TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

Homepage journal: http://jurnal.untirta.ac.id/index.php/ju-tek/

Original research article

Characteristics of biodegradable plastic from cellulose fiber of rice straw (Oryza sativa L.) with glycerol as a plasticizer

Sahasika Sean Putra [a,*], Ariki Zainulmuttaqin [a], Gavin Viryateja [a], Triastuti Rahayu [b]

[a] *State Senior High School 1 Ngawi, Jl. A. Yani No. 45, Ngawi, 63216, Indonesia*

[b] *Biology Education Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Surakarta*

ARTICLE INFO

Article history
Submitted 5 October 2024
Received in revised form 20 June 2025
Accepted 22 June 2025
Available online 24 June 2025

Keywords
Cellulose
Biodegradable
Plasticizer
Bleaching

Editor:
Iqbal Syaichurrozi

Publisher's note:
The publisher remains neutral regarding jurisdictional claims in published maps and institutional affiliations, while the author(s) bear sole responsibility for the accuracy of content and any legal implications.

ABSTRACT

Indonesia faces dual environmental challenges from plastic pollution and agricultural waste accumulation. To address these issues, innovative solutions are needed to transform waste into sustainable materials. This study valorizes rice straw (*Oryza sativa* L.) cellulose and used cooking oil (UCO) glycerol to develop biodegradable plastics through an accessible method. Cellulose was extracted from rice straw via alkaline (10% NaOH) and bleaching (20% H_2O_2) treatments, while glycerol was recovered from UCO through saponification. Bioplastic films were synthesized by solution casting with varying glycerol volumes (6, 9, 12 mL) and cellulose particle sizes (fine, semi-fine, coarse). Results demonstrated exceptional biodegradability, with ≥ 80% weight loss within 14 days in EM4-supplemented soil burial tests outperforming commercial cassava-based bioplastics (25% degradation). Higher glycerol volumes (12 mL) combined with coarse cellulose maximized water solubility (69.39%) and absorption (14.29%), while lower glycerol (6 mL) with fine cellulose minimized water uptake (5.88%). All formulations exceeded thickness standards (0.438–0.554 mm vs. JIS ≤ 0.25 mm), enhancing rigidity but reducing flexibility. Organoleptic analysis confirmed glycerol content inversely affected transparency and texture smoothness.

1. Introduction

The continuous utilization of conventional plastics can cause a negative environmental impact, due to the fact that this type of plastic is more difficult to be processed by decomposers and therefore takes a considerable amount of time. In contrast to conventional plastics, biodegradable plastics are plastics that have the capability to be decomposed naturally through biological processes into simpler substances that are more environmentally friendly [1]. Various studies have shown that biodegradable plastics combined with cellulosic materials produce products that are able to compete with conventional plastics.

* Corresponding author
Email address: sahasika.kaka@gmail.com

DOI: http://dx.doi.org/10.62870/tjst.v21i1.29042

Rice straw is one of several post-harvest waste products from paddy fields, composed of both the stem and leaves cuttings. Contain several components with potential for reuse, such as cellulose fiber (32.0-38.6%), hemicellulose (19.7-35-7%), lignin (13.5-22.3%), ash (10-17%), silica, minerals, and several bioactive compounds [2], [3]. Farmers' habit of preparing land quickly for the next planting period tends to be detrimental to the environment, this is because piles of straw will be burned, causing air pollution, besides the hot temperatures caused by the fire can be lethal for the survival of soil microbes [4]. This burning activity also neglect the potential of straw waste to be processed as valuable product.

In line with waste management, the International Council on Clean Transportation (ICCT) states that Indonesia has the potential to produce 715 kilotons of used cooking oil (UCO) in 2022 [5]. With such a vast amount, UCO should be managed optimally to support daily needs, for example by processing it into biofuel or glycerol. Inadequate management of UCO will also have an impact on the environment, such as the pollution of soil and water, increasing chemical oxygen demand of marine ecosystem, and disrupting microbial communities that affect the agricultural productivity [6]. One of the components of UCO is triglycerides, the presence of triglycerides in used cooking oil has strong potential to be reprocessed into one of the ingredients in the manufacture of biodegradable plastics [7], [8]. Both types of waste should be handled through proper processing to reduce their volume and produce functional, environmentally products such as biodegradable plastic.

Cellulose is one of the main components of plant cell walls, a practical material that is often applied in several industrial sectors. The implementation of cellulose fibers in various industries, including nanotechnology, pharmaceuticals, and textiles is due to its non-toxic and biodegradable nature [9]. A study states about its potential as a filler in polymer composites that can enhance material performance and reduce the environmental impact of non-biodegradable materials [10]. Similar research shows the use of rice straw as biodegradable plastic production, but still adds ingredients that are unfamiliar to general public, such as chitosan, sorbitol, TiO_2, and carboxymethyl cellulose (CMC), this makes it difficult for general public to replicate the findings [11], [12], [13]. Also, there is no research on the use of rice straw cellulose combined with glycerol from UCO.

The main objective of this study was to determine the physical characteristics of biodegradable cellulose fiber plastic made from rice straw waste (*Oryza sativa* L.) with glycerol from used cooking oil as plasticizer using simple method. In order to achieve the objectives of this study, readily available material such as NaOH, hydrogen peroxide, vinegar, and cornstarch were used. The result of this study is expected to provide insight to the general public on one way of processing agricultural and household waste into a functional and environmentally friendly local product.

