

Innovative Bioplastic Packaging Solutions Using Potato Starch, Origanum syriacum, and Cymbopogon winterianus

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Abstract: This thesis investigates the potential of potato starch, *Origanum syriacum*, and *Cymbopogon winterianus* for developing bioplastic materials that aim to the environmental and health risks associated with conventional plastic food packaging. The study focuses on formulating starch-based bioplastics enriched with natural plant extracts that provide antimicrobial activity, thereby enhancing food safety and extending shelf life. The resulting bioplastics exhibited tensile strength when compared to traditional plastics, stable pH values, reduced water solubility, and clear antimicrobial inhibition zones against *E. coli*, *P. aeruginosa*, *S. aureus*, and *C. kefyr*. They also demonstrated strong biodegradability, decomposing in soil within eight days. Overall, the findings highlight the promise of potato starch-based bioplastics as sustainable packaging materials that improve food protection while supporting global environmental goals and promoting responsible consumption.

Keywords: Bioplastic, potato starch, *Origanum syriacum*, *Cymbopogon winterianus*, plastic food packaging.

1- Introduction

Growing concern over the health and environmental impacts of plastic food packaging has drawn attention due to its harmful effects. Although plastics are inexpensive and convenient, they pose notable health risks due to chemical leaching, especially at high temperatures and contribute significantly to environmental pollution (Zeineddine et al., 2021). Compounds such as phthalates, BPA, and PFAS can migrate into food, leading to various health issues including obesity, asthma, reduced fertility, and cancer (Seewoo et al., 2023; Lebelo et al., 2021). Furthermore, discarded plastics degrade into microplastics that enter the food chain, threatening ecosystems and human well-being.

As public awareness increases, same does the demand for safer and more sustainable alternatives. Bioplastics derived from renewable sources, such as potato starch, present a promising solution. These materials can be enhanced with natural additives such as *Origanum syriacum* and *Cymbopogon winterianus*, which improve flexibility, antimicrobial activity, and food shelf-life. The biodegradable packaging not only reduces pollution but also supports circular economy principles. However, challenges remain, including material variability, high water absorbency, and processing limitations.

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2- Materials and Methods

All experiments were conducted in the Food Sciences and Technology laboratories at the Lebanese University. Each procedure was performed in multiple replicates to ensure reliability and accuracy. Repetition allowed for consistent measurements, and final results were expressed as averages for improved representation.

2.1 Preparation of bioplastic film

Bioplastic films were formulated using potato starch, glycerol, *Origanum syriacum*, *Cymbopogon winterianus* (lemongrass) and gelatin. Potato starch was selected for its biodegradability, low cost, and high compatibility with biopolymer systems. Glycerol enhanced the film's flexibility and microbial interactions. Extracts of *O. syriacum* and *C. winterianus* were incorporated for their antioxidant and antimicrobial properties, which contribute to extending food shelf life. Gelatin was added to enhance mechanical strength and structural integrity.

2.2 Preparation of leaf extract

The healthy leaves of *O. syriacum* and *C. winterianus* were picked and cleaned with clean tap water to eliminate dust particles. About 50 g of leaves were soaked in 500 ml of distilled water for 2 h. The soaked contents were allowed to cool and filtered through a typical kitchen filter to remove all debris.

2.3 Blend preparation and Bioplastics development

Hydrate 20 g of gelatin in 60 ml of distilled water for 10 min. Put 5 g of potato starch and dissolve it in a 500 ml casserole of plant extract and simmer till the temperature get 90 °C. Reduce the heat, add 5 ml of glycerol and the hydrated gelatin and kept on the magnetic stirrer to reach 90°C temperature (Kandasamy & Devarayan,).

The hot mixture was poured into silicone molds in a thin, uniform layer and left to dry at room temperature for 48 hours. After drying, the bioplastic sheets were carefully unmolded and cut into the desired shapes. The pieces were then assembled and sealed into bag form using an impulse heat-sealing machine, resulting in fully formed bioplastic packaging suitable for food products.

3- Tests and properties

3.1 Film moisture content (MC)

Moisture content was determined following the method described by Jumaidin et al. (2017). Three samples from each bioplastic film were dried in a hot-air oven at 105°C for 24 hours. Each sample was weighed before drying (W_1 , g) and after drying (W_2 , g). Moisture content was calculated using the following equation:

$$MC (\%) = MC^{(\%)} = \left(\frac{W_1 - W_2}{W_1} \right) \times 100$$

This measurement allowed for the assessment of water retention within the films, an important parameter influencing their mechanical strength, flexibility, and storage stability.

3.2 Film Thickness

Using calipers, the thickness of the bioplastic was measured in accordance with the following procedure. The samples were put between the caliper's jaws, and the thickness was measured five times before the average was determined (Turhan & Şahbaz, 2003).

