECOLA supports its innovation in preventing food loss by improving physical protection, lowering respiration rates, and lessening oxidation and moisture damage [12], Akilie suggest that using edible coatings with a high density can enhance product quality during storage.

ECOLA has a competitive density when compared to other edible coating studies, such as those that use alginate or cassava starch. For instance, the study by Johannes [13] found that edible coatings made from cassava starch have a lower density than taro stems because of their lower fiber content. This suggests that taro stems can make a fantastic substitute base material.

3.2 Tensile Strength Test

The test specimen that failed under static testing conditions serves as the basis for the tensile test, which yields the tensile strength, tensile strain, and tensile modulus of elasticity. **Figure 2** displays the results of the tensile test.

These results indicate that treatments P2 and P3 have higher tensile strength compared to P1. Taro stem starch acts as a structural component in the edible coating layer. In P1, the higher starch content (3 grams) results in a stiffer and more brittle structure, leading to lower tensile strength. An overly dense structure tends to crack easily under stress, resulting in lower tensile strength [14]. In P2 and P3, an increase in glycerol concentration compensates for the reduction in taro stem starch content. This causes the layer structure to become more flexible and stronger, thereby increasing the tensile strength. Glycerol acts as a plasticizer, which functions to increase the elasticity of the layer by reducing the interaction between polymer molecules and thereby preventing structural brittleness [15]

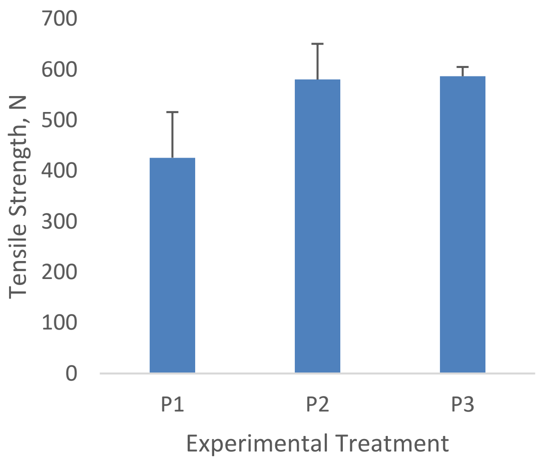

Figure 2. Tensile Strength Test Results

In P2 (2.5 ml glycerol) and P3 (3 ml glycerol), the increase in glycerol content results in a layer structure that is more flexible and resistant to tensile stress. This explains the higher tensile strength value compared to P1. Although P3 has the highest glycerol content, its tensile strength value is slightly lower than P2. This may occur because excess glycerol can cause the layer to become too soft and elastic, slightly reducing the layer's ability to withstand maximum tension.

The high tensile strength in P2 and P3 indicates that the edible coating layer has an optimal structure between density and elasticity. This is important because a strong and flexible layer can more effectively protect food from physical and microbial damage [16]. The superior tensile strength in P2 and P3 also supports the role of ECOLA as an innovation in preventing food loss. A layer with high tensile strength is more resistant to cracking or tearing during food storage and distribution processes. Therefore, the P2 formulation can be considered the best composition for enhancing the mechanical properties of the ECOLA edible coating, supporting food protection functions, and contributing to efforts to prevent food loss.

3.3 Modulus of Elasticity

According to the analysis results (**Figure 3**), P1 has the lowest modulus of elasticity. The high concentration of starch in the taro stem accounts for the low modulus of elasticity value. (3 gram). Excessive starch content tends to increase the plasticity of the material, reducing its elastic strength [17]. This is because the polysaccharide structure in starch forms a loose matrix. The fact that P2's elastic modulus went up shows that adding glycerol (2.5 ml) to the lower amount of taro stem starch (2.5 grams) makes the film structure stronger and more stable. Glycerol acts as a plasticizer within an optimal range that helps increase flexibility without weakening the mechanical strength of the film [18]. The decrease in modulus of elasticity value in P3 compared to P2 is due to the increase in glycerol to 3 ml. Excess glycerol makes the material more elastic but less strong due to reduced interaction between polymer chains [19].