2. Literature review

The existence of conventional petroleum-based plastic that remains in the ecosystem for a long time has caused a global environmental crisis, with an estimated global production of approximately 359 million tons annually [14]. The second-largest contributor of marine plastic pollution goes to Indonesia, which generating 3.2 million tons of unmanaged plastic waste annually. Citarum and Brantas River for example, transporting plastic debris into Java Sea ecosystems that threat many fisheries and coastal communities, and Bantar Gebang landfill that keep conventional plastic for decades. As a response to this issue, following by Perpres No. 35/2018, the Indonesian government mandating 30% reduction in plastic waste by 2025 [15]. Nevertheless, there is an action to reduce this issue, by using biodegradable plastic from local agriculture waste, which aligns with national sustainability goals while supporting circular economy principles.

Indonesia produced 53.1 million tons of rice in 2024 [16], yielding around 10 million tons of rice straw residue that usually burned and cause air pollution [4]. In fact, rice straw waste is reported contain cellulose fiber (32.0-38.6%), hemicellulose (19.7-35-7%), lignin (13.5-22.3%), ash (10-17%), silica, minerals, and several bioactive compounds [3]. Cellulose, one of the main components of plant cell walls, is a practical material that is often used in several industrial sectors including nanotechnology, pharmaceuticals, and textiles, due to their non-toxic and biodegradable properties [9]. A study has shown its potential as a filler in polymer composites, which can improve material performance and reduce the environmental impact of non-biodegradable materials [10]. The advantages of using cellulose in industry include its sustainability, natural biodegradability, cost-effectiveness, and versatility [17].

A long with world population growth, the demand of energy continuously increasing [18]. Energy is generally obtained from oil. Studies indicate that oil demand in 2030 will reach 17 million tons, with some of it being converted into used cooking oil. This type of oil can be used as a raw material in several industrial applications such as lubricants, solvents, cosmetics, and biofuel [19]. The by-product of this industrial application is glycerol, which can used as a plasticizer for biodegradable plastic [19].

Several studies have demonstrated the feasibility of converting cellulose extracted from agricultural residues into biodegradable plastics, especially the cellulose from rice straw that has been processed due to its high availability and renewability. For instance, bioplastic from rice straw cellulose has been successfully synthesized with various plplasticizersnd resulting the best bioplastic value in A treatment which is consisted of rice straw cellulose with addition of chitosan and orange peel extract [11]. A study comes from synthesizing rice straw bioplastic with addition of CMC and glycerol; this study shows that the result becomes not waterproof and easy to be degraded in lower CMC and glycerol content of 0.469% (w/w) and 0.939% (w/w) respectively [12]. Another result shows that bioplastic successfully created from rice straw and husk cellulose combined with CMC, TiO_2, and glycerin has good biodegradability within three to 5 days although the distribution of filling material remains a challenge [13].

Glycerol, a valuable by-product from biodiesel and oleo-chemical processes, is widely used as a low-toxicity plasticizer that able to enhance the flexibility and workability of bioplastic [20]. Study shows that application of glycerol for plasticizer in starch-based plastic offers sufficient flexibility and processability, whereas the native unplasticized starch-based plastic is too brittle for handling [21], [22]. Glycerol is used as a plasticizer for starch-based plastic due to its compatibility with amylose, which enhances mechanical properties by disrupting amylose packing [23]. Therefore, the presence of starch in this study is for flexibility and processability.

Integrating cellulose fibers with glycerol has been investigated to improve the performance of bioplastics, yet most research predominantly employs commercial-grade glycerol, with the application of waste-derived glycerol, particularly from used cooking oil, being relatively underexplored. This presents a valuable opportunity to explore the synergistic effects of combining locally sourced biomass, to develop a sustainable biodegradable plastic material. While various studies have examined the potential of agricultural biomass for creating biodegradable plastics, few have focused on the combination of rice straw-derived cellulose and glycerol from used cooking oil as synergistic components, which could provide a viable solution to both plastic pollution and waste management challenges.

3. Material and method

3.1. Preparation

The method of making straw powder is done by cleaning the rice straw from impurities which are then chopped into small flakes and then dried under the sunlight. After the chopped straw is dry, it is then pulverized with a blender until it becomes powder and sieved with 60, 80, and 100 mesh then resulting fine, semi-fine, and coarse size respectively. The straw powder then is stored in a clean and tightly closed container.

Each size of straw powder is mixed with 10% NaOH in a ratio of 1:10, then stirred until it becomes a heterogenous mixture and heated to a temperature of 95-100°C for 1 hour while continuing to stir. Next, the straw heterogenous mixture was filtered and the pulp was dried in the sun. The cellulose bleaching process uses a 20% v/v hydrogen peroxide (H_2O_2) solution in a ratio of (1:10) which is heated to a temperature of 90-95°C while stirring for 30 minutes. When done, the cellulose is washed with distilled water until the pH is neutral and dried in the sun [24].

The preparation of glycerol begins with the filtration of the used cooking oil using a filter and then heated to a temperature of 60-80°C. Then, for the saponification reaction, NaOH solution (30-50%) is added to the heated oil while continuously stirred for 60 minutes. After the saponification reaction is complete, the mixture is poured into a separating funnel and allowed to separate between the soap layer and the glycerol layer based on gravity. The glycerol layer will be at the bottom, while the soap layer will be at the top. The acidity (pH) of the glycerol should be neutral, then filtered to remove any impurities or residue left behind. The glycerol obtained is stored in a sealed environment [25].

3.2. The synthesis of biodegradable plastic

The making of biodegradable plastic uses a method that refers to research by Andahera, et al. [26] who made bioplastics from palm empty fruit bunch cellulose with the addition of different types and plasticizers. The tools needed are trays, thermometers, glass stirring rods, plastic as a base for pouring the mixture, and spatulas. The materials needed are 27 grams of rice straw cellulose powder, distilled water, cornstarch, and vinegar (acetic acid). All ingredients were mixed in a glass beaker while being heated over a 50°C fire and continuously stirred for 20 minutes to prevent clumping. Once done, then pour and mould the biodegradable plastic on a tray lined with plastic to prevent sticking. Flatten the poured mixture using a spatula until thin. Dry in the sun until dry.

