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Developing bioplastic mulch from Kuhol (*Pomacea canaliculata*) shell chitosan with potato peel starch and rice husk cellulose

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Abstract Results revealed tensile strength (TS) values ranging from 29,730 to 131,860 Pa. The starch-dominant formulation (25:50:25) recorded the highest average tensile strength and the highest elongation at break of 29.47%. Reduced amounts of chitosan and cellulose decreased tensile strength but increased elongation. The mean percent at water vapor permeability (WVP) of the produced bioplastics with potato peel starch, rice husk cellulose, and kuhol shell chitosan ratio of (33:33:33), (25:50:25), (40:40:20), and (20:40:40) were between 4.17 $\times 10^{-11}$ and 1.72 $\times 10^{-11}$ $cm^3 \cdot cm / cm^2 \cdot s \cdot Pa$. Low WVP indicated high water barrier properties (WBP), a positive feature for mulch film. As the amount of chitin in bioplastics increased the mass of the water vapor that escaped through them decreased. The lowest biodegradability rate was 8 % obtained from 40:40:20 ratio. The addition of chitosan increased the time required for biodegradation. Starch, cellulose and chitosan did not immediately contribute to NPK availability as it provided a carbon source for microbes during biodegradation first, thus requiring longer observation time. Research findings demonstrated a significant difference in the TS and elongation in the different ratios, with a p-value 0.002 for TS and <.0001 for elongation. However, there were no significant differences in the WVP, biodegradability, and NPK content. It is recommended to widen the testing parameters which includes testing the efficacy of the bioplastic mulch through enhancing soil moisture ability, plant growth, and weed suppressibility, using more advanced analytical techniques such as FTIR, XRD, SEM, and to improve the quality and size of the product, longer and wider experimentation to arrive in better and more reliable results.

Keywords: Biodegradable, Elongation, Tensile strength, Water vapor permeability, NPK

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Introduction

Recently, a renewed interest has shown a favorable use of shells as raw material for bioplastic synthesis. The potential for valuable raw materials for bioplastics is represented by waste shells, a major by-product (Popović *et al*., 2023). As a result, initiatives are being made to encourage the use of bioplastics thereby reducing the use of synthetic plastics. Chitosan, cellulose, starch, and protein derived from organic waste and renewable biomass are used to make bioplastics (Azahari *et al*., 2011), these offer new resource-efficient alternatives for agriculture and horticulture (Jiménez-Rosado *et al*., 2021). Bioplastics are gaining attention as an innovative approach to solving environmental problems brought on by the extended usage of traditional plastics, which has been shown to be detrimental to the environment (Abang *et al*., 2023). Thus, it is crucial to seek sustainable materials in the production of alternative bioplastics.

Because of their affordability, ease of production, durability, and resistance to water, plastics are utilized in numerous sectors such as agriculture, construction, and packaging. This leads to increasing plastic waste contributing to environmental problems. Most polymers used for plastic production are derived from petroleum which is difficult to biodegrade (Triawan *et al*., 2020). While plastic mulch offers significant agronomic benefits like improved crop yield and water conservation, its production, disposal, and leftover fragments in fields pose environmental threats. These leftover fragments degrade into microplastics (MPs), contaminating the soil and decreasing crop productivity threatening food security. These fragments become difficult to collect. In order to get the benefits of plastic mulches without harming the environment researchers are searching for substitute solutions like biodegradable mulches (Khalid *et al*., 2022).

Moreover, according to Quitos and Macanas (2023), 1.2-1.6M hectares of Philippine rice lands are under kuhol infestations increasing in Mindanao and Visayas, requiring 212M USD in control efforts. Kuhol is considered as major contributor to agricultural losses worldwide and poses a threat to biodiversity. (Penaredondo *et al*., 2015). It poses a risk to human health and the trophic structures of invaded habitats, and its ability to withstand saltwater poses issues in estuarine environments (Liu *et al*., 2022). The use of molluscicide which is used to control kuhol may also result in soil and water pollution, and biodiversity loss (Wang *et al*. 2020). Aranaz *et al*. (2009) and Ordaneza (2024) stated that kuhol shells can be potentially utilized as bioplastics to lessen the negative environmental effects of plastic waste. The shells of crustaceans and mollusks, like kuhol, have chitin, which can be transformed into chitosan to assist in producing eco-friendly bioplastics (Arbia *et al*., 2013). These chitosan-derived bioplastics break down in a matter of weeks releasing nutrients that promote plant growth and development (Swain *et al*., 2023). Additionally, the addition of chitosan into bioplastics improves mechanical, thermal stability, and water barrier qualities (Jiang *et al*., 2023). Using kuhol shells for bioplastic production, as discussed by Míguez *et al*. (2022), turns waste from invasive species into valuable bioactive compounds, fostering a more sustainable industry.

