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Development of Biodegradable Films from Carrot, Guava, and Banana Peel Fibers for Environmental Packaging Applications

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ABSTRACT

Polymeric materials, known for their lightweight and strength, are widely used today. However, their non-biodegradable nature poses significant environmental challenges. This research aimed to develop biodegradable films from fruits and vegetables, using alginate as a binding agent. Using a completely randomized design, seven experimental sets were prepared with carrots, Kimju guava, and Namwa banana peel fibers as the primary materials and alginate as the secondary material at three levels: 1.2, 1.8, and 2.4 by weight. The solution technique was employed to create the samples. Upon testing mechanical and physical properties, experimental set 3, consisting of 60% guava and 1.8% alginate, emerged as the optimal ratio. This combination exhibited favorable physical properties, including a thickness of 0.26 ± 0.02 mm, meeting the standards for food packaging films. Additionally, the tensile strength was 0.50 ± 0.01 N/m², and the elongation at break was 55.60 ± 0.44%. Regarding chemical properties, the moisture content of 5.64 ± 0.03% fell within the acceptable range for dried food. Furthermore, a 30-day soil burial test revealed that the sample from experimental set 3 exhibited the highest degradation rate. In conclusion, these findings suggest that guava can be a promising raw material for producing biodegradable plastics suitable for packaging applications.

Keywords: Biodegradable Films; Alginate; Carrots; Kimju Guavas; Namwa Banana Peel Fibers

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1. Introduction

Currently, synthetic plastics, sourced from the production of crude oil and natural gas, are ubiquitous in daily human life. However, their extensive use has resulted in a considerable accumulation of plastic waste, exacerbated by their slow degradation and the environmental challenges posed by their disposal. Disposal methods such as burying petrochemical plastics lead to protracted decomposition periods, spanning 350–450 years, and carry adverse health and environmental repercussions [1]. Moreover, incineration, another disposal option, necessitates substantial investment and operational costs [2].

The production and disposal of petroleum-based plastics emit considerable greenhouse gases and generate non-biodegradable waste, exacerbating environmental problems including land and ocean pollution, climate change, and threats to wildlife. The ecological consequences of conventional plastics are concerning; they require centuries to degrade and fragment into microplastics that infiltrate ecosystems and penetrate food chains, impacting both animal and human health. As a result, numerous countries are transitioning to bioplastics as a more sustainable alternative to alleviate these detrimental consequences. The increasing recognition of the environmental consequences linked to petroleum-based plastics has led to a change in consumer choices and governmental policies. A report by The European Bioinformatics Institute reveals a substantial 350% increase in global bioplastic production in 2019, up from 1.7 million tons in 2014. This dramatic rise indicates a growing market for bioplastics, driven by technological advancements and increasing investments in research and development. Countries are not only promoting the use of bioplastics through regulations and incentives but are also investing in infrastructure to support their production and disposal. Furthermore, the production of bioplastics typically generates fewer greenhouse gas emissions compared to traditional plastics, making them a more climate-friendly option. Many bioplastics are derived from renewable resources, such as plant materials, which can contribute to a circular economy where waste is minimized, and resources are continuously reused. This transition to bioplastics not only holds the potential to alleviate some environmental concerns associated with petroleum-based plastics but also fosters innovation and economic growth in the green technology sector, creating jobs and supporting sustainable practices across various industries. As public awareness grows and the demand for sustainable products increases, the bioplastics market is expected to continue its upward trajectory, paving the way for a more environmentally conscious future. The emission of greenhouse gases, including carbon dioxide and methane, contributes significantly to global warming and climate change. Thailand ranks 24th globally in greenhouse gas emissions. Consequently, research and development efforts have been directed towards biodegradable plastics as alternatives to conventional plastics [3]. The Thai Bioplastics Industry Association delineates two categories of biodegradable plastics: compostable plastics, which break down into carbon dioxide and water under controlled air conditions and are conducive to plant cultivation without toxic byproducts, and non-compostable plastics, sourced solely from crops and undergoing combined decomposition and degradation. Thus, biodegradable plastics comprise a combination of petrochemicals and crops, yielding products tailored for diverse applications and facilitating easy degradation. Biodegradable plastics are increasingly favored over petrochemical plastics due to the challenges associated with plastic and foam waste from petrochemical sources, amounting to 2.7 million tons annually, or an average of 7,000 tons per day, equivalent to 100 kilograms per person per year [1].