Table 1
Formulation of biodegradable plastics of straw cellulose fibre and used cooking oil glycerol plasticizer.

No	Sample code	Cellulose variation	Plasticiser volume	Cellulose	Distilled water	Vinegar 2%	Starch
1	H1	Fine	6 ml	3 gr	67 ml	6 ml	7 gr
2	H2	Fine	9 ml	3 gr	67 ml	6 ml	7 gr
3	H3	Fine	12 ml	3 gr	67 ml	6 ml	7 gr
4	SH1	Semi-fine	6 ml	3 gr	67 ml	6 ml	7 gr
5	SH2	Semi-fine	9 ml	3 gr	67 ml	6 ml	7 gr
6	SH3	Semi-fine	12 ml	3 gr	67 ml	6 ml	7 gr
7	K1	Coarse	6 ml	3 gr	67 ml	6 ml	7 gr
8	K2	Coarse	9 ml	3 gr	67 ml	6 ml	7 gr
9	K3	Coarse	12 ml	3 gr	67 ml	6 ml	7 gr

Table 2
Water solubility of biodegradable plastic.

Sampel code	KO	H1	H2	H3	SH1	SH2	SH3	K1	K2	K3
Water solubility (%)	30.00	40.00	55.81	69.23	64.10	59.46	54.55	36.84	45.00	69.39

In making this biodegradable plastic, several experimental variables were carried out, namely the volume of used cooking oil glycerol added (6 ml, 9 ml, and 12 ml). Other additional materials are distilled water as much as 67 ml, organic material (cellulose) 3 g of each variable, cornstarch 7 g, and vinegar acid 2% 1 ml (see Table 1). The cellulose variation used in this study comes from the results of the sieving process of straw powder, which is divided into 3 groups, namely fine, semi-fine, and coarse so that at the time of cellulose extraction it produces cellulose of different sizes.

3.3. Testing process

At this stage there are several tests namely water solubility, water absorption, biodegradable plastic thickness, biodegradation level, organoleptic results, morphology test, and SEM test. The morphology test was carried out by viewing under stereo microscope. The water solubility test was carried out by soaking the sample using 100 ml of distilled water for 24 hours in room temperature, then stirring, filtering and drying for further weighing [27]. The water absorption test was carried out by cutting a sample of 4 x 4 cm and then weighing it. The samples were then soaked with distilled water for 1 minute and then lifted, dried, and finally weighed [28], [29]. The thickness test was carried out by cutting a 4 x 4 cm sample, then given location points scattered in each corner and center of the biodegradable plastic and then measured with a micrometer screw gauge [30]. The biodegradation rate test was conducted by cutting a 4 x 4 cm sample and then burying it in soil with EM4 supplementation for 14 days [31]. Organoleptic test was conducted by inviting panelists to test the texture, aroma, and color [32]. The SEM test was carried out by selecting two treatments based on organoleptic test, plus a control treatment. As a control treatment (KO) comparison, a commercial product with the brand name TeloBag was presented.

3.4. Data analysis

After the data were successfully obtained, data processing and analysis were carried out using formulas that have been tested in several studies [25], [32], [33]. Eq. (1), Eq. (2), dan Eq. (3) calculate the solubility of the samples, respectively.

$$Solubility = \frac{Final\ weight\ of\ sample - initial\ weight\ of\ sample}{Initial\ weight\ of\ sample} x100\% \tag{1}$$

$$Absorbability = \frac{Final\ weight\ of\ sample - initial\ weight\ of\ sample}{Initial\ weight\ of\ sample} x100\% \tag{2}$$

$$Biodegradability = \frac{Initial\ weight\ of\ sample - Final\ weight\ of\ sample}{Initial\ weight\ of\ sample} x100\% \tag{3}$$

Table 3
Water absorption of biodegradable plastics.

Sample	KO	H1	H2	H3	SH1	SH2	SH3	K1	K2	K3
Initial weight (g)	0.1	0.34	0.33	0.42	0.35	0.34	0.32	0.40	0.39	0.49
Final weight (g)	0.11	0.36	0.35	0.46	0.39	0.38	0.36	0.45	0.44	0.56
Water absorption (%)	10.00	5.88	6.06	9.52	11.43	11.76	12.50	12.50	12.82	14.29
Water resistance (%)	90.00	94.12	93.94	90.48	88.57	88.24	87.50	87.50	87.18	85.71

Table 4
Thickness of biodegradable plastic (in mm).

Sites	Sample									
	KO	H1	H2	H3	SH1	SH2	SH3	K1	K2	K3
I	0.05	0.56	0.44	0.5	0.47	0.45	0.55	0.45	0.54	0.44
II	0.05	0.54	0.43	0.49	0.47	0.45	0.55	0.45	0.55	0.43
III	0.05	0.55	0.45	0.51	0.46	0.45	0.54	0.45	0.55	0.44
IV	0.05	0.56	0.45	0.51	0.46	0.45	0.56	0.44	0.54	0.43
V	0.05	0.56	0.45	0.5	0.46	0.44	0.55	0.45	0.55	0.45
Average	0.05	0.554	0.444	0.502	0.464	0.448	0.55	0.448	0.546	0.438