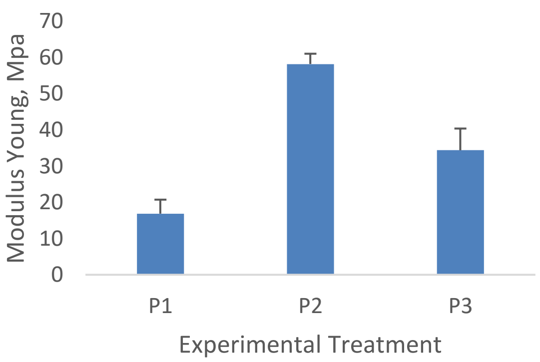

Figure 3. Modulus Young Test Results

The greatest increase in Young's modulus in treatment P2 indicates the optimal ratio of taro stem starch (2.5 grams) to glycerol (2.5 milliliters), resulting in a thicker and more uniform matrix structure. Both excess taro stem starch and plasticizer (glycerol) can impact the mechanical strength of the edible coating, as indicated by the lower modulus values in P1 and P3. When properly treated (P2), taro stem starch can serve as a raw material in edible coatings, enhancing the layer's mechanical strength and flexibility.

The development of edible coatings based on taro stem starch has significant potential in preventing food loss, especially in the distribution and storage chain of food products. With optimal mechanical characteristics, such as a high Young's modulus, edible coatings can protect against physical damage and moisture evaporation [20]. This innovation aligns with the 2045 food security goals, namely minimizing food loss through environmentally friendly technology based on local materials.

3.4 Organoleptic Test

Based on the results of the public feasibility test conducted by 50 respondents **(Figure 4).** The results of the public feasibility test indicate that treatment P1 received the highest scores in terms of color, aroma, and texture. This suggests that composition P1 is the most favored by consumers because it produces a coating with attractive visual characteristics, a neutral aroma, and excellent texture.

The higher starch content contributes to these outcomes by giving the mixture a more uniform and natural color [21]. Given that visual perception is the initial impression that shapes customer preferences for food, a visually appealing color is crucial to the consumer's adoption of a product [22]. This suggests that combining the maximum amount of taro stem starch (3 grams) with the least amount of glycerol produces a more balanced smell. However, the increase in glycerol content to 3 ml, which can result in a deviant smell due to certain chemical interactions during the heating process, is the reason for the decrease in aroma in P3 [23]. Earlier research directly links the Young's modulus to good texture in edible coatings; P1 has a lower Young's modulus value but maintains appropriate elasticity for a comfortable texture when applied [24].

The visual and sensory quality of edible coatings is crucial for market acceptance and their application in the food industry. With good consumer preference values, this technology can be widely applied in efforts to prevent food loss, support national food security, and promote the use of environmentally friendly natural materials.

