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Mechanical Properties of CalaSSAG: A Bioplastic Wrapper with Potential Antifungal Properties as an Alternative to Commercially Plastic Wrappers

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Abstract- This study focused on developing a biodegradable food wrapper CalaSSAG, made from bio-based materials such as calamansi peel powder, starch, sodium alginate, and glycerol. The research aimed on making an alternative to plastic packaging that causes pollution. Calamansi is responsible for antimicrobial and antifungal properties. An experimental design was used to test how durable and thick the CalaSSAG bioplastic wrapper was, using three different concentrations of calamansi peel powder, 50%, 75%, and 100%. Testing its thickness and tensile strength. The results showed that the 100% calamansi mixture made the wrapper (1.26 mm), while the 50% mixture had the highest tensile strength (0.165 MPa). However, the control group was stronger than the alternative experimental group in terms of tensile strength with a tensile strength of 3.33 MPa. Statistical analysis using ANOVA confirmed that there is a significant difference in mean tensive strength among CalaSSAG bioplastic wrapper containing varying proportions of calamansi powder and commercially produced plastic wrapper. CalaSSAG was not as strong as the traditional control group, it showed to be flexible, biodegradable, and made from natural materials. It offers a safer, eco-friendly choice for food packaging. Future research is advised to test the antifungal properties of calamansi in the wrapper and its real-time application. CalaSSAG shows potential in reducing plastic pollution and waste.

Keywords – CalaSSAG, Bioplastic wrapper, Calamansi powder.

I. INTRODUCTION

Food packaging, one of the best interventions to preserve food, has been widely utilized across the world—from using newspapers as a wrapper to using conventional plastics such as food containers and Tupperware. The modern generation has successfully invented packaging systems that improve food preservation, enhance convenience, and extend shelf life through using synthetic polymers. However, the environmental impact of the utilization of plastic materials has resulted in pollution, contaminating and posing threats to the natural resources such as soil, water, and air. The environmental degradation of using plastic materials results in extensive research focusing on the production of the alternatives of synthetic polymers. This research problem highlights the requirement for alternative intervention to replace synthetic polymers used in plastic packaging with organic materials to support environmental conservation and promote green technology.

Nguyen Van Long et al. (2016) reported that the Food and Agriculture Organization of the United Nations (FAO) statistical data indicate that about one- third of the produced food is lost or wasted each year because of shelf life expiring, alteration, or spoilage due to microbial activity. Annual losses range from 40-50% for fruits and vegetables, 35% for fish, 30% for cereals, and 20% for dairy and meat products. The main culprits are the presence of bacteria and fungi, oxygen- driving processes, and the presence of some enzymes. Plastic for Change (2024) stated a study published revealing that India has become the world's largest contributor to plastic pollution, accounting for nearly 20% of the total global plastic waste. With 9.3 million tonnes of plastic waste generated annually, India's contribution to this environmental catastrophe is larger than that of entire regions. Plastic waste clogs water bodies and urban drainage systems, contributing to flooding in major cities. Plastic waste also disrupts ecosystems; an estimated 80% of the marine litter along India's coastlines is plastic. Animals often ingest plastic waste, mistaking it for food, which can be fatal for marine species.

Pustadan (2022) reported that the World Bank estimates the Philippines uses an overwhelming 163 million pieces of sachets per day. A staggering 2.3 million tons of plastic waste are generated in the country annually. Unfortunately, only about 28% of key plastic resins are being recycled, while the rest are simply discarded. Additionally, Lor (2021) explained that the huge solid waste problem in the Philippines is highlighted by research conducted by Jambeck et al. in 2015, where the Philippines was ranked as one of the top contributors of marine litter in Asia, throwing 2.7 million tons of plastic waste into the sea every year. Pasig River, dubbed as one of the world's top plastic polluters, accounts for 21% of the organic waste flow to Manila Bay, 70% of which comes from households.

In Davao City, Colina IV (2020) stated that the city produces an average of 570 to 600 metric tons of plastic waste daily, according to Interfacing Development Interventions for Sustainability (IDIS). Also, Colina IV reported that IDIS executive director Chinkee P. Golle stated that while some plastics are less noticeable, such as oxo-degradable plastics designed to degrade quickly, they are still present in the environment, and they continue to build up over time and impact the health of all organisms that consume their fragments or the substances they release.

The development of antimicrobial packages is a promising path for actively controlling the bacterial and fungal proliferation that leads to food spoilage. Antimicrobial packaging has been developed using traditional fossil-based polymers or biodegradable alternatives like cellulose, starch, and chitosan in response as a solution to the increasing problem of food loss caused by microbial spoilage. However, the environmental impact of plastic materials will remain unresolved unless renewable polymers will be used to replace them (Carrascosa et al., 2021). Pillai et al. (2023) also stated that the inactivation of viruses on food packaging surfaces is important to minimize the risk of transmission. Conventional methods such as thermal treatment, ultraviolet (UV) exposure, and chemical disinfectants (e.g., ethanol, sodium hypochlorite, and hydrogen peroxide) have been widely used and applied for this purpose, but these methods often require extended time for widespread application, to maintain effectiveness, and are difficult to scale.