Furthermore, weed competition reduces crop yields, small-scale farmers who lack the funds to buy herbicides and other chemicals that increase crop yields are particularly affected by this. Therefore, mulching – the practice of leaving agricultural residue in the field after harvesting crops – can be an effective weed suppression strategy, particularly for sustainable farming methods (Hussain and Luqman, 2022). However, organic mulches are not as effective as plastic mulches. With plastic mulch, you can grow your crops early in the growing season, warm-season crops can be planted for up to three weeks ahead of time since mulching warms the soil. This does not apply to organic mulches. Plastic mulch performs better in the soil when it comes to absorbing heat (Heydari, 2022). Plastic mulch is pricey which would be hardly available to small land holding farmers. While specific studies on the affordability of mulching for farmers may be limited, findings underscore the potential economic benefits associated with the adoption of mulching practices.

Although previous studies have explored the use of chitosan-, starch-, and cellulose-based bioplastics, limited information is available regarding the utilization of kuhol shell-derived chitosan combined with potato peel starch and rice husk cellulose for biodegradable mulch production. Furthermore, studies evaluating the tensile strength, elongation at break, water vapor permeability, biodegradability, and soil nutrient contributions of such bioplastic mulch formulations remain scarce. Therefore, further investigation is needed to determine the suitability of these agricultural waste-derived materials as biodegradable mulch alternatives for agricultural applications.

Therefore, this study aimed to develop biodegradable mulch films from kuhol shell-derived chitosan, potato peel starch, and rice husk cellulose. Specifically, the study evaluated the tensile strength, elongation at break, water vapor permeability, biodegradability, and their nitrogen (N), phosphorus (P) and potassium (K) content of the developed bioplastic mulch. It also determined whether significant differences existed among the four formulations with respect to their mechanical, barrier, biodegradation, and soil nutrient properties.

Materials and methods

Research design

This study utilized an experimental research design to systematically assess and evaluate the physical and mechanical properties of bioplastic mulch derived from four distinct formulation ratios of chitosan, starch, and cellulose. The study consisted of four treatments corresponding to different formulation ratios, with each treatment replicated three times. Each bioplastic sample was tested for tensile strength, elongation at break, biodegradability, water vapor permeability, and NPK content following standardized procedures and protocols adapted from previous peer-reviewed studies. The experimental process aimed to identify the optimal blend of the three biopolymer components that would yield the most effective and sustainable mulch alternative. Data gathered from the tests were analyzed to generate evidence-based conclusions that directly address the research objectives, particularly in terms of environmental viability, performance consistency, and potential agricultural application.

Location and duration of the study

Kuhol shells were sent to Central Mindanao University (CMU) for species confirmation, TS test, and elongation at break. The production, drying, and curing of bioplastic samples, as well as their biodegradability and water vapor permeability (WVP), were conducted at the Wet Laboratory of San Isidro College in Malaybalay City, Bukidnon. The preparation and grinding of rice husk and kuhol shells were conducted in a residence in Casisang and Impalambong, Malaybalay, Bukidnon. A letter was also given to City Soils Laboratory, Malaybalay, Bukidnon, for the NPK analysis. The study was conducted over two (2) months, from February 24, 2024, to April 26, 2024.

Gathering of materials

The kuhol was gathered from a rice field in Simaya, Malaybalay, Bukidnon, and then boiled for ten minutes to extract the meat from the shells (Aduca *et al*., 2020). Rice husk was obtained from a miller in Brgy. Sto. Nino, Basakan District, Malaybalay. Potato peel was acquired from the local market. Glycerol was purchased from a chemical market in Cagayan de Oro. Additional materials and equipment were supplied by the research laboratory.