Biodegradable plastic film is another product capable of replacing synthetic plastics. This type of film can easily biologically decompose, thus enhancing tactile sensations and nutritional values. Its production involves a combination of polysaccharides, protein, and lipids to improve film properties. Natural polysaccharides like starch and pectin are also used in the production of consumer-grade films. Moreover, fruit peel films have been found to contain a high concentration of pectin, a polysaccharide found naturally in plant cell walls. This pectin serves various functions such as gel formation and acting as a stabilizer, emulsifier, and thickening and cation-binding agent. Carrots have been found to have the highest pectin content and are the most suitable for film formation [4]. Additionally, various peels of vegetables and fruits, such as oranges, Kimju guavas, and carrots, accumulate high amounts of pectin. This pectin, a natural polysaccharide, is a fundamental component of plant cell walls and can be mixed with water and other compounds to serve various functions, including thickening, gelling, stabilizing, emulsifying, and cation-binding agent [5]. Raw Namwa bananas are processed into banana flour, adding value to bananas. This is achieved by processing raw banana flour and modified banana flour using the cross-linking method with the distarch method, along with other components such as plasticizers and banana fiber to enhance strength. Additionally, the incorporation of polylactic acid (PLA) further improves the efficacy of steam barrier protection and strengthens the packaging material, making it suitable for food and vegetable packaging, replacing synthetic plastic packaging. As a natural packaging material, it is environmentally friendly and biodegradable [6]. Durian peels, a potential source of valuable pectin, were the focus of a study by [7]. The researchers conducted a series of experiments to determine the most effective method for extracting pectin from the white flesh of the peels. Three approaches were compared: using hydrochloric acid solution (0.05 M), distilled water, and high-pressure steam. To identify the optimal method, they measured the yield of extracted pectin from each approach. Additionally, they analyzed the physical and chemical properties of the pectin obtained. The results indicated that steam extraction yielded the highest amount of pectin, followed by hydrochloric acid and lastly, distilled water extraction. This suggests that steam may be the most suitable method for harnessing pectin from durian peels for various applications. A study by Dedduang [8] investigated pectin content in three guava varieties: Klom Sali, Pan Si Thong, and Kimju. Pectin was extracted from different parts (peel, pulp, and core) of each variety. The results revealed that Kimju possesses the highest pectin content, ranging from 15.5 ± 1.08% to 19.44 ± 0.83%. Klom Sali followed with 8.56 ± 0.56% to 11.45 ± 0.24%, while Pan Si Thong had the lowest amount, ranging from 8.69 ± 0.29% to 9.92 ± 0.24%.

Building upon the aforementioned premise, the researchers have embarked on the development of biodegradable film crafted from natural resources, intended for eco-conscious packaging solutions. The aims encompass determining the optimal ratios for fabricating biodegradable film and scrutinizing its physical attributes such as thickness, tensile strength, and elongation, alongside its chemical features like moisture content and pH level, as well as its biological characteristics encompassing water absorption capacity and biodegradability. Moreover, this study delves into consumer acceptance of the biodegradable film as a viable alternative for eco-friendly packaging, with the overarching goal of preserving food quality and prolonging shelf life, thereby substituting synthetic plastics derived from the petrochemical sector and mitigating plastic waste concerns. Additionally, the utilization of naturally biodegradable plastics sourced from carrots, Kimju guavas, and Namwa banana fiber, all pivotal fruits within the local economy of Sawai Cheek Subdistrict, Mueang District, Buriram Province, not only ensures consumer safety but also presents economically valuable and readily available materials for the production of biodegradable and environmentally friendly packaging materials. Crucially, this research augments the value of agricultural yields, fostering optimal utilization and reaping agricultural benefits.

2. Research Methodology

2.1. Instruments and Equipment

1. Balance (2 and 4 decimal places, Scientific Promotion Company)
2. Magnetic stirrer with heating (Hotplate Stirrer), Model MR 3001, Heidolph Company
3. Juicer, Model EM-11, SHARP Company
4. Digital vernier caliper (2 decimal places)
5. Scanning electron microscope (SEM), Model 1450 VP, LEO Company
6. Vacuum oven, Model 282A, Fisher Scientific Company
7. Hot air oven, Model FED 240, BINDER Company
8. Dial thickness gauge, MOORE & WEIRHT
9. Moisture meter, Sartorius ME Model
10. Universal tensile tester, Model Micro 350, Testometric Company
11. Acrylic sheet (30x30x0.4 cm) for molding
12. Plastic container with lid (10 liters)

2.2. Materials

The development of biodegradable films involved three experimental sets: biodegradable films

produced from carrots, biodegradable films produced from Kimju guavas, and biodegradable films produced from Namwa banana fiber. The primary raw materials were sourced from economically significant fruits in the local economy of Sawai Cheek Subdistrict, Mueang District, Buriram Province, as shown in **Figure 1**.