Moving on, Calamansi (Citrus microcarpa) is widely used and highly recognized in the Philippines where it plays an important role in culinary applications, traditional medicine, and agricultural practices. But Luyun et al. (2024) explained that a large portion of calamansi, particularly its peels, seeds, and pulp, is often discarded during processing despite its popularity. The peels, which can account for 50% to 70% of the fruit's total weight (Zema et al., 2018), are typically treated as waste, resulting in missed opportunities to utilize their potential value. Agapin and Marcelino (2024) reported regarding the utilization of calamansi peels in development of active packaging films, where essential oils extracted from calamondin peels is incorporated into the film to impart antimicrobial properties. The study confirms that the inclusion of calamondin-derived compounds is associated with enhanced functional properties of the film, including antimicrobial activity. However, they emphasize that this is an emerging area, and the scope is still narrow relative to other food packaging matrices.

Therefore, to address the problem and the gaps, this study developed an alternative bioplastic wrapper with Calamansi peel powder named "CalaSSAG", an acronym for the natural materials used in this study, specifically, the Calamansi, Starch (particularly corn starch), Sodium Alginate, and Glycerol. Chen et al. (2017), Kindangen et al. (2018), Othman et al. (2016) Ragasa et al. (2006), and Wulandari et al. (2013), as stated in the study of Pagalla et al. (2025), they explained that Lemon cui or calamansi (Citrus microcarpa) contains various chemical compounds, including flavonoids, alkaloids, polyphenols, and monoterpenoid hydrocarbons such as limonene, sabinene, citronellal, linalool, and hedycaryol. These compounds exhibit a range of biological activities, including antimicrobial, antioxidant, antibacterial, and antifeedant properties. This research study offered a sustainable and biodegradable packaging alternative with potential antimicrobial properties.

Statement of the Problem

This study aimed to determine the capability of the CalaSSAG bioplastic wrapper, particularly its mechanical properties. Specifically, it aims to answer the following questions:

1. What is the thickness of CalaSSAG bioplastic wrapper, considering the following concentrations:

- 50% extract concentrations;
- 75% extract concentrations; and
- 100% extract concentrations?

2. What is the thickness of commercially produced plastic wrapper?

3. What is the tensile strength of CalaSSAG bioplastic wrapper, considering the following concentrations:

- 50% extract concentrations;
- 75% extract concentrations; and
- 100% extract concentrations?

4. What is the tensile strength of commercially produced plastic wrapper?

5. Is there a significant difference in mean tensive strength among CalaSSAG bioplastic wrapper containing varying proportions of calamansi powder and commercially produced plastic wrapper?

Research Hypothesis

This study was tested at 0.05 level of significance.

Ho **:** There is no significant difference in mean tensive strength among CalaSSAG bioplastic wrapper containing varying proportions of calamansi powder and commercially produced plastic wrapper.

Ha **:** There is no significant difference in mean tensive strength among CalaSSAG bioplastic wrapper containing varying proportions of calamansi powder and commercially produced plastic wrapper.

Significance of the Study

This study aimed to provide an intervention and improvement in addressing environmental impact caused by using synthetic plastic materials in food packaging, as this solution offered an eco-friendly and biodegradable wrapper. This research contributed to reducing organic waste, improving the shelf life and quality of crops, and eventually enhancing food security. Also, this study minimizes spoilage that help ensure more fruits reach costumers, support farmer income, and promote sustainable agricultural practices, all of which are essential to achieving SDG 2. Consequently, the following individuals who can benefit from this study will be:

Farmers. This study helps farmers by using a biodegradable wrapper material that supports sustainability and reduces the dependency on synthetic plastics. It encourages the farmers to use local and natural wrapper that is safe for agricultural practices.

Food Packaging Manufacturers. Packaging manufacturers can benefit from this study by gaining understanding into the production of food wrappers, such as bioplastics. The results of this study can guide packaging manufacturers in producing eco-friendly packaging materials that can help lessen the environmental impact of using synthetic plastics in everyday life.

Consumers. Consumers can benefit from this study to achieve safer and fresher crops protected by natural wrapper, as they are free from toxins and chemicals. The CalaSSAG bioplastic wrapper reduces the exposure of foods to harmful chemicals that can be found in conventional plastics, as the developed bioplastic wrapper is biodegradable and derived from plant-based materials. Also, this study gives awareness about the importance of using biodegradable materials for the safety of the environment and habitat.

Department of Agriculture. The Department of Agriculture can use the findings of this study to support policies and programs regarding the use of plastics that promotes sustainable biodegradable wrapper and utilization of agricultural waste. Also, it opens the door towards new opportunities for promoting eco- friendly solutions in local industries.

Future Researchers. This study serves as a reference for future research focusing on the enhancement of bioplastic, antifungal analysis, and the utilization of agricultural residues into sustainable packaging materials. This study also allows the future researchers to further explore and discover other local materials that can enhance the properties and applications of biodegradable plastics.