Extraction process

Extraction of chitosan from kuhol shell

A modified method from Kaewboonruang *et al*. (2016) for isolating chitosan from prepared kuhol powder was conducted. Distributed 80 grams of the powder into three beakers and subjected it to deproteinization using 100 milliliters of 2M NaOH solution, heated and stirred at 100 degrees Celsius for two hours, followed by filtration and washing to neutral pH. The resulting residue was dried at 100 degrees Celsius for three hours and weighed. Demineralization was carried out using 30 milliliters of 5 % 1M HCl, boiled and stirred for 45 minutes at 100 degrees Celsius, washed, filtered, and dried at 100 degrees Celsius for two hours, with the residue subsequently weighed. The isolated chitin then underwent deacetylation with 510 milliliters of 50% NaOH, boiled for two hours at 100 degrees Celsius, cooled for 30 minutes at room temperature, stirred for hours, filtered, washed to neutral pH, and oven-dried at 90 degrees Celsius for 24 hours to yield chitosan, which was weighed and stored in an airtight container.

Starch extraction

Potato peels were washed, crushed, and sieved. After adding water to the ground peel, the filtrate containing starch granules was recovered by squeezing it through a muslin cloth. The starch granules are treated with 0.1 N sodium hydroxide to separate the protein and lipid fractions from the starch. The starch granule suspension was rinsed multiple times until it became transparent. The starch was then dried for 24 hours in an oven at 40 degrees Celsius (Thakur *et al*., 2013).

Extraction process of cellulose from rice husk

The methods from Yunus *et al*. (2019) were adapted. The 800-grams rice husk was washed and sun-dried. It was then crushed with a hammer mill to decrease the size before being filtered through an 80-mesh sieve to produce finer rice husk powder. The delignification process included putting 10 grams of rice husk powder into 250 milliliters pour 100 milliliters of 12 % NaOH solution into the beaker. Using a magnetic stirrer the mixture was constantly stirred while it was heated to 80 degrees Celsius for three hours. Following filtration of the mixture distilled water was used to wash the precipitate until its pH was neutral. A 250 milliliters beaker containing 100 milliliters of 2.5 % NaOCl solution was filled with the leftover delignification material in preparation for bleaching. After heating the mixture to 80 degrees Celsius it was stirred for one hour. To make cellulose from rice husk, the solid was filtered and rinsed with distilled water until it reached a neutral pH and then left to stand for an hour.

Production of bioplastic mulch

The research done by Dewi *et al*. (2023) served as the model for this method with a few changes. In 5 % acetic acid, chitosan was dissolved. Gelatinization was carried out by combining starch with 400 milliliters distilled water and heated to between 60 and 80 degrees Celsius while being constantly stirred. After combining the chitosan solution with the cellulose and gelatinized starch, 40 milliliters of glycerol plasticizer are added. Certain ratios are followed when adjusting the amounts of chitosan, starch, and cellulose. The mixture was printed into a 26 by 17 by 4 centimeters aluminum tray after a 30-minute homogenization process. After that the samples were dried for seven hours at 70 degrees Celsius in an oven. The film layers were removed from the cast after the mixture had cooled and dried.

Table 1. Bioplastic mulches composition

Treatment	Chitosan (g)	Starch (g)	Cellulose (g)	Glycerol (mL)	5 % Acetic Acid (mL)	Distilled water (mL)
1 (33:33:33)	20	20	20	40	40	400
2 (25:50:25)	15	30	15	40	40	400
3 (40:40:20)	24	24	12	40	40	400
4 (20:40:40)	12	24	24	40	40	400

Tensile strength

TS test is used to determine how much it could be pulled or stretched before breaking. The Central Mindanao University (CMU) College of Engineering Universal Testing Machine (UTM) was utilized to measure TS. The TS was calculated in pascals or pounds per square inch by dividing the maximum force and the minimum cross-sectional area as stated by Maulida *et al*. (2020). The samples that were analyzed included bioplastic products that were created using four different ratios of chitosan starch to cellulose.