Figure 1. Primary Materials Utilized in the Research (carrots, guava, and banana peel fiber) [9].

2.3. Experimental Design

Bioplastic films were prepared using various ratios of carrot, Kimju guava, and Namwa banana peel fibers. A completely randomized design was adopted, dividing the experiment into seven sets, each with three replications. The following ratios were used:

Set 1: Carrot: Alginate (60:1.8)
Set 2: Kimju guava: Alginate (60:1.2)
Set 3: Kimju guava: Alginate (60:1.8)
Set 4: Kimju guava: Alginate (60:2.4)
Set 5: Namwa banana peel: Alginate (60:1.2)
Set 6: Namwa banana peel: Alginate (60:1.8)
Set 7: Namwa banana peel: Alginate (60:2.4)

To enhance the film's flexibility, 2.25 grams of xylitol and 1 gram of calcium chloride were added per gram of solid material in all sets [10].

2.4. Production of Biodegradable Films

Materials Preparation Method: Carrots, Kimju guavas, and Namwa banana fibers were washed and cleaned. Carrots and Kimju guavas were cut into pieces measuring 2×2 cm, while the fibers were scraped from the banana peel. Subsequently, they were steamed for approximately 40 minutes, allowed to cool, and then blended until smooth. Portions of 60 grams each of the blended carrots, Kimju guavas, and banana fibers were weighed to prepare them for forming into biodegradable film sheets, as shown in **Figure 2**.

Biodegradable Film Sheets Forming Preparation: The main ingredients, each weighing 60 grams, were weighed and placed in a beaker. Distilled water (140 milliliters) was added to the beaker, and the mixture was boiled and stirred. Next, 1.8 grams, 2.4 grams, and 1.2 grams of alginate were sequentially dissolved in the mixture, followed by 50 milliliters of distilled water for carrots, Kimju guavas, and Namwa banana fiber weighing 60 grams each, respectively. Additionally, 2.25 grams of xylitol were added to the mixture for carrots, Kimju guavas, and Namwa banana fiber weighing 60 grams each. Furthermore, one gram of calcium chloride was added to the mixture for carrots, Kimju guavas, and Namwa banana fiber weighing 60 grams each. The temperature was controlled at 50 degrees Celsius, then removed from the heat and stirred by hands for 20 minutes. The mixture was allowed to cool until the temperature of the ingredients reached 25 degrees Celsius. Then, the previously prepared alginate solution was added to a container and stirred by hands for another 20 minutes. Once the mixture was well blended, it was poured onto the mold or template prepared (avoiding air bubbles) and placed in an oven at 65 degrees Celsius for six hours. The film was allowed to cool for one hour to reach room temperature.

Figure 2. Procedure for the Preparation of Biodegradable Films (1. Add 140 mL of distilled water 2. Prepare xylitol, calcium chloride, and alginate 3. Dissolve 1.2, 1.8, and 2.4 grams of alginate, respectively 4. Stir manually 5. Pour into the mold) [9].

2.5. Biodegradable Plastic Biophysical Properties Study

Biophysical properties were analyzed, including thickness using a vernier caliper, tensile strength, and elongation using an analog tensile testing machine. Chemical properties, such as moisture content, were determined by oven-drying the samples at 105 degrees Celsius until constant weight was achieved, and weight changes were recorded. pH values were measured using a pH meter. Biological properties, including water absorption capacity and biodegradability, were assessed.