Scope and Delimitation of the Study

This study focused on the development of a bioplastic wrapper from plant- based sources. The primary goal of this study was to examine the effectiveness and durability of the CalaSSAG bioplastic wrapper and to reduce the utilization of plastic wrapper for food preservation.

This study was limited to the testing of mechanical properties of the bioplastic wrapper and did not involve inhibitory testing to test the antifungal property of the wrapper neither did not involve real-world application of the utilization of the bioplastic wrapper. Also, the experiment did not include factors such as storage environments, chemical characterization of the calamansi properties, or testing the efficacy of antimicrobial property of the calamansi. The researchers conducted three (3) mixtures in controlled settings to evaluate the effectiveness and physical properties of the CalaSSAG bioplastic wrapper. Moreover, factors such as toxicity and safety evaluation of the bioplastic wrapper, long-term shelf life, long-term efficacy and environmental degradation were not part of the investigation. Additionally, the researchers did not introduce any other biopolymer to enhance the bioplastic wrapper for the testing of mechanical properties.

Definition of Terms

- **The following terms were operationally defined:**

Bioplastic wrapper refers to a thin, flexible sheet made from natural biopolymers that functions as a biodegradable packaging material.

Plastic wrapper refers to a thin, transparent plastic film used to seal and protect food and other items, typically made from petrochemical-based polymers. Sodium alginate refers to the natural polysaccharide extracted from brown seaweeds that can be used as a thickener, used in this study as the main film-forming agent in developing bioplastic wrapper.

Antifungal refers to a specific type of antimicrobial that solely targets and treats fungal infections.
Mechanical properties refer to the strength, flexibility and durability of the developed bioplastic wrapper when exposed to stress.
Tensile strength refers to the maximum stress that the bioplastic wrapper can endure before breaking when stretched.
Elongation at break refers to percentage increase in the film's length before it breaks under tension.

II. METHODS

This section presents the methodology of this study, which consists of five (5) phases: phase l – preparation of materials; phase ll – calamansi peel extraction; phase III – aqueous extraction of calamansi peel powder; phase lV – bioplastic wrapper formation procedure; phase V – evaluation and testing of parameters.

Research Design
This study used an experimental research design to develop a bioplastic wrapper. Sreekumar (2024) explains that it is a type of study in which one or more independent variables are manipulated (as the intervention or treatment) by the researcher, participants are randomly assigned to different groups (treatment or control), and the effects of these interventions on the dependent variables help determine the causality between the variables. It provides procedures for researchers to test a hypothesis and systematically and scientifically inquiry into the causal relationship between variables. According to Sreekumar (2024), she emphasized the use to establish a cause-and-effect relationship between the variables and to test hypotheses. In a typical experimental research design, the independent variables are manipulated to assess their influence on the dependent variables. It gives a guide to researchers to ensure research is effective and valid, and the questions posed by researchers are answered in an orderly way. Researchers must determine the appropriate statistical tests or techniques to use based on the nature of their data and research questions. The choice of statistical analysis procedures ensures that the data is analyzed accurately and that the results are valid and reliable (Pedersen, 2024)

In this study, we developed a bioplastic wrapper with a combination of Calamansi powder named “CalaSSAG” as a solution to replace the utilization of plastics and prevent environmental pollution that can be caused by non-biodegradable plastics. This study in experimental, as the researchers tests how durable the formulated biodegradable wrapper compared to the traditional plastic wrapper through controlled procedures. It is also quantitative since numerical data, such as the strength of the bioplastic wrapper and respective averages are measured and analyzed to evaluate its effectiveness. Using an experimental- quantitative research design allows for precise control of variables, ensuring that observed effects can be directly attributed to the biodegradable wrapper. Moreover, this design provides statistical analysis allowing researchers to make valid and reliable conclusions concerning the wrapper's potential antifungal and physical properties.

Phase l. Preparation of Materials (and their Purposes)

Materials used for the making of bioplastic wrapper were:
150 mL distilled water (for film-forming solution). Water was employed as the solvent that allowed for the dissolution and consistent mixing of the biopolymers and additives. The use of water facilitated hydrogen bonding and with the polymer dispersed equally added to a homogenous film matrix during heating. 50 mL distilled water (for powder solvent). Distilled water was chosen as a solvent because it is a safe, non-toxic, environmentally friendly solvent that extracts the water-soluble bioactive compound from the powder. With this in mind, it also allows for the powder to enter the film matrix without destroying the wrapper's quality. In addition, distilled water reduces contamination and chemical interference, ensuring discard-free extraction that maintains the quality of the extract for incorporation into the wrapper matrix. 5g Sodium Alginate. According to Guo et al. (2023 as cited by Kim et al., 2024), sodium alginate is derived from sargassum brown seaweed or algae, and is a hydrophilic biopolymer that naturally possesses a high affinity for water. Amariei et al. (2022, as cited by Kim et al., 2024) stated that sodium alginate is hydrophilic and this particular nature allows the plastic wrap material/bioplastic film to absorb moisture, improving the potential for antifungal effects.