$$Tensile\ strength, \sigma = \frac{Tensile\ force\ (F)}{Area\ (A)} \quad \text{Equation 1}$$

Elongation at break

The flexibility of bioplastics was indicated by elongation at break, which was expressed as a percentage. The UTM from the College of Engineering at CMU was used to measure it, following the method outlined by Lubis *et al*. (2018).

$$Percent\ elongation\ (\%) = \frac{(Elongation\ at\ rupture)}{(Initial\ gage\ length)} \times 100\ \% \quad \text{Equation 2}$$

WVP

ASTM E 96 guidelines were followed when performing the WVP test. Distilled water was first added to a dish sealed with a test sample and placed in an oven for twenty-four hours at 37 degrees Celsius. Following this time the water vapor transmission (WVT) rate for each specimen being tested was computed by weighing the water that remained in the dish.

$$WVT = \frac{G}{tA} \quad \text{Equation 3}$$

The amount of water lost (G) the test duration (t) which is equal to 24 hours in seconds and the area of the dish mouth (1. 77 cm^2) or available surface area (A) were used to calculate the water vapor transmission (WVT) rate which was expressed in $g/s{\cdot}cm^2$. Permeability (P) was subsequently computed using the WVT values obtained based on Equation (4).

$$P = \frac{WVT\ x\ Th}{p\ x\ \Delta P} \quad \text{Equation 4}$$

The thickness of the film specimen, denoted by Th, was in centimeters, and ρ represented the water density at the test temperature of 37 degrees Celsius, which equaled 1 g/cm^3. ΔP indicated the pressure difference across the film, assumed to be the same as the water vapor pressure at 37 degrees Celsius, which was 6330 Pascal (Taheri *et al*., 2020).

Biodegradability

Using a method from Chowdhury *et al*. (2022), the biodegradability test was conducted. The bioplastics are buried in the soil for seven days in order to measure the amount of weight loss. The following formula was used to calculate the sample's weight reduction:

$$Biodegradability\ (\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \quad \text{Equation 5}$$

NPK test

Following the biodegradation period, soil samples from each treatment and the control were collected and submitted to the City Soils Laboratory for organic matter, phosphorus, and potassium analyses. Standard laboratory procedures were used to determine nutrient concentrations. The resulting values were compared among treatments to assess the effect of the biodegraded bioplastic mulch on soil nutrient status.

Statistical analysis

Data obtained from the tensile strength, elongation at break, water vapor permeability, biodegradability, and NPK analyses were expressed as mean ± standard deviation. Prior to inferential analysis, the data were subjected to a normality test to determine whether the assumptions required for parametric analysis were satisfied. Since the data met the assumptions of normality, one-way Analysis of Variance (ANOVA) was used to determine whether significant differences existed among the four bioplastic mulch formulations. Statistical significance was evaluated at the 0.05 probability level. When the computed p-value was less than 0.05, the null hypothesis was rejected and the treatments were considered significantly different. When the p-value was greater than 0.05, the null hypothesis was accepted and the treatments were considered not significantly different.

Results

Properties of the chitosan bioplastic mulch from various ratios

The mechanical, water barrier, biodegradability, and soil nutrient properties of bioplastic mulch films produced from different ratios of kuhol shell chitosan, potato peel starch, and rice husk cellulose are presented in Table 2.

Tensile Strength

The tensile strength values of the bioplastic mulch films ranged from 29,730 ± 4,360 Pa to 131,860 ± 21,390 Pa (Table 2). Treatment 2 (25:50:25) recorded the highest mean tensile strength (131,860 ± 21,390 Pa), followed by Treatment 3 (40:40:20) with 70,500 ± 16,540 Pa, Treatment 4 (20:40:40) with 45,780 ± 34,580 Pa, and Treatment 1 (33:33:33) with 29,730 ± 4,360 Pa. One-way ANOVA revealed a statistically significant difference among treatments ($p = 0.002$). Since the p-value was less than 0.05, the null hypothesis was rejected.