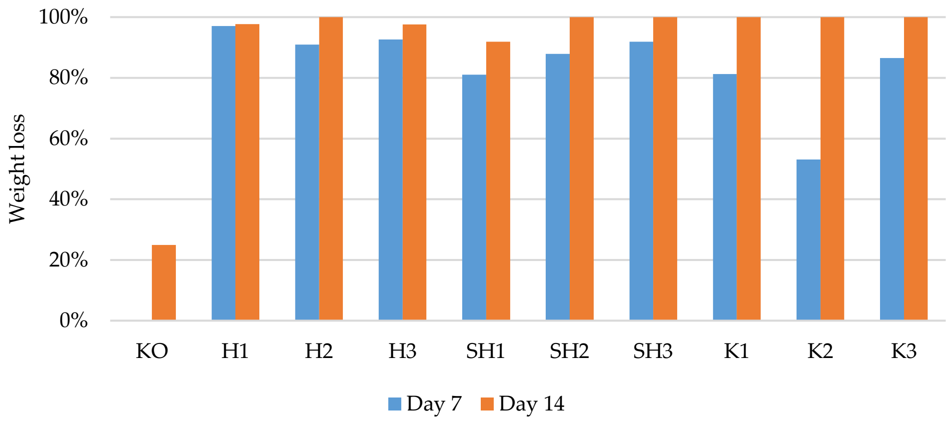

Fig. 1. Weight loss of biodegradable plastic due to decomposition in soil.

4. Results and discussion

4.1. Results

Water solubility testing of biodegradable plastics showed varied results, depending on the formulation used. Soaking the biodegradable plastics in distilled water for 24 hours revealed that the K3 sample had the highest water solubility rate at 69.39%, while the KO (control) sample had the lowest rate at 30.00% (see Table 2). The water absorption test on biodegradable plastics was conducted by immersing the samples in distilled water at room temperature for 1 minute. The results indicated that the K3 sample had the highest absorbency at 14.29%, while the H1 sample exhibited the lowest absorbency at 5.88% (see Table 3).

Film thickness is one of the important factors that affect other properties, such as opacity, density, and mechanical properties. Therefore, biodegradable plastic thickness testing was conducted to assess the suitability of the produced plastic [34]. The plastic was cut into 4 x 4 cm squares and divided into five measurement sites: upper left corner (I), upper right corner (II), lower left corner (III), lower right corner (IV), and center (V). Measurements were taken using a micrometer screw gauge, and the results are presented in Table 4. The biodegradability can be measured by conducting a biodegradable test through the soil burial test technique. Samples were buried 5 cm deep for 14 days and weighed before and after the burial showed on Fig. 1.

Table 5
Organoleptic test result of biodegradable plastics

Sample	Texture	Visual	Aroma
KO	Smooth	Very translucent	Very strong aroma
H1	Mediocre	Translucent	Almost no aroma
H2	Pretty rough	Slightly Translucent	Almost no aroma
H3	Very rough	Very not Translucent	Almost no aroma
SH1	Mediocre	Translucent	No aroma
SH2	Mediocre	Translucent	Almost no aroma
SH3	Mediocre	Slightly Translucent	No aroma
K1	Smooth	Translucent	Almost no aroma
K2	Pretty rough	Barely translucent	Almost no aroma
K3	Rough	Very not Translucent	Almost no aroma

The organoleptic test in this study was conducted to assess the biodegradable plastic produced. The organoleptic test was conducted with the help of nine panelists. The panelists were given the opportunity to assess the biodegradable plastic results by giving a score from a scale of one to nine. The assessment criteria were based on the panelist's level of liking for texture, visual, and aroma. Texture assessment, panelists were asked to feel the biodegradable plastic comparing the texture from very rough to very smooth. Visual assessment is based on seeing the color of the biodegradable plastic whether it is translucent or not. The aroma assessment is based on the smell of the panelists whether it is flavorful or not. The following table presents the results of the average score of the biodegradable plastic organoleptic test in Table 5. The overall morphology of the biodegradable plastics is beige to ivory white in color with different brightness levels and texture shapes varying from fine to coarse according to the main ingredients of the biodegradable plastics, then for flexibility at the beginning of manufacturing all types of treatment have a high flexibility. The results of this organoleptic test then became the basis for selecting samples to be tested in more depth through the stereo microscope and scanning electron microscope.

4.2. Discussions

The result of water solubility test showed that significant variation among samples shown in Table 2, with K3 exhibiting the highest solubility (69.39%) and the commercial KO product the lowest (30.00%) after 24-hour immersion. The high solubility of experimental samples (e.g., K3, H3) is in line with the study of cellulose film from cattail conducted by Khotsaeng et al. which show an increase in solubility due to the reaction of glycerol hydroxyl groups with water, thereby increasing the hydrophilicity of the biodegradable plastic surface [35]. Moreover, the presence of cellulose in the experimental samples contributes to their increased solubility, as cellulose contains abundant accessible hydroxyl groups that facilitate hydrogen bonding with water. This structural characteristic enhances water interaction and promotes dissolution. In contrast, KO's lower solubility likely results from the effects of its polyvinyl alcohol (PVOH) matrix and cassava starch-water reaction [36]. A study states that the interaction between starch and additives can reduce or even prevent interaction with water [37]. In this context, KO treatment, which is a commercial product made from cassava starch, glycerin, PVOH, and without cellulose, allows for a decrease in interaction with water and solubility.

Water absorption values ranged from 5.88% (H1) to 14.29% (K3), as shown in Table 3. Samples with coarse cellulose showed consistently higher absorption than the fine cellulose. This inverse finding is likely influenced by the glycerol volume content and cellulose properties. The findings in this study are supported by bioplastic research results, which show that adding cellulose from Robusta coffee husks increases water absorption. In addition, differences in size also have an effect, as they can cause inhomogeneity during the mixing process [38]. Although K3 used coarse cellulose, it utilized 12 mL of glycerol that contributed significantly to water uptake by enhancing flexibility and porosity of matrix [39]. While H1 only used 6 mL of glycerol and fine cellulose, the low amount of glycerol may have created a denser and less porous structure, decreasing water interaction [23]. This inverse relationship highlights glycerol's dominance over fiber size in short-term absorption kinetics.