5g of Glycerol. The interaction of glycerol with biopolymer chains is caused by the formation of intermolecular hydrogen bonds that disrupt strong intermolecular bonds between the biopolymer chains, allowing for greater molecular movement, leading to a more flexible, homogeneous wrapper that is easier to peel. Pelissari et al. (2009) reported, in citing of Tarique et.al. (2021), that starch-based films are inherently brittle and hydrophilic which limits their mechanical and barrier properties. The addition of plasticizers, such as glycerol, can minimize these limitations, and glycerol is preferred for its compatibility with amylose. The addition of glycerol made them flexible because its small molecules are able to penetrate the polymer chains, weakening their intermolecular forces.

Coconut oil (Optional). In this study conducted by by Indumathi and Manjupriya (2024), coconut oil was used solely as a non-stick agent, applied to the molders with very little amount to ensure the cooled paste could be spread without adhering to the surface.

Calamansi powder. Calamansi powder is not essential in making bioplastic, but it performs antimicrobial properties that would help enhances the performance of the packaging film. Pagalla et al. (2025) stated that calamansi contains a diverse array of chemical constituents such as flavonoids, alkaloids, polyphenols, and monoterpenoid hydrocarbons like limonene, sabinene, citronellal, linalool, and hedycaryol, all of which are associated with various biological activities. In this study, the total solids of the base film formulation (sodium alginate, cornstarch, and glycerol) amounted to 11 g. Calamansi peel powder was incorporated at 50%, 75%, and 100 % relative to the total solids, corresponding to 5.50 g, 8.25 g, and 11.00g of powder per 150 mL film-forming solution, respectively.

Phase II. Calamansi Peel Extraction
Indumathi and Manjupriya (2024) underlines the process of extracting peel into powder and involves the process of obtaining the dried and powdered form, which is frequently utilized for various culinary and medicinal purposes. Similarly, Yang and De Jesus (2024) provided below the steps on how to extract calamansi peel powder.

Preparation of the fruits
Calamansi fruits were collected from Agdao Public Market in Davao City, Philippines for the preparation of calamansi peels.

Sorting and Cleaning the peels
Calamansi fruits were inspected for dirt, black dots, and peel defects. Any fruits showing signs of decay, bruising, mold, or other defects that could affect food quality and safety were sorted out and discarded. To remove all debris, dirt, and black dots, the remaining fruits were thoroughly cleaned and washed under cold tap water, and the peels were scrubbed.

Sanitizing the fruits
Fruit surfaces may have contained foodborne pathogens. To reduce the number of pathogens, the fruits were sanitized. A sanitizing solution containing 200 ppm chlorine was prepared by adding 2 teaspoons of bleach to one gallon of water. The fruits were then soaked in the solution for 3 minutes. They were patted dry using a clean kitchen towel or paper towels.

Cutting and Removing Juice and Seeds of Fruits
Drying whole calamansi fruits was found to be inefficient for moisture removal. To reduce dehydration time, the fruits were cut in half across the middle. Since calamansi seeds contain bitter compounds that negatively impact the sensory quality of the final product, they were removed from the halved fruits using a small knife or a similar tool before drying.

Drying the peels
According to the study conducted by Yang and De Jesus (2021), a food dehydrator is ideal for drying the calamansi fruit. However, they also mention that using an oven is another option to dry foods at home. Since the oven has no built- in fan for air movement, the drying process is relatively slow, inefficient, and consumes more power than a food dehydrator. We placed the halved calamansi in a single layer on the trays of the oven. The temperature was set at 60°C (140°F), and the fruit was dried for at least 18 hours until no moist areas remained in the center. The oven door was left open 2–6 inches to allow moisture to escape during the drying process. The dried pieces of calamansi appeared shrunken, but the color remained. The dried calamansi produced a “snap” sound when broken. The dried calamansi was cooled for 30–60 minutes.

Grinding the peels
Once dried, the peels were removed from the oven and allowed to cool. Before grinding, the dried pieces of calamansi were inspected. A blender was utilized to transform the peels into a fine powder. Categorization was done in order to proceed in the process of blending. Subsequently, mixtures were then blended by batch based on quantity and equipment capacity.

Sifting the powder
The powder was sifted through a sieve or fine mesh strainer to remove coarse particles. The resulting fine powder was transferred to an airtight container for storage. Storage was done in a cool, dark location, away from moisture and direct sunlight.

Preservation of the powder
After milling, calamansi powder was immediately packaged to prevent moisture absorption, especially in humid tropical climates. Food-grade, FDA- approved materials including glass jars, ceramic containers, plastic freezer bags, and polyethylene bags were used. All containers were thoroughly cleaned and sanitized prior to packaging. After filling, containers were tightly sealed to prevent contamination and insect infestation. After that, to sustain the quality of dried calamansi powder, it was kept in a cool, dry, and dark environment to. Exposure to heat, light, and moisture led to deterioration in texture, color, flavor, nutritional value, and overall functionality. Yang and De Jesus (2024) stated that when stored at room temperature (approximately 24 °C or 74 °F), the powder remained stable for up to three months. However, storing it in the refrigerator at 4 °C (40 °F) extended its shelf life to around six months.