Table 2. Mean ± standard deviation of the mechanical, water barrier, and biodegradability and soil nutrient properties of bioplastic mulch films produced from different ratios of kuhol shell chitosan, potato peel starch, and rice husk cellulose

Treatment	Tensile strength (Pa) Mean ± SD	Elongation at break (%) Mean ± SD	Water Vapor Permeability ($cm^3 \cdot cm / cm^2 \cdot s \cdot Pa$) Mean & SD	Biodegradability (%) Mean ± SD	NPK content		
					Organic Matter (%)	Phosphorus (ppm) Mean ± SD	Potassium (ppm) Mean ± SD
1 (33:33:33)	29,730 ± 4,360	25.04 ±3.31	$1.72 \times 10^{-11} \pm 8.54 \times 10^{-12}$	42 ± 0.14	exceeded	21.63 ± 0.99	188 ± 1.73
2 (25:50:25)	131,860 ±21,390	29.47 ±1.60	$4.17 \times 10^{-11} \pm 8.67 \times 10^{-12}$	25 ± 0.00	exceeded	22.21 ± 1.98	180 ± 3.00
3 (40:40:20)	70,500 ±16,540	10.11 ±1.63	$2.01 \times 10^{-11} \pm 2.14 \times 10^{-11}$	8 ± 0.14	exceeded	20.87 ± 2.42	180 ± 0.00
4 (20:40:40)	45,780 ±34,580	8.23 ±0.57	$3.69 \times 10^{-11} \pm 1.07 \times 10^{-11}$	17 ± 0.14	exceeded	24.84 ± 3.73	193 ± 1.73
No mulch (control)	N/A	N/A	N/A	N/A	exceeded	24.20 ± 1.70	187 ± 11.36
One-Way ANOVA Summary (*p*)	*p*= 0.002	*p*= <.000	*p*= 0.138	*p*= 0.055	N / A	*p*= 0.256	*p*= 0.059

Significant at < 0.05 level

NPK content range from Casisang, Malaybalay City, Bukidnon, City Agriculture's Office

Organic Matter %		Phosphorus (ppm)		Potassium (ppm)	
0-2.0	Low	0-6	Very Low	0-75	Low
2.1 – 3.5	Medium	7-10	Low	76-113	Medium
3.6- 4.5	High	11-15	Medium	114-150	High
> 4.5	Very High	16-20	High	>150	Very High
		>20	Very High		

Elongation at Break

The elongation at break values ranged from 8.23 ± 0.57% to 29.47 ± 1.60% (Table 2). Treatment 2 (25:50:25) recorded the highest elongation value (29.47 ± 1.60%), followed by Treatment 1 (33:33:33) with 25.04 ± 3.31%, Treatment 3 (40:40:20) with 10.11 ± 1.63%, and Treatment 4 (20:40:40) with

8.23 ± 0.57%. One-way ANOVA indicated a statistically significant difference among treatments ($p < 0.001$). Therefore, the null hypothesis was rejected.

Water vapor permeability

The water vapor permeability values ranged from $1.72 \times 10^{-11} \pm 8.54 \times 10^{-12}$ to $4.17 \times 10^{-11} \pm 8.67 \times 10^{-12}$ $cm^3 \cdot cm/cm^2 \cdot s \cdot Pa$. Treatment 2 (25:50:25) recorded the highest mean water vapor permeability value, while Treatment 1 (33:33:33) recorded the lowest value. Treatments 3 and 4 recorded values of $2.01 \times 10^{-11} \pm 2.14 \times 10^{-11}$ and $3.69 \times 10^{-11} \pm 1.07 \times 10^{-11}$ $cm^3 \cdot cm/cm^2 \cdot s \cdot Pa$, respectively. One-way ANOVA showed no statistically significant difference among treatments ($p = 0.138$). Since the p-value was greater than 0.05, the null hypothesis was accepted.

Biodegradability

The biodegradability values after seven days of soil burial ranged from 8 ± 0.14% to 42 ± 0.14%. Treatment 1 (33:33:33) recorded the highest biodegradability value (42 ± 0.14%), followed by Treatment 2 (25 ± 0.00%), Treatment 4 (17 ± 0.14%), and Treatment 3 (8 ± 0.14%). One-way ANOVA indicated no statistically significant difference among treatments ($p = 0.055$). Therefore, the null hypothesis was accepted.