The measured thickness showed in Table 4 exceed the Japanese Industrial Standard (JIS), which ranges ≤ 0.25 mm. In this study, the thickest sample was H1 (0.554 mm) and the thinnest sample was KO (0.05 mm). If the thickness exceeds the standard, it will affect the texture and aroma when bioplastics are used as packaging materials and will interfere with product stability [40]. Based on our findings, it has great potential to be utilized as secondary packaging for non-food products.

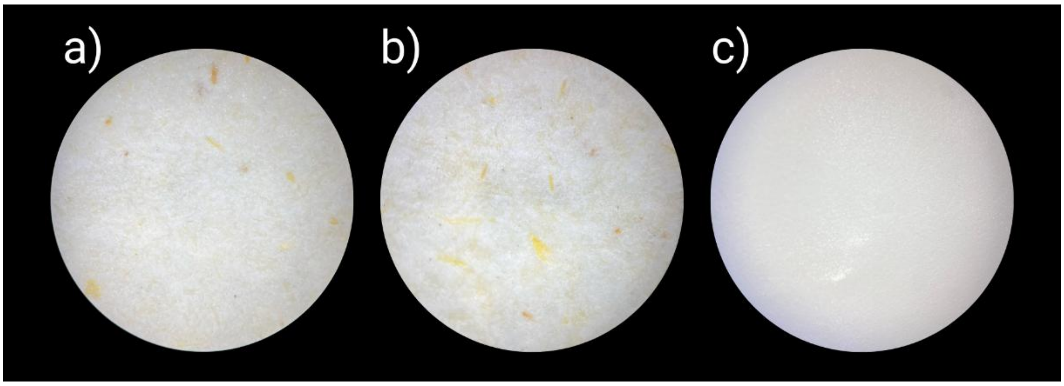

Fig. 2. Visualization of samples as seen on a stereo microscope a) SH1; b) SH2; and c) KO.

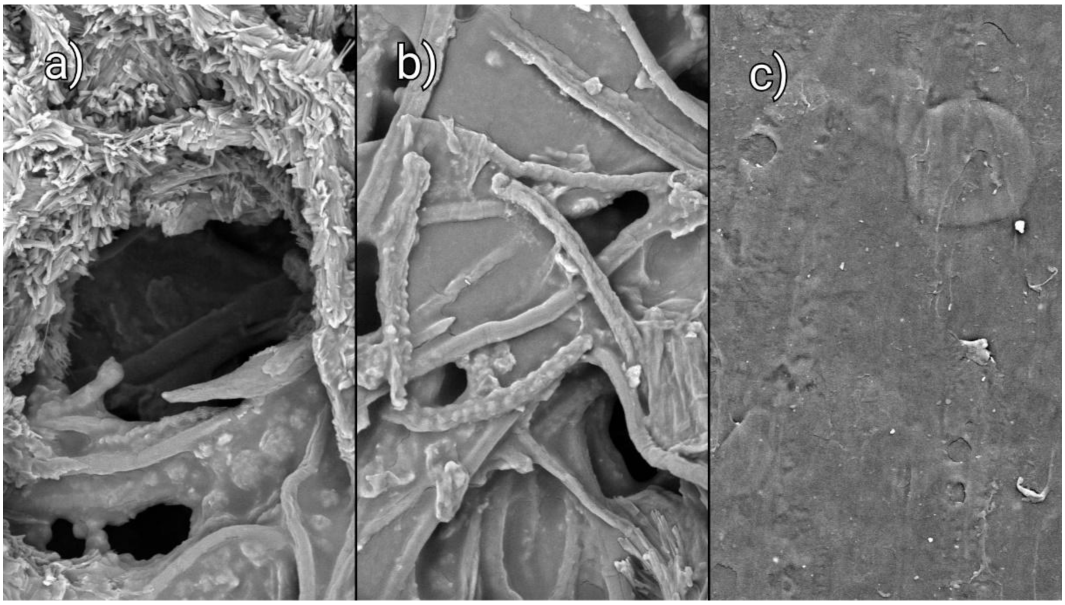

Fig. 3. Visualization through scanning electron microscope a) SH1; b) SH2; and c) KO.

The decomposition process occurs due to the interaction between easily degradable polymers and microorganisms such as fungi, bacteria, and other microorganisms [41]. The biodegradability test of bioplastics shows the impact of damage or decomposition of environmentally friendly plastics due to the influence of microorganisms [23]. In this study, samples were buried in soil supplemented with EM4, and the results are shown in Fig. 1. In this study, we found that almost all treatments had experienced a weight reduction of > 80% on the seventh day, and on the fourteenth day, they were almost completely degraded. This was driven by EM4 supplementation, which enriched the microbes in the soil. The presence of cellulolytic bacteria in EM4 played a major role in the degradation process of rice straw cellulose contained in biodegradable plastics, as it can break down cellulose effectively with cellulosic enzyme secreted from the bacteria [42]. The use of glycerol in this study facilitates water interaction with bioplastic due to its hydrophilic nature. The presence of non-homogenized cellulose allows gaps for water molecules to enter, thereby accelerating the degradation process [38]. In the control treatment (KO), decomposition over 14 days only reached 25%. The KO sample is a sample derived from environmentally friendly plastic made from cassava flour that has been marketed, where the manufacturing process involves polyvinyl alcohol (PVOH). The company producing TeloBag claims that its product will decompose within 180 days; we suspect this process accelerates due to supplementation with EM4, causing decomposition to occur more rapidly because the soil is rich in microorganisms.