For the biodegradation test, samples were cut into 3.5 cm x 3.5 cm squares, with three samples per condition, and dried at 55°C to determine their initial weight (A0). These samples were subsequently interred in pots at a depth of 10 cm, topped with commercial potting soil, and incubated for 30 days. Following incubation, the samples were collected, purified, dried at 150°C for 15 minutes, and reweighed (A1). The biodegradation percentage was determined using a methodology established on Equations (1) by[11] as follows.

$$\text{Biodegradation}\,(\%) = \left[\ \frac{\text{A0}\ -\text{A1}}{\text{A0}}\ \right] \text{X } 100 \qquad (1)$$

2.6. Morphological Analysis

The morphology of the bioplastic film samples was examined using a Scanning Electron Microscope (SEM) model 1450VP manufactured by LEO. The instrument was operated at an accelerating voltage of 10 kilovolts. The surface of the films was imaged at magnifications of 30x, 100x, 500x, and 3000x. Before examination, the film samples were sized appropriately and coated with a layer of gold.

2.7. Evaluation of Potential Applications as Packaging

The biodegradability of the bioplastic films was evaluated for their potential as antimicrobial packaging. An antifungal activity test was conducted using the paper disc method with Aspergillus flavus A39, a fungus known to produce high levels of aflatoxins. The fungus was spread onto Potato Dextrose Agar (PDA) plates at a concentration of 106 spores per milliliter and allowed to incubate for 3–5 minutes. Film samples, cut into 5x5 mm squares, were then placed on the agar plate with three replicates per plate. The plates were incubated at room temperature for 48 hours. The results were recorded by observing the clear zone, or the area around the sample where fungal growth was inhibited[12].

3. Research Results

3.1. Results of Biodegradable Film Production

The research team conducted experiments and investigated the optimal mixing ratios for biodegradable film production until they obtained the most suitable formula, as detailed in **Table 1.**

Table 1 reveals that the characteristics of the biodegradable films across all seven experimental sets exhibit variations. These differences stem from the varying proportions of alginate, leading to unique properties for each film formulation. Notably, experimental sets 5 and 7, being incapable of molding, were consequently, omitted due to their lack of suitability for application. Subsequently, the remaining experimental sets underwent further examination to assess the physical properties of the biodegradable films in the following sequence.

3.2. Physical Properties Analysis of Biodegradable Films

The research team analyzed the physical properties of the biodegradable films, encompassing thickness, tensile strength, and elongation, as detailed in **Table 2**.

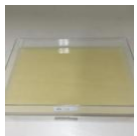
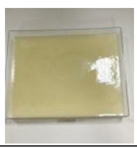
From **Table 2**, it is found that the thickness of the biodegradable films in all five experimental sets meets the standard for food wrapping films, with a thickness not exceeding 0.3 millimeters. Furthermore, upon considering the tensile strength and elongation, it is observed that three experimental sets, namely sets 1, 3, and 6, exhibit significantly high tensile strength and elongation. Therefore, these experimental sets were selected for further investigation of their chemical properties.

3.3. Chemical Properties Analysis of Biodegradable Films

The research team conducted an analysis of the chemical properties of the biodegradable films, including moisture content and pH value, as detailed in **Table 3.**

In **Table 3**, it is evident that the moisture content of the biodegradable films across all three experimental sets ranged from 5.50% to 8.66%, aligning with the standard for dry food, i.e., not exceeding 15%. Alginate emerges as a key factor influencing moisture levels, as it enhances the production process's flexibility, augments the biodegradable films' properties, and minimizes adhesion to molds. Hence, controlling the quantity of alginate is essential to prevent excessive moisture in the biodegradable films. Regarding the pH values of the biodegradable films in all three experimental sets, they ranged from 4.30 to 4.67, in accordance with the Office of Food and Drug Administration's announcement no. 420 of Ministry of Public Health in the year 2020. This announcement stipulates that low-acid foods have a pH value lower than 4.6. Consequently, it can be inferred that the biodegradable films in all three experimental sets adhere to the standard for dry food.

Table 1. The experimental sets for biodegradable film production.

Experimental Set	Main Ingredients			Secondary Ingredients	Characteristics		Appearance of Biodegradable Films
	Carrots (grams)	Kimju Guavas (grams)	Namwa Banana Fiber (grams)	Alginate (grams)	Shape Retention	Stability	
1*	60	-	-	1.8			• Orange color • Thick • Smooth surface, easy to peel off • Moldable
2	-	60	-	1.2			• Greenish-yellow color • Thick • Smooth texture • Moldable
3	-	60	-	1.8			• Greenish-yellow color • Thick • Smooth texture • Moldable
4	-	60	-	2.4			• Greenish-yellow color • Thick • Smooth texture • Moldable
5	-	-	60	1.2			• Brown color • Thick • Rough texture • Not moldable
6	-	-	60	1.8			• Brown color • Thick • Rough texture • Moldable
7	-	-	60	2.4			• Brown color • Thick • Rough texture • Not moldable

Note: This sign * denotes the experimental sets and formulations of biodegradable film production adapted from the research and development of packaging by [5] as prototype experiments.