3.3 Film Solubility

Two samples of 1 g each, were taken from each film to determine the solubility of films and dehydrated for 24 h using an oven at a temperature of 105 °C to measure initial dry matter of every film (W_i). The samples were later dipped in a beaker containing 30 mL of distilled water at temperature 23 ± 2 °C for the time period of 24 h with continuous stirring. The insoluble fraction of film sample was separated from the solution, dried at 105 °C for 24 h and weighed to get (W_0)

g which was used in calculating soluble matter percent representing samples water-solubility given

by Equation shown below (Abotbina et al., 2021) :Solubility (%) = $\left(\frac{W_i - W_0}{W_i} \right) \times 100$

3.4 Tensile test

Bioplastic film samples were prepared according to standard dimensions, with a width of 30 mm, length of 110 mm, and an average thickness of 0.36 mm. Dumbbell-shaped specimens were cut from the films, with five specimens tested per formulation. Tensile strength (MPa) was measured during stretching using a universal testing machine, and the mechanical properties were reported as the average of the five measurements (M. K. Marichelvam et al., 2019). All tensile tests were conducted in the AUB laboratory.

3.5 Biodegradability Test

Biodegradability of the films was evaluated by burying four 1 g samples in topsoil at a depth of approximately 7.5 cm. The films were cut into small strips and buried to simulate natural soil conditions. Samples were retrieved at 2-day intervals over 8 days for analysis. Biodegradation was assessed based on mass reduction of the specimens over time, using the following equation:

Equation 1: *Weight Loss (%) = $[(W_0 - W)/W_0] \times 100$, where W_0 and W are the weights of samples before and after the test.*

This method allows for evaluating the rate and extent of natural decomposition of bioplastic films under soil conditions.

(Jeyasubramanian, K. Balachander,R., 2016)

3.6 Antimicrobial Activity test

The antimicrobial activity of the potato peel based-bioplastic samples (P0 and P1; where P0 refers to potato peel based-bioplastic samples without plant extracts and P1 refers to potato peel based-bioplastic samples with plant extracts) was evaluated using the disc diffusion method against three bacterial species (*E. coli*, *P. aeruginosa*, and *S. aureus*) and a yeast (*C. kefyr*). 100 µl of freshly prepared bacterial/yeast suspension (0.5 McFarland) was added and spread evenly on the Mueller-

Hinton agar (MHA) plate. Then, the bioplastics discs (P1 and P2) and a negative control (plastic pot) of equal diameters (6 mm) were positioned on the surface of the MHA plate. After that, the plates were incubated at 37°C for 24 h for the bacteria and at 30°C for 48 h, and for the yeast, respectively. Tetracycline (250 µg/ml) and fluconazole (250 µg/ml) were used as reference antibiotic and reference antifungal agent, respectively (positive controls). After incubation, the diameter of the clear zone of inhibition surrounding the discs was measured (Nasution et al., 2023). Each zone of inhibition of a diameter greater than 7 mm was considered as a positive inhibition result (Vasireddy et al., 2018). This test was conducted in triplicate and the diameter of the zone of inhibition was measured in millimeters and expressed as mean±SEM.

4- Results

4.1 moisture content

The moisture content can be influenced by several factors, including the type of starch used, the presence of additives, and the processing conditions (e.g., drying temperature and time). It's shown that the sample 1 (with plant) presents the least water absorption, however, sample 2 in the 2 replications have showed highest moisture content. The low moisture content <10% shows that there is low chance of microbial development and that the bioplastic films are stable. From this, we can say that the bioplastic with plant extract is the best and beneficial for food packing since it extends the shelf life and maintains the quality of food (Azmin et al., 2022).

Table 1: Moisture content in percentage for samples with and without plant extracts

Samples	Replications	Moisture content in percentage
	R1	2%

Sample 1 with plant extracts	R2	3%
Sample 2 Without plant extracts	R1	6%
	R2	5%

4. 2 Thickness test

Previous studies have reported that starch–gelatin bioplastics typically have a thickness ranging from 0.07 to 0.33 mm, with higher starch concentrations producing thicker films due to increased viscosity of the film-forming solution (Susilawati et al., 2019). In this study, the measured thickness of the bioplastic films was approximately 0.11 mm (Fig. 5), which is well within the acceptable range for food packaging applications. (figure 1)



Figure 1: Thickness measurement for starch–gelatin bioplastics typically

4.3 solubility test

Biodegradable films made from native and oxidized potato starch generally exhibit low solubility (<10%), enhancing their stability and water resistance (Fonseca et al., 2018). This property is

crucial for food packaging, where exposure to moisture is common (Oluwasina et al., 2021). As shown in Table 3, all tested bioplastic samples had solubility below 10%, indicating excellent water resistance. Among the samples, S2 (incorporating plant extracts) showed the lowest solubility, making it the optimal choice for applications requiring superior moisture barrier properties.