Based on Table 5, we can determine that there are several test parameters, namely texture, visual, and aroma in organoleptic tests. Where this is influenced by the level of glycerol plasticizer given and the variation of cellulose size. In the first aspect, texture, there are results that show smooth to rough. In sample H1 with 6 ml glycerol and fine cellulose, the texture was normal. But with the increase of glycerol to 9 ml in H2 the texture turned quite rough, and at 12 ml or H3 the texture became very rough, this also applies to the coarse treatment K1-K3 respectively. Although the volume of glycerol added is different, if the concentration is optimal, further addition will not change the texture significantly [43]. For KO, smooth results can be obtained because it is made from starch and is different from other treatments. Then on the visual aspect, all samples experienced a decrease in translucency as the level of glycerol added increased. This is because the addition of glycerol increases elongation, solubility, and water vapor transmission rate, but decreases tensile strength and transparency [44]. From the aroma, we can know that the addition of glycerol does not have a major impact in changing the aroma of straw. Except for the KO, which has a very strong aroma caused by the difference in the processed materials.

We used organoleptic results to select samples for further observation using a stereo microscope and SEM. Observations under the stereo microscope in Fig. 2 showed that samples containing cellulose still had slight yellow spots due to uneven delignification, compared to the KO treatment, which showed clarity. More in-depth observations in Fig. 3 showed that samples SH1 and SH2 still had cavities that allowed water molecules to enter, while the KO sample showed no cavity and tended to be dense.

This study offers valuable insights into the use of rice straw–derived cellulose and glycerol from used cooking oil for the synthesis of biodegradable plastic using a simple, low-cost method. However, several limitations should be addressed in future studies, including the purification of crude glycerol and the inclusion of standard mechanical testing such as tensile strength and elongation.

5. Conclusions

This study successfully demonstrated the feasibility of producing biodegradable plastic films from rice straw–derived cellulose fiber and crude glycerol obtained from used cooking oil. The experimental films exhibited water solubility values ranging from 40.00% to 69.39% and water absorption between 5.88% and 14.29%, substantially higher than the commercial KO control (30.00% solubility, 10.00% absorption). These differences were driven primarily by glycerol content and the presence of cellulose, whose abundant hydroxyl groups enhanced hydrophilicity and matrix porosity. All experimental samples degraded by more than 80% within 14 days under EM4-supplemented soil burial, whereas the KO film reached only 25% mass loss, underscoring the accelerated biodegradation conferred by rice straw cellulose and microbial inoculation.

Although the average film thickness (0.438–0.554 mm) exceeded the JIS packaging standard (≤ 0.25 mm), this work highlights a simple, low-cost method to convert agricultural and household wastes into value-added, environmentally friendly materials. The organoleptic assessment, microscopy observations (stereo and SEM), and preliminary physical tests provide a multifaceted characterization of the bioplastic's performance and potential application in areas such as disposable packaging or short-lifetime agricultural films. By integrating locally abundant biomass with waste-derived plasticizer, this approach contributes to circular economy objectives and offers a scalable pathway for rural and community-level bioplastic production.

Declaration statement

Sahasika Sean Putra: Conceptualization, Methodology, Writing-Original Draft & Editing. **Ariki Zainulmuttaqin, Gavin Viryateja**: Collecting data. **Triastuti Rahayu**: Writing-Review.

Acknowledgement

The research team would like to express their sincere gratitude to all parties who have supported the completion of this research. Special thanks go to the Biology Education Study Program, FKIP Universitas Muhammadiyah Surakarta, for their academic guidance and access to laboratory facilities. We also extend our appreciation to SMA Negeri 1 Ngawi for providing encouragement and support throughout the research process. Lastly, we thank the individuals and panelists who participated in the organoleptic tests and all those who contributed to the success of this study, directly or indirectly.

Disclosure statement

The authors declare no conflicts of interest.

Funding statement

The study was funded by SMA Negeri 1 Ngawi, through the 2024 BOS budget. The funding body had no role in the design of the study, data collection, analysis, or interpretation of the results.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

AI Usage Statement

Generative AI and AI-assisted tools were used to enhance the language and readability of this manuscript. The authors have reviewed and revised all AI-generated content to ensure its accuracy and alignment with the research. The authors remain fully responsible for the work's scientific content, conclusions, and integrity, and disclose the use of AI to ensure transparency and adherence to publisher guidelines.

References

[1] S. Nizamuddin, A. J. Baloch, C. Chen, M. Arif, and N. M. Mubarak, "Bio-based plastics, biodegradable plastics, and compostable plastics: Biodegradation mechanism, biodegradability standards and environmental stratagem," *Int. J. Biodeterior. Biodegrad.*, vol. 195, p. 105887, Nov. 2024, doi: 10.1016/j.ibiod.2024.105887.

[2] B. A. Goodman, "Utilization of waste straw and husks from rice production: A review," *J. Bioresources Bioprod.*, vol. 5, no. 3, pp. 143–162, Aug. 2020, doi: 10.1016/j.jobab.2020.07.001.

[3] S. Mirmohamadsadeghi and K. Karimi, "Recovery of silica from rice straw and husk," in *Current Developments in Biotechnology and Bioengineering*, Amsterdam, The Netherlands: Elsevier, 2020, pp. 411–433, doi: 10.1016/B978-0-444-64321-6.00021-5.

[4] M. Sofiyuddin, S. Suyanto, S. Kadir, and S. Dewi, "Sustainable land preparation for farmer-managed lowland agriculture in Indonesia," *For. Policy Econ.*, vol. 130, p. 102534, Sep. 2021, doi: 10.1016/j.forpol.2021.102534.

[5] T. Kristiana, A. O'Connell, and C. Baldino, "Producing high quality biodiesel from used cooking oil in Indonesia," White Paper, Aug. 2023.