Table 2. Physical properties of biodegradable films.

Experimental Set	Main Ingredients			Secondary Ingredients	Physical Properties		
	Carrots (grams)	Kimju Guavas (grams)	Namwa Banana Fiber (grams)	Alginate (grams)	Thickness (Millimeters)	Tensile Strength (N/m^2)	Elongation (%)
1	60	-	-	2.4	$0.26^{ns} \pm 0.00$	$0.51^{b} \pm 0.00$	$55.44^{a} \pm 0.50$
2	-	60	-	1.2	$0.27^{ns} \pm 0.01$	$0.89^{a} \pm 0.00$	$46.76^{b} \pm 0.69$
3	-	60	-	1.8	$0.26^{ns} \pm 0.02$	$0.50^{b} \pm 0.01$	$55.60^{a} \pm 0.44$
4	-	-	60	2.4	$0.26^{ns} \pm 0.02$	$0.89^{a} \pm 0.01$	$45.64^{b} \pm 1.20$
6	-	-	60	1.8	$0.26^{ns} \pm 0.02$	$0.50^{b} \pm 0.00$	$54.40^{a} \pm 1.45$

Note:

1. "ns" indicates no statistically significant difference.
2. English letters appearing similarly in each column signify no statistically significant difference in means at a 95 percent confidence level, according to the Duncan's Multiple Range Test (DMRT) method.

Table 3. Chemical Properties of Biodegradable Films.

Experimental Set	Main Ingredients			Secondary Ingredients	Chemical Properties	
	Carrots (grams)	Kimju Guavas (grams)	Namwa Banana Fiber (grams)	Alginate (grams)	Moisture Content (%)	pH Value (pH)
1	60	-	-	2.4	$5.50^{b} \pm 0.00$	$4.30^{ns} \pm 0.04$
3	-	60	-	1.8	$5.64^{b} \pm 0.03$	$4.43^{ns} \pm 0.10$
6	-	-	60	1.8	$8.66^{a} \pm 0.13$	$4.67^{ns} \pm 0.15$

Note:

1. "ns" indicates no statistically significant difference.
2. English letters appearing similarly in each column signify no statistically significant difference in means at a 95 percent confidence level, according to the Duncan's Multiple Range Test (DMRT) method.

3.4. Biological Properties Analysis of Biodegradable Films

The research team conducted an analysis of the biological properties of the biodegradable films, focusing on their water absorption capacity and natural degradation over a 30-day period when buried in soil. Details are presented in **Tables 4** and **5**.

From **Table 4**, the results of the water absorption test for the biodegradable films were presented. Samples were immersed in distilled water, and images were recorded at intervals of 0, 5, 30 minutes, 12 hours, and 24 hours, respectively. It was found that the biodegradable films absorbed water and swelled. During the initial 0–5 minutes, the changes in the samples were similar. However, after 30 minutes, the biodegradable films began to swell and absorb water more. After 12 hours, experimental set 6 almost dissolved in water, while experimental sets 1 and 3 remained intact. After 24 hours, experimental sets 1 and 3 still maintained their shape without becoming mushy in water, indicating their superior water resistance. Therefore, experimental sets 1 and 3 were selected for further investigation of their natural degradation behavior when buried in soil for 30 days in the subsequent order.

For the biodegradation test, the biodegradation of the bioplastic films was tested using a soil burial method. The results showed that the percentage of biodegradation increased with the increase in fiber content. This is because the increased fiber content resulted in a more porous internal structure, allowing for greater water absorption from the soil [13]. As a result, the samples swelled more, leading to a loss of mass during polymer degradation [14]. In samples prepared using a carrot: alginate ratio of 60:1.8 and guava: alginate ratio of 60:1.8, 100% biodegradation was observed within 30 days. For the natural degradation test of the biodegradable films buried in soil for 30 days, the degradation process of the biodegradable films was monitored by observing the changes in their physical characteristics through photographs taken at different time intervals. The alterations in the physical appearance of the biodegradable film samples over time were compared. Details of these changes were presented in **Table 5**.