Organic matter content

The organic matter content of all treatments and the control exceeded the maximum quantifiable range reported by the laboratory; therefore, no numerical values were available for statistical analysis.

Phosphorus content

The phosphorus content ranged from 20.87 ± 2.42 ppm to 24.84 ± 3.73 ppm. Treatment 4 (20:40:40) recorded the highest phosphorus content (24.84 ± 3.73 ppm), while Treatment 3 (40:40:20) recorded the lowest phosphorus content (20.87 ± 2.42 ppm). Treatments 1 and 2 recorded phosphorus contents of 21.63 ± 0.99 ppm and 22.21 ± 1.98 ppm, respectively. One-way ANOVA showed no statistically significant difference among treatments ($p = 0.256$). Since the p-value was greater than 0.05, the null hypothesis was accepted.

Potassium content

Potassium content ranged from 180 ± 0.00 ppm to 193 ± 1.73 ppm. Treatment 4 (20:40:40) recorded the highest potassium content (193 ± 1.73 ppm), followed by Treatment 1 (188 ± 1.73 ppm). Treatments 2 and 3 both recorded potassium contents of 180 ppm. One-way ANOVA indicated no statistically significant difference among treatments (p = 0.059). Therefore, the null hypothesis was accepted.

Discussion

Properties of the chitosan bioplastic mulch from various ratios

Tensile strength

The significant difference in tensile strength among the formulations indicates that the ratio of potato peel starch, kuhol shell chitosan, and rice husk cellulose influenced the mechanical properties of the bioplastic films. The higher tensile strength observed in the starch-dominant formulation suggests that starch played an important role in strengthening the polymer matrix. This finding is consistent with Nasir and Othman (2021), who reported that tensile strength increased with increasing starch concentration. Similarly, Marichelvam *et al*. (2019) found that higher amylose content contributes to stronger intermolecular bonding, thereby improving tensile properties.

The results also agree with Dewi *et al.* (2023), who reported that chitosan enhances the mechanical properties of bioplastics through the formation of interchain hydrogen bonds with amylose and amylopectin. Although cellulose is commonly used as a reinforcing filler, excessive cellulose content may reduce matrix homogeneity due to uneven particle distribution. Dewi *et al.* (2023) observed that poor dispersion of cellulose can negatively affect tensile strength, which may explain the lower tensile strength obtained in formulations containing higher cellulose proportions.

Variations in tensile strength may also be influenced by differences in film thickness resulting from manual production. According to Maryam *et al*. (2022), tensile strength is affected by film thickness, with thicker films generally exhibiting greater resistance to applied force. In addition, the type of binding agent and the strength of intermolecular bonding contribute to the overall mechanical performance of bioplastics.

In comparison with established standards, the tensile strength values obtained in this study exceeded the ASTM D882-12 requirement for thin LDPE films (0.024 MPa) reported by Adhitama *et al.* (2023). However, the values remained below the 16 MPa minimum tensile strength specified by European Standard EN 17033:2018 for biodegradable mulch films used in agriculture and horticulture. This indicates that further optimization of the formulation is necessary to improve the mechanical performance of the developed bioplastic mulch.

Percent elongation at break

The significant difference observed in elongation at break among the bioplastic formulations indicates that the proportions of potato peel starch, kuhol shell chitosan, and rice husk cellulose influenced the flexibility of the films. Higher elongation values generally indicate greater flexibility and resistance to breakage during stretching, whereas lower elongation values indicate increased rigidity and brittleness (Naser *et al*., 2021). The elongation values obtained in this study exceeded the minimum 5% elongation requirement, indicating that the developed bioplastic films possessed acceptable ductility.

The findings are consistent with Chun *et al*. (2012), who reported that increasing filler loading results in a reduction in elongation at break. According to their study, fillers restrict polymer chain mobility and induce localized deformation within the polymer matrix, thereby reducing the ability of the material to stretch before rupture. Similarly, Gabriel *et al*. (2021) reported that increasing filler concentration can improve the strength of bioplastics while simultaneously reducing their flexibility.