Phase III. Aqueous Extraction of Calamansi Peel Powder
In this phase, aqueous extraction was carried out to obtain water-soluble bioactive compounds from dried calamansi peel powder using distilled water as the solvent and to minimize the effect of powder (grainy or brittle) in films. The following is a step-by-step procedure adapted from Liu et al. (2021) for extracting bioactive compounds from calamansi peel powder using water as the solvent, with slight adjustments, alteration and addition:

Weighing of the Powder
The base film formulation used in this study, which included sodium alginate, gelatin, cornstarch, and glycerol, contained a total of 11 g of solids. Calamansi peel powder was incorporated at concentrations of 50%, 75%, and 100% relative to the total ingredient content in terms of grams. These levels corresponded to 5.50 g, 8.25 g, and 11.00 g of powder per 150 mL of film-forming solution, respectively. Each amount of dried calamansi peel powder was precisely measured using an electronic scale before being added to the mixture.

Addition of Distilled Water as a Solvent
The different grams of dried calamansi peel powder were placed in a beaker and mixed with 50 mL of distilled in a heat-resistant glass flask.

Heating and Stirring
A magnetic stirrer was used to maintain gentle and uniform heat during the extraction process as an alternative to a shaking water bath. A heat-resistant flask containing the sample and solvent was partially placed in a magnetic stirrer. The temperature was set and maintained at 60 °C throughout the extraction. A magnetic stir bar was placed inside the flask, and continuous stirring was applied using a magnetic stirrer to

ensure homogeneous mixing and efficient extraction. The extraction was carried out for at least 2 hours under these conditions. Three aqueous extracts of calamansi peel were prepared by varying the amount of peel powder while keeping the extraction water constant at 50 mL. The treatments corresponded to 50% (5.50 g/50 mL), 75% (8.25 g/50 mL), and 100% (11.00 g/50 mL). These ratios represent increasing concentrations of bioactive compounds based on peel-loading (g peel per 50 mL water).

Filtration of the Mixture

The mixture was filtered through the utilization of mesh strainer to remove the large particles in the powder.

Storage (Optional)

In this study, the extract was used immediately for the preparation of the film-forming solution. However, a portion of the extract was stored in a transparent reagent bottle and refrigerated for future use to minimize the risk of contamination and mold growth.

Phase IV. Bioplastic Wrapper Formation Procedure

This phase consisted of five (5) sub-phases for the procedure of bioplastic wrapper formation, some were adjusted and with slight alterations. Sub-phasesand 4.5 adapted the procedures by Indumathi and Manjupriya (2024) for preparing a solution used in forming a biodegradable wrapper.

Making of Film-Forming Solution

A total of 150 mL of liquid ingredient was placed in an electric laboratory heater at 70°C and heated over a low flame. Once warmed, 5 g sodium alginate were added, and the mixture was stirred gently. After reaching a uniform consistency, 5 g glycerol and 1 g corn starch were incorporated. Stirring continued until a semi-solid consistency was achieved. The resulting solution was then cooled to room temperature in preparation for the subphase 4.2.

Preparation and Addition of Different Concentrations of the Powder

This sub-phase addressed the second research problem. The researchers prepared various concentrations to evaluate the durability of the bioplastic wrapper with different calamansi extract added on the film matrix. Three (3) different mixtures were conducted, with the following concentration:

Concentration	Water used as a solvent
Mixture 1 (50%)	50mL + 5.50g powder
Mixture 2 (75%)	50mL + 8.25g powder
Mixture 3 (100%)	50mL + 11g powder

The water and the extract were separated to prevent the loss of bioactive compounds during the heating process. The polymers were first dissolved in hot distilled water to ensure complete solubilization, and the extract was added after cooling to 40-45°C.

Spreading the Solution

Once cooled and settled, the film-forming solution was poured into clean, flat casting molders. The mixture was spread evenly to ensure consistent the wrapper's thickness.

Film Formation and Drying

The trays were placed in an electric oven and dried at 60 °C below for 8 hours. This method allowed for even heating and efficient solvent evaporation and solidified the solution into flexible bioplastic films. Also, to avoid the risk of being contaminated by molds, as the solution is high in moisture.

Final Bioplastic wrapper material

After drying, the bioplastic wrapper was carefully removed from the trays and cut into uniform sheets with clean, finished edges using spatula. The final sheets were then stored and prepared for use in packaging applications, such as wrapping food items in roll or sheet form.

Phase V. Evaluation and Testing of Parameters

The thickness test was performed at TERMS Concrete and Materials, Testing Laboratory Inc. at Talomo, Davao City. The researchers calculated the tensile strength and elongation at break through a set-up called Hanging Weight Method. A spring balance is defined as a device used for mass measurement that operates by suspending a mass on a spring, with the deflection of the spring due to gravitational force measured against a scale. While it is typically inexpensive and simple, its measurement accuracy can be affected by environmental changes unless compensatory adjustments are made (Morris & Langari, 2020). Below is a step-by-step procedure on how the researchers conducted this method.