Table 4. Water absorption capacity of biodegradable films.

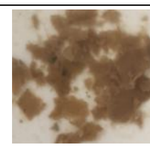
Experimental Set	Period				
	0 mns	5 mns	30 mns	12 hrs	24 hrs
1 Carrots 60 grams: Alginate 1.8 grams					
3 Kimju guavas 60 grams: Alginate 1.8 grams					
6 Namwa banana fiber 60 grams: Alginate 1.8 grams					

Table 5. Natural degradation of biodegradable films by soil burial method for 30 days.

Experimental Set	Characteristics of Degradation			
	Before Soil Burial	After 10 Days of Soil Burial	After 20 Days of Soil Burial	After 30 Days of Soil Burial
1 Carrots 60 grams: Alginate 1.8 grams				
3 Kimju guavas 60 grams: Alginate 1.8 grams				

In **Table 5**, the results of the natural degradation test of the biodegradable films buried in soil for 30 days are presented. It was found that before burial, the samples of biodegradable films from experimental set 1 appeared smooth and orange in color. After 10 days of burial, signs of tearing and soil residues on the biodegradable plastic film were observed, making it impossible to weigh to calculate the percentage of weight loss. After 20 days of burial, the biodegradable films began to show increased tearing, becoming more fragile and changing in shape. After the complete 30-day burial period, the biodegradable films were completely deteriorated. As for experimental set 3, before burial, the samples of biodegradable films appeared smooth and greenish-yellow in color. After 10 days of burial, the biodegradable films absorbed moisture from the soil, although the soil retained its original form, and soil residues were present on the biodegradable plastic film, preventing it from being weighed to calculate the percentage of weight loss. After 20 days of burial, the biodegradable films showed increased tearing, becoming more fragile and changing in shape. After 30 days of burial, the biodegradable films were completely degraded to the extent that they could no longer be weighed between the soil layers. Therefore, it can be concluded that both sets of biodegradable films underwent significant degradation, eventually merging with the soil.

3.5. Morphology

The morphology of the film samples in the experimental set with a guava: alginate ratio of 60:1.8 is presented. The images were obtained using a scanning electron microscope at the magnifications of 30x, 100x, 500x, and 3000x, as shown in **Figure 3**.