[6] A. Kumar *et al.*, "Valorization of used cooking oil: Challenges, current developments, life cycle assessment and future prospects," *Discover Sustain.*, vol. 6, no. 1, p. 119, Feb. 2025, doi: 10.1007/s43621-025-00905-7.

[7] M. Asif, "Process advantages and product benefits of interesterification in oils and fats," *Int. J. Nutr. Pharmacol. Neurol. Dis.*, vol. 1, no. 2, pp. 134–139, Jul. 2011, doi: 10.4103/2231-0738.84203.

[8] M. U. H. Suzihaque, H. Alwi, U. K. Ibrahim, S. Abdullah, and N. Haron, "Biodiesel production from waste cooking oil: A brief review," *Mater. Today: Proc.*, vol. 63, pp. S490–S495, 2022, doi: 10.1016/j.matpr.2022.04.527.

[9] K. P. Gupta *et al.*, "An update on overview of cellulose, its structure and applications," in *Cellulose*, London, U.K.: IntechOpen, 2019, doi: 10.5772/intechopen.84727.

[10] A. A. B. Omran *et al.*, "Micro- and nanocellulose in polymer composite materials: A review," *Polymers*, vol. 13, no. 2, p. 231, Jan. 2021, doi: 10.3390/polym13020231.

[11] S. Chadijah, H. Harianti, A. Febryanti, A. Alif, M. Maulidiyah, and A. A. Umar, "Synthesis of bioplastics on rice straw cellulose using orange peel extract, chitosan, and sorbitol," *Walisongo J. Chem.*, vol. 5, no. 2, pp. 111–119, Dec. 2022, doi: 10.21580/wjc.v5i2.10090.

[12] I. Inayati, A. Abdulloh, and Z. B. R., "Fabrication of bioplastic from rice straw," *Equilib. J. Chem. Eng.*, vol. 4, no. 1, pp. 17–22, Jan. 2021, doi: 10.20961/equilibrium.v4i1.43155.

[13] G. W. Hardi *et al.*, "Development and characterization of bioplastics from straw and rice husk for: Effect of addition of glycerin, CMC, and TiO2," *Hydrogen: J. Kependidikan Kim.*, vol. 12, no. 6, pp. 1217–1226, Dec. 2024, doi: 10.33394/hjkk.v12i6.13821.

[14] N. Singh, O. A. Ogunseitan, M. H. Wong, and Y. Tang, "Sustainable materials alternative to petrochemical plastics pollution: A review analysis," *Sustain. Horizons*, vol. 2, p. 100016, Mar. 2022, doi: 10.1016/j.horiz.2022.100016.

[15] Ministry of Environment and Forestry, "National plastic waste reduction strategic actions for Indonesia," Republic of Indonesia, Jakarta, Indonesia, 2020.

[16] Indonesia Statistics, "Luas panen, produksi, dan produktivitas padi menurut provinsi, 2024," Badan Pusat Statistik, Jakarta, Indonesia, 2024.

[17] A. Masek and A. Kosmalska, "Technological limitations in obtaining and using cellulose biocomposites," *Front. Bioeng. Biotechnol.*, vol. 10, p. 912052, Aug. 2022, doi: 10.3389/fbioe.2022.912052.

[18] A. E.-F. Abomohra, M. Elsayed, S. Esakkimuthu, M. El-Sheekh, and D. Hanelt, "Potential of fat, oil and grease (FOG) for biodiesel production: A critical review on the recent progress and future perspectives," *Prog. Energy Combust. Sci.*, vol. 81, p. 100868, Nov. 2020, doi: 10.1016/j.pecs.2020.100868.

[19] Z. Chen and D. Liu, "Toward glycerol biorefinery: Metabolic engineering for the production of biofuels and chemicals from glycerol," *Biotechnol. Biofuels*, vol. 9, no. 1, p. 205, Dec. 2016, doi: 10.1186/s13068-016-0625-8.

[20] Z. Eslami, S. Elkoun, M. Robert, and K. Adjallé, "A review of the effect of plasticizers on the physical and mechanical properties of alginate-based films," *Molecules*, vol. 28, no. 18, p. 6637, Sep. 2023, doi: 10.3390/molecules28186637.

[21] Z. Y. Ben, H. Samsudin, and M. F. Yhaya, "Glycerol: Its properties, polymer synthesis, and applications in starch based films," *Eur. Polym. J.*, vol. 175, p. 111377, Jul. 2022, doi: 10.1016/j.eurpolymj.2022.111377.

[22] Y. G. T. Girijappa, S. M. Rangappa, J. Parameswaranpillai, and S. Siengchin, "Natural fibers as sustainable and renewable resource for development of eco-friendly composites: A comprehensive review," *Front. Mater.*, vol. 6, p. 226, Sep. 2019, doi: 10.3389/fmats.2019.00226.

[23] J. Tarique, S. M. Sapuan, and A. Khalina, "Effect of glycerol plasticizer loading on the physical, mechanical, thermal, and barrier properties of arrowroot (*Maranta arundinacea*) starch biopolymers," *Sci. Rep.*, vol. 11, no. 1, p. 13900, Jul. 2021, doi: 10.1038/s41598-021-93094-y.

[24] R. A. Hakim, Y. Darni, and L. Lismeri, "Sintesis produk biofoam berbahan baku pati sorgum dan jerami padi sebagai filler," *J. Teknol. Inov. Ind.*, vol. 5, no. 1, pp. 18–26, 2024.

[25] G. A. N. Huda, F. F. Azima, Y. Yuliani, and A. Widayoko, "Pemanfaatan kulit pisang Cavendish sebagai pengganti bahan plastik biodegradable dengan penambahan minyak jelantah sebagai gliserol," *BIOCAPIL*, vol. 3, no. 1, pp. 268–275, Feb. 2024.