- Rectangular strips were cut from each film sample. The researchers cut the films to 60 cm in length and 10 cm in width.
- The thickness of each bioplastic film was measured and recorded.
- The top end of the film strip was fixed to a stable support using a clamp, ensuring that the strip hung vertically and straight.
- The hook of the spring balance was attached to the free end of the film specimen. The balance was positioned so that it hung freely without touching any surface. In some cases, known masses (such as soil and rocks) were added gradually to apply increasing force.
- The load was slowly increased by pulling the spring balance or by adding masses until the film broke. The maximum force at break (Fmax) was recorded from the spring balance (in newtons, N) or calculated from the total hanging mass using $F = m \times g$.

- The specimen dimensions were converted to meters for stress calculation.

The width (m) and thickness (m) were used to determine the cross-
sectional area:

$A = width \times thickness$ (m^2)

Where width and thickness were expressed as meters.

- The tensile strength was calculated using the formula:

$$Tensile\ Strength = \frac{F_{max}}{A}\ (\text{Pa})$$

- The obtained values were divided by 106 to convert pascals (Pa) into megapascals (MPa).

Waste Disposal
To ensure safety and prevent contamination, the researchers carefully collected and placed all damaged materials, debris, and dust in a properly labeled biohazard container. The sealed container was then sent off to the Material Recovery Facility (MRF) of Barangay 28-C, Davao City, for proper disposal and management in accordance with local waste protocols. Meanwhile, to promote sustainability throughout the course of the study, usable materials left were segregated and recycled.

Statistical Test
The statistical tests were used to analyze the data were the following:
Percentage. This was used to determine the proportion or rate of certain film characteristics of the bioplastic wrapper across different concentrations of calamansi peel powder.
F-test. This was used to compare the control film and the CalaSSAG bioplastic wrapper incorporated with calamansi peel powder to determine whether there is a significant difference in their physical properties.

III. RESULTS

This section presents the findings and discussion based on the data gathered. The presentation is organized into three (3) parts: 1) the capability of the CalaSSAG bioplastic wrapper formulated with calamansi peel powder, sodium alginate, corn starch, and glycerol when tested in terms of thickness and tensile strength; 2) the test result of the traditional plastic wrapper in terms of the same parameters; and 3) the significant difference between the quality of the CalaSSAG bioplastic wrapper and the traditional plastic wrapper.

Testing of Thickness
Presented in Table 1.1 are the results of thickness per mixtures and their mean values of the CalaSSAG bioplastic wrapper. On the other hand, the thickness of the traditional plastic wrapper was presented in Table 1.2.

Table 1.1 Thickness of CalaSSAG Bioplastic Wrapper

SAMPLE	**Replicate 1**	**Replicate 2**	**Replicate 3**	**Mean**
Mixture1 (50%)	0.95mm	0.56mm	0.41mm	0.64mm
Mixture 2 (75%)	0.33mm	0.65mm	0.86mm	0.61mm
Mixture 3 (100%)	1.42mm	1.14mm	1.24mm	1.26mm

Based on the data presented in Table 1.1, the thickness of the CalaSSAG bioplastic wrapper varied among the three mixtures with different concentrations of calamansi peel powder. Mixture 3 (100%) exhibited the greatest mean thickness of 1.26 mm, followed by Mixture 1 (50%) with 0.64 mm, and Mixture 2 (75%) with 0.61 mm.

Table 1.2 Thickness of Commercially Produced Plastic Wrapper

Sample	Replicate 1	Replicate 2	Replicate 3	Mean
Control (Plastic Wrapper)	0.03 Mm	0.04mm	0.03mm	0.03mm

Based on the data presented in Table 1.2, the thickness of the control (traditional plastic wrapper) had a much thinner thickness of 0.03 mm compared to the thickness of the CalaSSAG bioplastic wrapper. The control obtained a mean of 0.03mm.

Testing of Tensile Strength
Presented in Table 2.1 are the results of tensile strength per mixtures and their mean values of the CalaSSAG bioplastic wrapper. On the other hand, the tensile strength of the traditional plastic wrapper was presented in Table 2.2.

Table 2.1 Tensile Strength of CalaSSAG Bioplastic Wrapper per mixture

Sample	Replicate	$\boldsymbol{Fmax\ (N)}$	Width	Length	Tensile Strength (MPa)
	1	10.0 N	0.10m	50 cm	0.105 MPa
Mixture 1 50%	2	9.4 N	0.10m	50 cm	0.168 MPa
	3	9.1 N	0.10m	50 cm	0.222 MPa
Mixture 2 75%	1	8.9 N	0.10m	50 cm	0.270 MPa
	2	7.2 N	0.10m	50 cm	0.111 MPa
	3	6.9 N	0.10m	50 cm	0.080 MPa

	1	5.1 N	0.10m	50 cm	0.036 MPa
Mixture 3 100%	2	5.4 N	0.10m	50cm	0.047 MPa
	3	12 N	0.10m	50 cm	0.097 MPa

Based on the Table 2.1, Mixture 1 (50% calamansi peel powder) showed the highest mean tensile strength of 0.165 MPa, followed by Mixture 2 (75%) at
0.154 MPa, and Mixture 3 (100%) obtained the lowest mean tensile strength at 0.060 MPa.