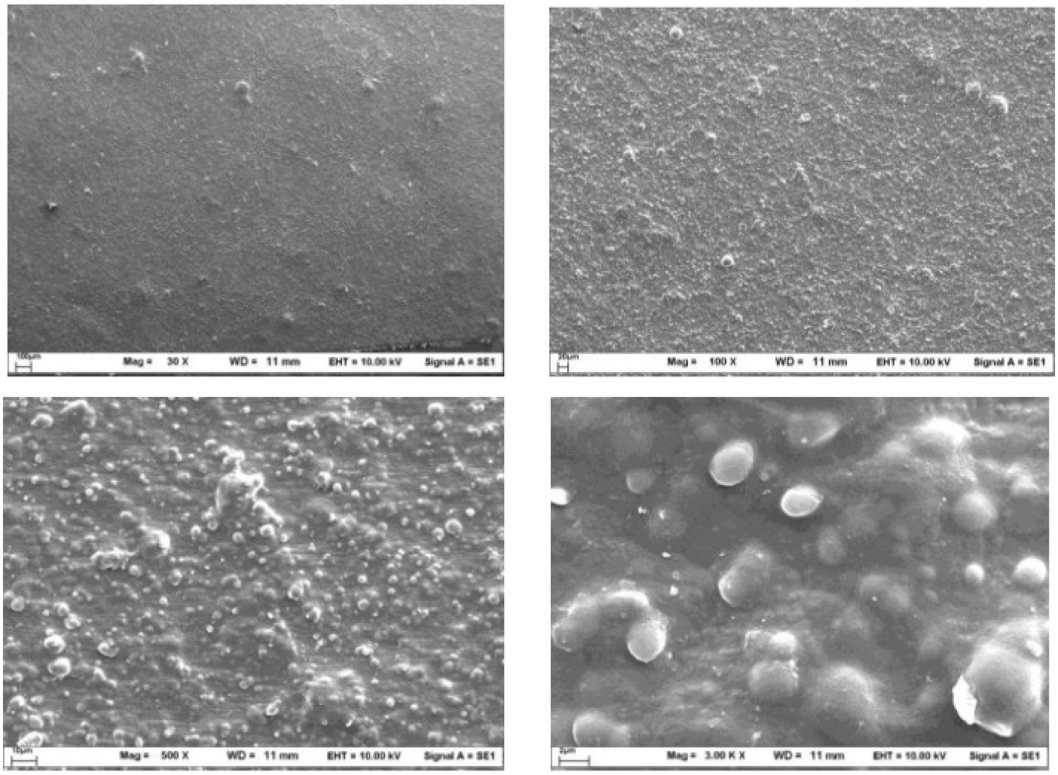


Figure 3. Surface Morphology of Film Samples Produced from Guava: Alginate at a Ratio of 60:1.8 at Magnifications of 30x, 100x, 500x, and 3000x [9].

Figure 3 demonstrates that the film samples derived from guava and alginate at a 60:1.8 ratio displayed a notable development of gel structures. Upon meticulous scrutiny at 500x magnification and beyond, it becomes apparent that the gelation within these films was imperceptible to the unaided eye. The findings corroborate prior studies [15] suggesting that gel formation improves the film's flexibility.

3.6. Evaluation of Potential Application as Packaging Material

This study examined the feasibility of utilizing biodegradable films as packaging materials, considering their significant potential in foodpackaging applications [16]. Based on the cited research and the findings from the characterization tests of guava-based biofilms, which indicated their potential as antimicrobial packaging [17], the films were evaluated against Aspergillus flavus, a fungus recognized for producing aflatoxins and frequently encountered in dried agricultural products. Previous studies by [18] have shown that guava-based biofilms can inhibit the growth of Aspergillus flavus. However, in this study, no clear zone was observed, indicating the absence of any inhibitory substances diffusing from the film. Furthermore, no fungal growth was detected on the film surface. These results suggest that the guava-based biofilms have the potential to be used as food packaging materials.

4. Discussion

Synthetic plastics, derived from crude oil and natural gas production processes, are widely used in everyday human life. The prevalence of these materials has led to a significant accumulation of plastic waste, primarily because of their long decomposition times. It can take hundreds of years for conventional plastics to break down, which poses a severe threat to ecosystems and wildlife. Moreover, the disposal processes for these materials often result in environmental problems, including land and ocean pollution [19]. For instance, marine life often ingests plastic debris, leading to injury and death, while microplastics can infiltrate food chains and eventually enter human diets, raising concerns about long-term health effects. Given these pressing environmental issues, there has been an increasing focus on researching and developing biodegradable plastics as alternatives to traditional synthetic materials. Biodegradable plastics, which can decompose through natural processes, offer a promising solution to the plastic waste crisis. Researchers are particularly interested in sourcing raw materials from natural origins, such as starch, cellulose fibers, and even local fruits and vegetables, which are considered renewable and inexpensive resources [20]. Utilizing these bio-based materials not only helps reduce reliance on fossil fuels but also promotes sustainable agricultural practices, contributing to a circular economy where waste is minimized, and resources are reused.

The development of biodegradable films as edible packaging innovations is particularly noteworthy in the context of addressing the plastic waste issue. Such packaging solutions not only help mitigate environmental impacts but also add value to agricultural products by utilizing surplus or less desirable crops. For example, incorporating agricultural by-products or underutilized fruits into packaging films can create new markets and revenue streams for farmers while simultaneously reducing waste [21]. Packaging used for food wrapping plays a crucial role in maintaining food quality and extending shelf life. Effective packaging protects food from environmental contamination, delays spoilage, and prevents deterioration caused by bacteria, chemicals, and physical damage [22]. The challenges posed by traditional packaging materials have led to innovative approaches that explore the use of natural biodegradable materials. By harnessing the functional properties of these materials, researchers aim to create packaging that is not only environmentally friendly but also effective in preserving food quality. Experimental studies indicate that certain fruits, such as carrots and Kimju guavas, can be processed into edible food-wrapping films. Kimju guavas, in particular, have shown promising results. They exhibit suitable mechanical properties, excellent barrier characteristics, and high consumer acceptance scores. This is particularly significant because consumer perception plays a vital role in the adoption of new packaging technologies. A product that aligns with consumers' values regarding sustainability and environmental responsibility is more likely to succeed in the marketplace.