Table 2: Solubility percentage for samples with and without plant extracts

Samples	Replicated	Solubility (%)
S1 Without plant extracts	R1	2
	R2	3
S2 With plant extracts	R1	3
	R2	1

4.4 Tensile test

Table 3: Tensile stress and extension for samples with and without plant extracts

Samples	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Tensile extension at Maximum Load [mm]	Modulus (Automatic) [MPa]
S1	6.26184	1.55767	0.66165	27.12765	4.3263

Without plant extracts					
S 2 with plant extracts	5.48301	1.89069	0.56416	22.56637	6.72051

The tensile properties of the bioplastic samples are summarized in Table 4. Sample S1 (without plant extracts) exhibited higher maximum load and tensile strain but lower tensile stress and modulus compared to Sample S2 (with plant extracts). In contrast, S2 displayed increased stiffness and higher tensile stress at maximum load, suggesting that the incorporation of plant extracts enhances both the mechanical strength and rigidity of the bioplastic films. This indicates that the addition of natural extracts not only improves functional properties such as antimicrobial activity but also contributes to the structural performance of the material.

4.5 biodegradability test

Table 4: Biodegradability for samples with and without plant extracts

Samples	Day 0	Day 2	Day 4	Day 6	Day 8
Sample 1 Without plant	1.04g	0.92	0.53	0.21	0.1
Replicated	1.04g	0.89	0.61	0.19	0g
Sample 2 With plant	1.04g	0.90	0.51	0.14	0
Replicated	1.04g	0.87	0.47	0.12g	0g
Bioplastic bag (control)	1.04g	1.04g	1.04g	1.04g	1.04g

The biodegradability of the bioplastic films was monitored over an 8-day period, with samples showing a gradual reduction in weight every two days. By the 6th day, 80–90% of the films had degraded, with samples containing plant extracts decomposing more rapidly. By the 8th day, all films were completely degraded, demonstrating full biodegradability. The accelerated degradation of the films is attributed to the action of soil microbes and the presence of higher glycerol concentrations, which enhance microbial accessibility. Environmental factors such as soil pH, temperature, humidity, oxygen availability, and microbial diversity also play critical roles in the degradation process. Overall, the bioplastics showed 100% weight loss by day 8, confirming their potential as fully biodegradable packaging materials

4.6 Anti- antimicrobial test

Table: Mean diameter of zone of inhibition for potato peel based-bioplastic samples (incorporated with and without plant extract) against various microorganisms represented as mean±SEM

Mean diameters of zones of inhibition (mm)				
Sample Microorganism	P0	P1	Positive control	Negative control
<i>E. coli</i>	10.36±0.16	12.52±0.22	19.06±0.26	-
<i>P. aeruginosa</i>	-	10.98±0.16	16.50±0.27	-
<i>S. aureus</i>	-	11.48±0.32	12.19±0.04	-
<i>C. kefyr</i>	-	30.77±1.00	35.23±1.31	-

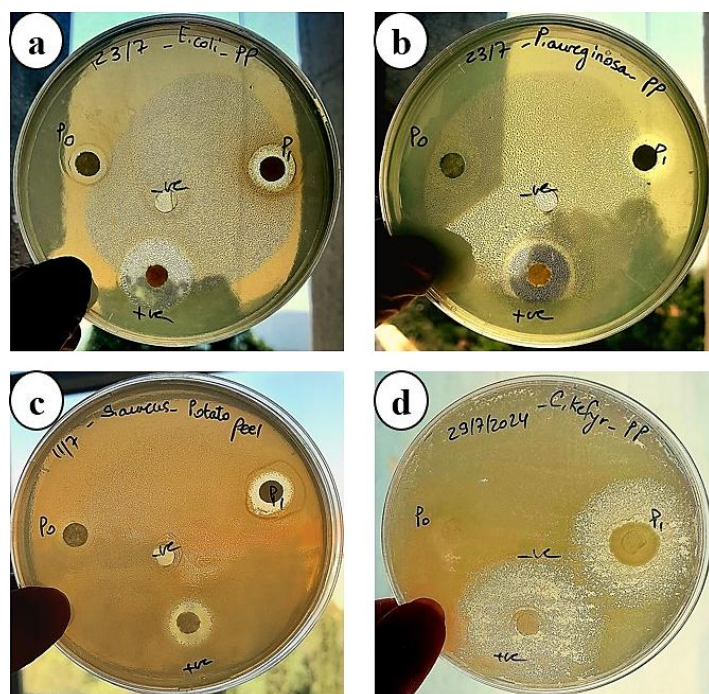


Figure 2: Antimicrobial activity of potato peel based-bioplastic samples (incorporated with and without plant extract) against a) *E. coli*, b) *P. aeruginosa*, c) *S. aureus*, and d) *C. kefir*.