The results also agree with Sari *et al*. (2023), who found that increasing chitosan content decreases elongation at break due to stronger intermolecular interactions and enhanced hydrogen bonding within the polymer network. These interactions produce a more compact and rigid structure, limiting polymer chain movement during stretching. Likewise, Shi *et al*. (2014) reported that increasing cellulose content can reduce elongation because cellulose functions as a reinforcing filler that strengthens the material but decreases its flexibility.

In addition, variations in film thickness resulting from manual production may have contributed to differences in elongation values. Tan and Rodrigue (2019) demonstrated that thickness variations affect elongation measurements, while Takeda *et al*. (2017) reported that thickness differences influence tensile and elongation behavior through changes in stress distribution during testing. Even when the same plasticizer concentration is maintained, differences in formulation ratios may affect the elasticity of bioplastic composites (Liew *et al*., 2014). These observations are further supported by Chandran et al. (2024), who reported that filler concentration significantly influences the mechanical properties of plastic composites, including elongation and elasticity.

Water vapor permeability

The absence of a significant difference in water vapor permeability (WVP) among the bioplastic formulations suggests that variations in the proportions of potato peel starch, kuhol shell chitosan, and rice husk cellulose had limited influence on the barrier properties of the films. The relatively similar

WVP values obtained among treatments indicate that all formulations exhibited comparable resistance to water vapor transmission.

The findings are consistent with Bilck *et al*. (2010), who reported that polymer films with stable and hydrophobic characteristics generally exhibit low water vapor permeability. Low WVP is desirable in agricultural mulch films because it reduces evaporative moisture loss and improves water-use efficiency by minimizing moisture exchange between the soil and the surrounding environment. Similarly, Immirzi *et al*. (2009) reported that lower WVP values may contribute to longer irrigation intervals and improved water conservation.

Low water vapor permeability is desirable in mulch films because it reduces moisture exchange between the soil and the surrounding environment, thereby improving water-use efficiency and reducing evaporative water loss. In most agricultural applications, lower moisture exchange rates contribute to improved moisture conservation. As reported by Surya *et al.* (2021), a decrease in WVP corresponds to improved water barrier properties, whereas an increase in WVP indicates reduced barrier performance. The relatively low WVP values obtained in this study therefore suggest that the developed bioplastic mulch possesses favorable water barrier characteristics.

The results also agreed with Dawam Abdullah *et al*. (2020), who observed that increasing chitosan content reduces water vapor transmission in starch-based bioplastics. Chitosan can improve barrier properties by reducing the affinity of the polymer matrix for water, thereby limiting the movement of water vapor through the film. However, the hydrophilic nature of starch may counteract this effect because starch readily absorbs moisture, which can increase water vapor permeability (Muñoz-Gimena *et al*., 2023). The interaction between these opposing properties may explain the comparable WVP values observed among treatments.

When compared with conventional agricultural films, the WVP values obtained in this study were lower than those reported for polyvinyl chloride (PVC) and polyethylene films by Bilck *et al*. (2010). However, the values remained higher than the water vapor permeability standard reported for low-density polyethylene mulch films (Menossi *et al*., 2021; Li *et al*., 2018). These findings suggest that the developed bioplastic mulch possesses moderate water barrier properties but may require further formulation improvements to achieve barrier performance comparable to commercial mulch films.

Biodegradability

The absence of a significant difference in biodegradability among the formulations suggests that the variations in the proportions of potato peel starch, rice husk cellulose, and kuhol shell chitosan had limited influence on the degradation behavior of the bioplastic films during the seven-day observation period. This finding indicates that all formulations retained their biodegradable characteristics despite differences in composition.

The results are consistent with Dewi *et al*. (2023), who reported that increasing chitosan content may reduce the rate of biodegradation because chitosan exhibits resistance to microbial decomposition. Chitosan can also form hydrogen bonds with amylose and amylopectin, producing a stronger polymer matrix that is more resistant to degradation. Conversely, cellulose may promote biodegradation because it is a natural polysaccharide that can be utilized by microorganisms as a carbon source, thereby facilitating decomposition (Menossi *et al.*, 2021).