The attributes of Kimju guavas make them particularly well-suited for developing environmentally friendly packaging. These fruits contain natural polymers that can form films with desirable characteristics, including flexibility, durability, and biodegradability. Furthermore, Kimju guavas are rich in vitamins and nutrients, which can contribute to the functional benefits of the packaging. For instance, the antimicrobial properties of certain compounds found in guavas could enhance the shelf life of wrapped products by inhibiting the growth of spoilage microorganisms. Beyond their potential in food packaging, the utilization of Kimju guavas and similar natural materials presents an opportunity for value addition in agricultural sectors. By developing these fruits into films for wrapping candies or fruit purees, producers can diversify their product offerings and increase profitability. This value addition not only provides economic benefits to farmers and producers but also encourages the sustainable use of agricultural resources.

In summary, the development of biodegradable films from natural sources such as Kimju guavas presents a multifaceted solution to the growing problem of plastic waste. By integrating sustainability into packaging design, we can effectively address environmental concerns while also enhancing the value of agricultural products. As consumer demand for eco-friendly solutions continues to rise, the further development of these biodegradable films will play a crucial role in transforming the packaging industry, promoting a shift towards more sustainable practices that benefit both the environment and the economy. In light of these advancements, it is imperative for researchers, policymakers, and industry stakeholders to collaborate and innovate, paving the way for a greener future where biodegradable materials become the norm rather than the exception.

5. Conclusions

A study on the utilization of economic plants and fruits to produce biodegradable films for environmental packaging applications has been conducted. Experiments were carried out using primary materials such as carrot, guava, and banana peel fiber. The optimal ratio for the biodegradable film was found in Experiment 1 (carrot: alginate = 60:1.8), Experiment 2 (guava: alginate = 60:1.2), Experiment 3 (guava: alginate = 60:1.8), Experiment 4 (guava: alginate = 60:2.4), and Experiment 6 (banana peel fiber: alginate = 60:1.8). Since the ratio of alginate affects the thickness, formation, and stability, the resulting biodegradable films exhibited good flexibility. The thickness of the films was within the standard for food packaging films, not exceeding 0.3 millimeters. Group 1, including Experiments 1, 3, and 6, produced smooth, flexible, and non-brittle films. Moreover, they exhibited high toughness, making them suitable for developing films with good physical properties. The moisture content of the films in all three experiments ranged from 5.50-8.66 percent, which is below the standard for dried food, which is 15 percent. The main factor affecting moisture content was alginate, as it helps increase flexibility and improve the film's properties, as well as reduce adhesion to the mold. Therefore, the amount of alginate was controlled to prevent excessive moisture in the films. Additionally, the pH of the films ranged from 4.30 to 4.67. A lower pH resulted in higher film viscosity, leading to increased flexibility and better food preservation. In the 24-hour water absorption test, the film samples swelled during the first 5 minutes. After 12 hours, the samples showed significant swelling. Further observation revealed that in Experiment 1 (carrot: alginate = 60:1.8), the film initially appeared smooth and orange. However, after 10 days of burial in soil, the film began to tear and had soil particles attached, making it difficult to weigh and calculate the percentage weight loss. After 20 days, the film deteriorated further, and after 30 days, it completely disintegrated. Similarly, in Experiment 3 (guava: alginate = 60:1.8), the film initially appeared smooth and yellow-green. After 10 days of burial, the film absorbed soil moisture but maintained its shape. After 20 days, the film began to tear and disintegrate. After 30 days, the film completely disintegrated. Therefore, both films in Experiments 1 and 3 showed good biodegradability. However, considering all the quality parameters, Experiment 3 was found to be the most suitable for developing biodegradable films for environmental packaging. The film produced in Experiment 3 possessed desirable properties and met all the specified film standards. Additionally, the primary material, guava, is readily available locally and is rich in vitamins and minerals, particularly vitamin C.

6. Recommendations from the Research

To facilitate practical implementation and streamline the production process, it is advisable to investigate industrial-scale manufacturing methods. Given that this research primarily deals with the preparation of biodegradable films in small quantities, there could be variations in properties when these films are utilized in real-world applications. Thus, exploring industrial-scale production methods would aid in addressing potential property variations.

Author Contributions

Conceptualization, investigation, data curation, conducting experiment, formal analysis, writing—original draft,methodology, writing—review & editing, resources, editing & original draft, S.S.; writing—review and editing, validation, K.B.

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The authors agree to share their research data upon request.

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Conflicts of Interest

The authors assert that there are no conflicts of interest pertaining to this work.

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