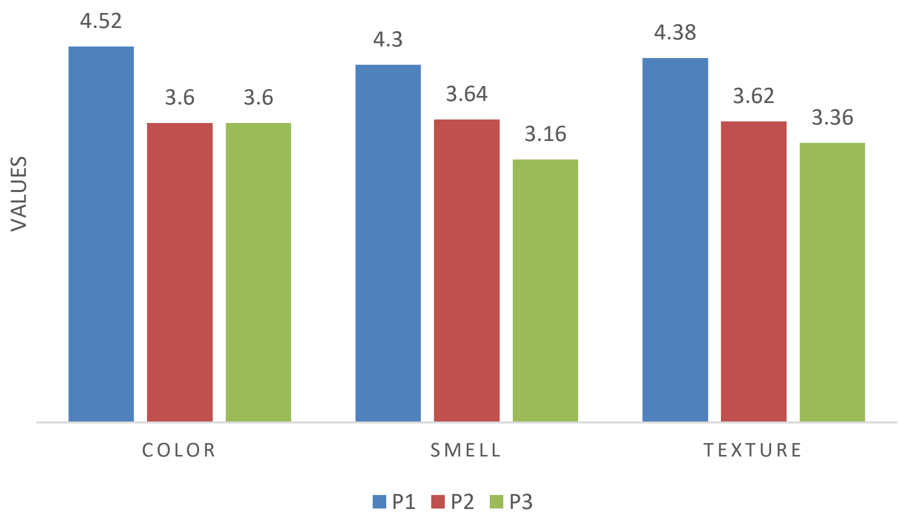

Figure 4 Results of the ECOLA Public Feasibility Test

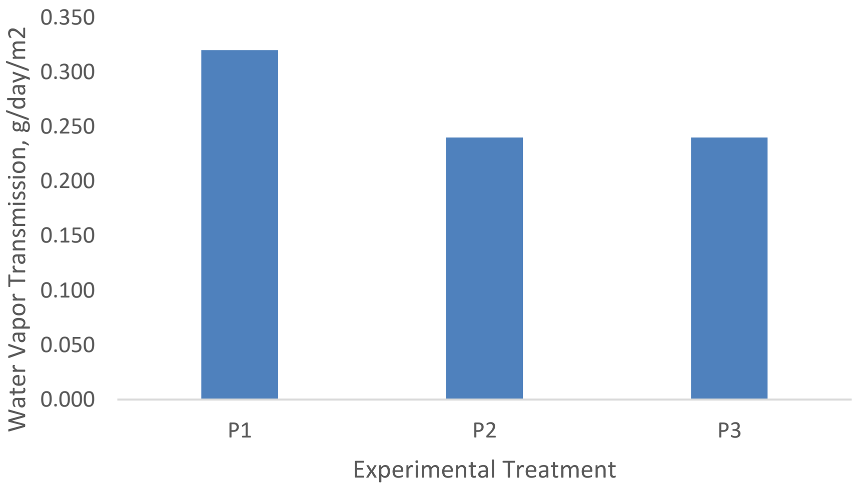

Figure 5 Water Vapor Transmission Rate Test

3.5 Water Vapor Transmission Rate Test

WVTR (water vapor transmission rate) is the rate of vapor under conditions where water vapor will penetrate the film layer at specific temperature and relative humidity conditions.

Figure 5 displays the results of the water vapor transmission test for three edible fruit coating samples with codes P1, P2, and P3. The purpose of the water vapor transmission test is to evaluate the edible coating layer's ability to prevent water vapor from leaving the fruit product and entering the surrounding environment. High water vapor transfer accelerates the decrease of fruit quality, including wrinkling and moisture loss, which makes this parameter crucial.

With a value of approximately 0.32 g/day/m^2, P1 has the highest water vapor transmission. This suggests that sample P1 has the lowest transmission resistance for water vapor, which facilitates faster water vapor escape. Transmission values are lower for P2 and P3, at about 0.24 g/day/m^2. It is clear from this that P2 and P3 are more effective than P1 at preventing the spread of water vapor. This difference suggests that the materials' composition or the amount of edible coating utilized in each sample varied.

An edible coating creates a selective barrier that preserves the fruit's shelf life and quality by reducing water loss and slowing down its respiration rate. Tests for the transmission of water vapor are crucial to evaluating the edible coating layer's water vapor barrier performance. The tests determine whether the coating layer remains physically stable when exposed to ambient humidity.

According to previous research, edible coatings based on polysaccharides (such as chitosan or starch) typically exhibit high water vapor permeability because of their hydrophilic nature [25]. Because of their hydrophobic qualities, hydrophobic compounds like vegetable oils or lipids can improve water barrier qualities [26]. To increase the efficiency of edible coatings in preventing the transfer of water vapor, polysaccharides and lipids are frequently combined [27].

A number of elements, including the composition of the coating material, influence water vapor transmission. P1 likely has a lower hydrophobic content than P2 and P3, which accelerates the transmission of water vapor. The coating layer's ability to effectively block water vapor depends on its thickness and concentration [27]. You can combine taro stem starch with used cooking oil to enhance the hydrophobic qualities of the coating and reduce the transmission rate of water vapor [27].