The lack of a statistically significant difference may also be attributed to the use of similar amounts of plasticizer among treatments. Shafqat *et al*. (2021) reported that glycerol enhances biodegradation by increasing water penetration into the bioplastic matrix, thereby promoting microbial activity. Similarly, Wahyuningtyas and Suryanto (2017) found that glycerol and starch contribute to the degradation process by increasing moisture absorption and facilitating microbial attack. The relatively similar starch concentrations among treatments may have further contributed to the comparable biodegradation rates observed in this study, consistent with the findings of Maryam *et al*. (2022).

According to ISO 17556:2019 and EN 17033:2018, biodegradable mulch films are expected to undergo complete biodegradation within 24 months under appropriate environmental conditions (Menossi *et al*., 2021). Although the present study evaluated biodegradation for only seven days, the observed degradation of all formulations suggests the potential for continued biodegradation over time. However, longer-term studies are necessary to determine whether the developed bioplastic mulch can fully satisfy the biodegradability requirements specified by international standards. Furthermore, biodegradation rates may vary depending on environmental factors such as soil conditions, climate, and microbial activity (Menossi *et al*., 2021).

NPK content

The absence of significant differences in phosphorus and potassium contents among the treatments suggests that variations in the ratios of potato peel starch, rice husk cellulose, and kuhol shell chitosan had limited influence on soil nutrient availability during the experimental period. Similarly, organic matter content exceeded the upper limit of the laboratory reference range for all treatments, indicating that the soils contained sufficient organic matter for plant growth.

The findings are consistent with Zhang *et al.* (2019), who reported no significant differences in nutrient contents among soils treated with biodegradable mulch films, polyethylene mulch films, and bare soil over a two-year period. Their study demonstrated that biodegradable mulches did not adversely affect soil nutrient status despite differences in mulch composition. Likewise, the results of the present study suggest that the application of bioplastic mulch did not significantly alter phosphorus and potassium availability in the soil.

The elevated organic matter content observed in all treatments agrees with the findings of Soliman and Mansour (2024), who reported that chitosan application can increase soil organic matter. Higher organic matter levels are beneficial because they improve soil structure, enhance microbial activity, and contribute to nutrient retention (Biernbaum, 2012; Traunfeld, 2023). Organic matter also serves as a reservoir of nutrients and supports the gradual release of essential elements during decomposition (Nathan, 2017).

The lack of significant differences in phosphorus and potassium contents may be attributed to the relatively short duration of the experiment. According to Ma *et al.* (2020) and Soliman and Mansour (2024), starch-, cellulose-, and chitosan-based biodegradable materials initially function as carbon sources for soil microorganisms during decomposition rather than directly releasing large quantities of nutrients. Menossi *et al.* (2021) also noted that the effects of biodegradable mulch films on soil microbial activity and nutrient dynamics may require longer observation periods to become evident.

Although no significant differences were observed among treatments, the nutrient levels obtained in this study remained within ranges considered favorable for plant growth. Furthermore, Zhang *et al.* (2022) reported that long-term application of biodegradable mulch films can increase the availability of phosphorus, potassium, and total nitrogen in soil. These findings suggest that the developed bioplastic mulch is unlikely to negatively affect soil fertility and may contribute to maintaining soil quality over time.

Overall, the findings of this study indicated the potential of utilizing kuhol shell chitosan, potato peel starch, and rice husk cellulose as raw materials for biodegradable mulch production. The different formulation ratios significantly affected the tensile strength and elongation at break of the bioplastic mulch, while water vapor permeability, biodegradability, phosphorus content, and potassium content did not significantly differ among treatments. The developed bioplastic mulch exhibited biodegradability and water barrier properties suitable for agricultural applications; however, its mechanical properties remained below the requirements of European Standard EN 17033:2018 for biodegradable mulch films, indicating the need for further formulation improvement. These findings suggested that agricultural waste-derived biopolymers can serve as sustainable alternatives for mulch production while contributing to waste valorization and environmental sustainability. Therefore, future studies are recommended to optimize the proportions of chitosan, starch, and cellulose, evaluate the mulch under actual field conditions, assess its effects on soil moisture retention, plant growth, and weed suppression, and employ advanced characterization techniques such as FTIR, XRD, and SEM, together with longer-term biodegradation and field-performance assessments, to further improve the quality, reliability, and agricultural applicability of the developed bioplastic mulch.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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