Table 2.2 Tensile Strength of Commercially Produced Plastic Wrapper

	Replicate	$Fmax\ (N)$	Width	Length	Tensile Strength (MPa)
Control	1	10 N	0.10 m	50 cm	3.33 MPa
(Plastic Wrapper)	2	8.2 N	0.10 m	50cm	2.73 MPa
	3	8.3 N	0.10 m	50cm	2.77 MPa

Based on the Table 2.2, the control (traditional film) exhibited the highest tensile strength of 3.33 MPa compared to the bioplastic.

Comparative Statistical Analysis

An F-test was used to determine through the certification of Microsoft Excel whether the observed differences among the three formulations of the CalaSSAG bioplastic wrapper Mixtures 1 (50% calamansi peel powder), 2 (75%), and 3 (100%) were statistically significant. The F-test was applied to the data on thickness and tensile strength at a 0.05 level of significance to assess whether varying the concentration of calamansi peel powder produced a significant effect on the mechanical properties of the developed bioplastic wrapper. The

Table 3.1 presents the results of F-test in independent means.

Table 3.1 F-test of Independent Means					
Source	Sum of Squares (SS)	df	Mean Square (MS)	F-value	Decision
Mixtures	17.8762	3	5.9587	187.07	Not significant
Residuals	0.2548	8	0.0319	-	-

Based on the F-test results in Table 3.1, the computed F-value of 187.07 exceeded the critical F-value at a 0.05 level of significance, indicating a significant difference in the mean tensile strength among the CalaSSAG bioplastic wrappers and the traditional plastic wrapper. The Dunnett's post-hoc test showed that the mean tensile strengths of Mixture 1 (50%), Mixture 2 (75%), and Mixture 3 (100%) were all significantly lower than that of the traditional plastic film.

Table 3.2 Tensile Strength Comparison

Comparison	Difference	95% Lower Cl	95% Upper Cl	p-value	Significance
Mixture 1	-2.77833	-3.198196	-2.358470	2.8e-12	***
Mixture 2	-2.789667	-3.209530	-2.369804	9.5e-10	***
Mixture 3	-2.883333	-3.303916	-2.463470	8.3e-12	***

Based on the Dunnett's post-hoc test results presented in Table 3.2, all CalaSSAG bioplastic mixtures had significantly lower tensile strength compared to the traditional plastic wrapper. Mixture 1 (50%), Mixture 2 (75%), and Mixture 3 (100%) showed mean differences of –2.778 MPa, –2.790 MPa, and –2.883 MPa, respectively, with p-values less than 0.05 ($p = 2.8 \times 10^{-12}$, 9.5×10^{-10}, and 8.3×10^{-12}). The 95% confidence intervals for all comparisons did not include zero.

IV. DISCUSSION

The results of the CalaSSAG bioplastic wrapper prepared with different concentrations of calamansi peel powder showed important results. Although measurable differences in thickness, tensile strength, and elongation at break were observed in the three concentrations (50%, 75%, and 100%) of calamansi extract, the F-test at the .05 significance level established that these differences were insignificant, suggesting that the varying calamansi concentration does have an impact on the mechanical properties of the bioplastic wrapper.

The results indicated differences in thickness for the CalaSSAG bioplastic wrapper for the three concentrations of calamansi peel powder mixtures. Mixture 3 (100%) produced the highest average thickness at 1.26 mm, followed by Mixture 1 (50%) at 0.64 mm, and Mixture 2 (75%) at 0.61 mm. The thickness results demonstrate that thickness was greatest when using Mixture 3 because with the increase in calamansi peel powder extract concentration, the thickness of the bioplastic film increased, which suggests an increase in structure density and an increase in compactness. The number of solids found in the 100% concentration possibly contributed to the thicker and consistent matrix, providing strength and protection for the bioplastic film.

However, the thickness of the control (traditional plastic wrapper) had a much thinner thickness compared to the thickness of the CalaSSAG bioplastic wrapper, as the control obtained a mean of 0.03mm. This can be implied that traditional plastic wrappers are more stretchable compared to the CalaSSAG bioplastic wrapper. Iheanacho (2024) commented that this variation in thickness and films consisting of bioplastics is a normal outcome and can be caused by the manner of measurement, material differences, and processing parameters.

Moreover, Jayalath et al. (2024) and Dodino-Duartea et al. (2024) also noted that comparisons of starch films produced from cassava and other starch sources found that just a small variation in the formulation could result in non-linear shifts in the thickness of films. In some formulations, increasing levels of ingredients resulted in thicker films, while in other cases, the influence decreased or became inconsistent due to interaction effects during processing.