Edible coatings are applied to fruits to reduce respiration and water loss, thereby increasing their shelf life. Avoid microbial and physical harm while storing. This can be achieved by reducing food loss and enhancing food resilience [28]. Related research has demonstrated the effectiveness of edible coatings based on starch and vegetable oil in slowing the transfer of water vapor. Combining starch with hydrophobic substances like coconut oil or used cooking oil creates a denser layer that hinders water vapor from passing through [27]

3.6 Results of the Fruit Shelf Life Test (Coating Test)

As part of a treatment test, we assessed the ripeness of mangoes, tomatoes, and avocados coated with ECOLA for 21 days. We then compared the ripeness of these fruits after 21 days without ECOLA use. The findings of the taro stem starch edible coating test's effectiveness analysis indicate a notable influence on the product's room temperature shelf life. Fruits coated with this edible coating may have a longer shelf life compared to those not coated with taro stem starch.

We conducted a 14-day fruit shelf-life test. All three fruits (avocado, mango, and tomato) were in fresh condition (+++) on days 1–5, which are known as fresh days. On day three, all fruit varieties, particularly tomatoes with their high water content, began to exhibit wilting (++) symptoms in the control K(-) group. The quality of tomatoes deteriorates more quickly than that of avocados and mangoes. This is due to the thin skin of tomatoes, which speeds up respiration and transpiration [29].

Treatments P2 and P3 better maintain fruit quality by inhibiting microbial growth and slowing down moisture loss [27]. In terms of prolonging the fruit's shelf life, treatments P2 and P3 are more successful than P1 and control K(-). The active ingredients, like polysaccharides (starch or chitosan) that slow down respiration and transpiration, may be better mixed in the coating that can be eaten on P2 and P3. Vegetable oil acts as a hydrophobic barrier to prevent moisture loss [27]. Antimicrobials found in nature suppress the growth of fungi, as observed in research using plant extracts [30].

Table 3 Result of the Fruit Shelf Life Test (Coating Test)

Day	C(-)	Treatment								
		T1			T2			T3		
		A	M	T	A	M	T	A	M	T
1	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
2	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
3	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
4	++	+++	+++	+++	+++	+++	+++	+++	+++	+++
5	++	+++	+++	+++	+++	+++	+++	+++	+++	+++
6	++	+++	+++	++	++	++	++	+++	++	++
7	+	+++	++	++	++	++	++	++	++	++
8	+	++	++	++	++	++	++	++	++	++
9	+	++	++	++	++	++	++	++	++	++
10	+	++	++	++	++	+	+	++	++	++
11	-	++	++	++	+	+	+	++	++	+
12	-	++	++	++	+	+	+	++	+	+
13	-	++	++	+	+	+	-	+	+	+
14	-	++	+	+	+	-	-	+	+	-

Information:

A = Avocado

M = Mango

T = Tomato

+++ = Fruit in fresh condition

++ = Fruit in wilted condition

+ = The fruit is starting to mold.

- = The fruit is experiencing quite severe mold.

4. CONCLUSION

Through the combination of taro stem starch and used cooking oil, the ECOLA invention successfully increases fruit shelf life by up to 14 days, lowers food loss, and promotes food security by 2045. P2 is the best formulation; it has excellent tensile strength, ideal density, and the capacity to prevent moisture loss. Additionally, the public likes ECOLA, particularly its color, texture, and perfume. ECOLA's use of organic waste not only benefits the environment but also advances cutting-edge food technology and sustainable waste management.

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the author(s).

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Vania Evangelista Evelina Susanto: Conceptualization, Methodology, Investigation, Data curation, Data analysis, Writing original draft.
Putu Udayani Pradnya Maheswari,: Data curation, Data analysis, Methodology, Writing original draft.
Made Chantika Artameivia Pradnya Putri,: Data curation, Data analysis
Ni Made Margiani: Data curation, Data analysis

All authors have read and agreed to the published version of the manuscript.

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