The results show that both tested samples (P0 and P1) exhibit antimicrobial activity, but their effectiveness varies depending on the microorganism. For *E. coli*, P1 (12.52 ± 0.22 mm) demonstrates a stronger inhibitory effect than P0 (10.36 ± 0.16 mm), although both are less effective than the positive control (19.06 ± 0.26 mm). A similar trend is observed with *P. aeruginosa* and *S. aureus*, where only P1 shows measurable activity (10.98 ± 0.16 mm and 11.48 ± 0.32 mm, respectively), indicating that P0 has little to no effect on these strains. In the case of *C. kefir*, P1 exhibits a notably high inhibition zone (30.77 ± 1.00 mm), approaching that of the positive control (35.23 ± 1.31 mm), suggesting strong antifungal activity. The negative control shows no inhibition across all tested microorganisms, confirming the validity of the assay. These observations are consistent with the agar diffusion images, where larger clear zones are visible around P1 compared to P0.

Discussion

Bioplastics derived from renewable sources such as potato starch are increasingly being explored as alternatives to conventional plastics. In this study, the incorporation of natural plant extracts from *Origanum syriacum* and *Cymbopogon winterianus* was investigated to improve the functional properties of starch-based films, particularly for potential food packaging applications.

The prepared bioplastic films showed an average thickness of approximately 0.11 mm, which falls within a suitable range for packaging materials. This suggests that the formulation used in this work can produce films with practical applicability.

Moisture content is an important parameter affecting the stability of packaging materials. In this study, films containing plant extracts exhibited lower water absorption compared to the control sample. Overall, all samples showed moisture content values below 10%, indicating relatively good resistance to water and a lower likelihood of microbial growth. This improvement may be attributed to the presence of hydrophobic compounds in the plant extracts, which could limit water interaction with the polymer matrix.

A similar trend was observed for solubility, where all samples demonstrated values below 10%, reflecting good water resistance. Notably, the extract-containing films showed the lowest solubility, suggesting enhanced barrier properties. This could be linked to stronger interactions between the bioactive compounds and the polymer network, resulting in a more compact structure.

In terms of mechanical properties, differences were observed between the control and extract-enriched films. The control sample exhibited higher elongation, indicating greater flexibility, whereas the films containing plant extracts showed increased tensile stress and modulus. This suggests that the addition of plant extracts contributes to a stiffer and stronger material. Such behavior may result from interactions between phenolic compounds in the extracts and the polymer chains, which can reinforce the structure.

The biodegradability results demonstrated that all films degraded rapidly within a short period. Significant degradation (80–90%) was observed by day 6, with complete degradation achieved by day 8. Interestingly, films containing plant extracts degraded slightly faster, which may be due to their influence on the structural integrity of the matrix. These findings confirm the environmentally friendly nature of the developed materials.

The antimicrobial analysis further supported the functional advantages of incorporating plant extracts. Films containing extracts showed stronger antimicrobial activity compared to the control, particularly against *Candida kefir*. Although the activity was lower than that of the positive control,

the results indicate that these films possess notable antifungal properties. This could be related to bioactive compounds such as essential oils and phenolics, which are known to disrupt microbial cell membranes.

Overall, the results of this study demonstrate that the incorporation of *Origanum syriacum* and *Cymbopogon winterianus* can improve multiple properties of starch-based bioplastics, including moisture resistance, mechanical strength, biodegradability, and antimicrobial activity. These findings support the potential use of such materials in sustainable food packaging applications. However, further studies are recommended to evaluate their performance under real storage conditions and to optimize their formulation for large-scale production.

5. Conclusions

This study demonstrates the potential of potato starch-based bioplastics, enhanced with natural plant extracts such as *Origanum syriacum* (Syrian oregano) and *Cymbopogon winterianus* (lemongrass), as sustainable alternatives to conventional plastic packaging. Derived from renewable resources, these bioplastics exhibit excellent biodegradability and comply with the food safety standards. The films showed robust mechanical properties, making them suitable for food packaging applications. Additionally, the incorporation of plant extracts conferred antimicrobial and antioxidant properties, helping to prolong the freshness of packaged foods.

These findings support global sustainability goals by promoting responsible consumption and production while addressing public health and environmental concerns. Further research is recommended to optimize bioplastic formulations and conduct comprehensive safety assessments. Overall, this work contributes to the growing body of knowledge on eco-friendly packaging solutions, highlighting the feasibility of replacing conventional plastics with biodegradable alternatives.

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Abbreviations

The following abbreviations are used in this manuscript:

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