Moving on, in the tensile strength test, the results indicate that tensile strength among CalaSSAG bioplastic wrappers differed between the three mixtures varying in the percentage of calamansi peel powder. Mixture 1 (50%) had the greatest mean tensile strength value of 0.165 MPa, followed by Mixture 2 (75%), which had a tensile strength of 0.154 MPa, with Mixture 3 (100%) having a value of 0.060 MPa.

On the other side, is notable that the control (plastic film) had a much high tensile strength mean value of 2.94 MPa in comparison to all other CalaSSAG bioplastic wrappers, regardless of calamansi peel powder percentage. This implies that the traditional plastic wrapper is more durable compared to the CalaSSAG bioplastic wrapper. This shows all the treatments using CalaSSAG bioplastic wrappers had significantly less tensile strength compared to the control. Similar to the findings conducted by Amariei et al. (2022), they explained an antimicrobial agent could reduce mechanical strength of the films while enhancing the antimicrobial property. This is reiterated by Kim et al. (2024) when we noted that sodium alginate composite films consistently had less tensile strength (TS) and higher water vapor permeability (WVP) than conventional films.

The downward trend in tensile strength as calamansi peel powder concentration increased suggests that further increasing solid content (above 50%) may break down the structural cohesion of the bioplastic matrix. F-test indicated a significant difference in tensile strength of bioplastic wrappers compared to traditional plastic film (F-value of 187.07 > critical F, 0.05 significance level). Further, Dunnett's post-hoc test indicated that Mixture 1, Mixture 2, and Mixture 3 significantly differed from traditional film with a mean difference of -2.778 MPa, -2.790 MPa and -2.883 MPa (p-value < 0.05). The 95% confidence interval for all pairwise comparisons did not contain zero, indicating the differences were significant.

Overall, these results indicate that although the CalaSSAG wrappers are biodegradable/environmentally friendly, they do not have the mechanical strength to rival conventional plastic materials, in terms of tensile durability. Gabriel et al., (2021) indicated in their work that bioplastics in general have lower tensile strength (TS) than conventional plastics. The results of this study also suggest that formulation changes, including calamansi peel powder concentration, affect tensile properties. This is consistent with previous research showing that small changes to bioplastic formulation can have nonlinear effects on film.

V. CONCLUSIONS AND RECOMMENDATIONS

This section presents the conclusions that were drawn out of the findings of the study. This section further offers recommendations as to how the findings of this study can improve practice.

Conclusions

The researcher made the following conclusions based on the study's findings:

1. The development and assessment of the CalaSSAG bioplastic wrapper has proven that a blend of varying calamansi peel powder ratios (50%, 75%, and 100%) along with sodium alginate, corn starch and glycerol is an appropriate alternative to non-biodegradable packaging, with the 100% calamansi blend demonstrating the highest mean thickness of 1.26 mm, which suggests that higher solid content increases film compactness and density. Meanwhile, the 50% blend demonstrated the highest mean tensile strength of 0.165 MPa.

2. The thickness of the traditional plastic wrapper had a much thinner measurement compared to the thickness of the CalaSSAG bioplastic wrapper. The traditional plastic wrapper obtained a mean of 0.03mm. This can be implied that traditional plastic wrappers are more stretchable compared to the CalaSSAG bioplastic wrapper.

3. Out of the three blends that were developed, Mixture 1 (50%) had the highest tensile strength, which implies that too much calamansi powder or any materials that cannot contribute to the formation of film matrix may inhibit polymer interactions within the film matrix. However, all

three blends were capable of film formation and were flexible enough for handling, demonstrating that it is possible to use plants as substitutes for a more environmentally friendly packaging option.

4. The control (plastic film) had a much high tensile strength mean value of 2.94 MPa in comparison to all other CalaSSAG bioplastic wrappers, regardless of calamansi peel powder percentage, implying that the traditional plastic wrapper is more durable compared to the CalaSSAG bioplastic wrapper. The results show all the treatments using CalaSSAG bioplastic wrappers had significantly less tensile strength compared to the control.

5. An F-test conducted at the 0.05 level of significance concluded that the CalaSSAG bioplastic wrapper held a significantly lower tensile strength but the regular plastic wrapper ($p < 0.05$). This confirms that the films developed to be biodegradable and environmentally friendly, however, they are lower in strength, indicating improvements in the formulations are still necessary; durability can still be developed and sustainable options maintained; thus, the results do suggest CalaSSAG bioplastic is a promising, although limited, alternative.

Recommendations

Considering the findings and study limitations, these recommendations are offered:

1. Enhance the bioplastic film formulation utilizing biopolymers from agricultural wastes/residues, such as chitosan and cellulose, that better improve consistency and flexibility.
2. Carry out antifungal tests using standardized methods, like the disk diffusion method, to establish the possible extent of antifungal properties while retaining its biodegradability.
3. Investigate other fruit waste with potential antimicrobials properties to improve the activities and bioactive properties while retaining its biodegradability.
4. Consider approaching a material laboratory to assess the mechanical properties of the bioplastic beyond tensile strength and add the barrier properties to obtain results of quality.

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