[26] C. Andahera, I. Sholikhah, D. A. Islamiati, and M. D. Pusfitasari, "Pengaruh penambahan jenis dan konsentrasi plasticizer terhadap kualitas bioplastik berbasis selulosa dari tandan kosong kelapa sawit," *Indones. J. Pure Appl. Chem.*, vol. 2, no. 2, pp. 46–53, Oct. 2019, doi: 10.26418/indonesian.v2i2.36901.

[27] L. Behera, M. Mohanta, and A. Thirugnanam, "Intensification of yam-starch based biodegradable bioplastic film with bentonite for food packaging application," *Environ. Technol. Innov.*, vol. 25, p. 102180, Feb. 2022, doi: 10.1016/j.eti.2021.102180.

[28] T. Muharam, D. Fitriani, D. F. M. Jannah, M. Z. A. Ghifari, and R. P. Sihombing, "Karakteristik daya serap air dan biodegradabilitas pada bioplastik berbasis pati singkong dengan penambahan polyvinyl alcohol," in *Prosiding SNAST*, Nov. 2022, pp. D35–D49, doi: 10.34151/prosidingsnast.v8i1.4152.

[29] D. A. Permata, Y. M. Putri, and S. D. Ismanto, "Variasi penambahan gliserol pada pembuatan bioplastik limbah cair tahu," *J. Teknol. Pertan. Andalas*, vol. 28, no. 1, pp. 46–53, Apr. 2024, doi: 10.25077/jtpa.28.1.46-53.2024.

[30] E. Papilaya, A. N. Bowaire, A. Yapen, E. S. Sinaga, and O. Togibasa, "Pengaruh konsentrasi kitosan pada sintesis dan karakterisasi bioplastik berbasis pati sagu (*Metroxylon sp.*) asal Kabupaten Jayapura," *J. Fis. Pembelajarannya (PHYDAGOGIC)*, vol. 6, no. 2, pp. 130–136, Apr. 2024.

[31] F. Hidayat, S. Syaubari, and R. Salima, "Pemanfaatan pati tapioka dan kitosan dalam pembuatan plastik biodegradable dengan penambahan gliserol sebagai plasticizer," *J. Litbang Ind.*, vol. 10, no. 1, pp. 33–38, Jun. 2020, doi: 10.24960/jli.v10i1.5970.33-38.

[32] Cengristitama and V. D. N. Insan, "Pemanfaatan limbah sekam padi dan minyak jelantah untuk pembuatan bioplastik," *J. TEDC*, vol. 14, no. 1, pp. 15–23, Feb. 2020.

[33] I. Nairfana and M. Ramdhani, "Karakteristik fisik edible film pati jagung (*Zea mays* L) termodifikasi kitosan dan gliserol," *J. Sains Teknol. Lingkungan*, vol. 7, no. 1, pp. 91–102, Jun. 2021, doi: 10.29303/jstl.v7i1.224.

[34] S. Nigam, A. K. Das, and M. K. Patidar, "Synthesis, characterization and biodegradation of bioplastic films produced from *Parthenium hysterophorus* by incorporating a plasticizer (PEG600)," *Environ. Challenges*, vol. 5, p. 100280, Dec. 2021, doi: 10.1016/j.envc.2021.100280.

[35] N. Khotsaeng, W. Simchuer, T. Imsombut, and P. Srihanam, "Effect of glycerol concentrations on the characteristics of cellulose films from cattail (*Typha angustifolia* L.) flowers," *Polymers*, vol. 15, no. 23, p. 4535, Nov. 2023, doi: 10.3390/polym15234535.

[36] S. P. Bangar, W. S. Whiteside, A. O. Ashogbon, and M. Kumar, "Recent advances in thermoplastic starches for food packaging: A review," *Food Packag. Shelf Life*, vol. 30, p. 100743, Dec. 2021, doi: 10.1016/j.fpsl.2021.100743.

[37] D. Donmez, L. Pinho, B. Patel, P. Desam, and O. H. Campanella, "Characterization of starch–water interactions and their effects on two key functional properties: Starch gelatinization and retrogradation," *Curr. Opin. Food Sci.*, vol. 39, pp. 103–109, Jun. 2021, doi: 10.1016/j.cofs.2020.12.018.

[38] A. S. Rusdianto, M. Usman, T. Lindriati, E. Ruriani, and N. S. Mahardika, "The characterization of biodegradable plastics from cassava starch with varied addition of robusta coffee skin (*Coffea canephora*) and glycerol," *Int. J. Food, Agric. Nat. Resources*, vol. 3, no. 3, pp. 34–38, Dec. 2022, doi: 10.46676/ij-fanres.v3i3.68.

[39] S. Lusiana, D. Putri, I. Z. Nurazizah, and Bahruddin, "Bioplastic properties of sago-PVA starch with glycerol and sorbitol plasticizers," *J. Phys.: Conf. Ser.*, vol. 1351, no. 1, p. 012102, Nov. 2019, doi: 10.1088/1742-6596/1351/1/012102.

[40] M. Jufri, R. A. Lusiana, and N. B. A. Prasetya, "Effects of additional polyvinyl alcohol (PVA) on the physiochemical properties of chitosan-glutaraldehyde-gelatine bioplastic," *J. Kim. Sains Apl.*, vol. 25, no. 3, pp. 130–136, Mar. 2022, doi: 10.14710/jksa.25.3.130-136.

[41] A. Edhirej, S. M. Sapuan, M. Jawaid, and N. I. Zahari, "Preparation and characterization of cassava bagasse reinforced thermoplastic cassava starch," *Fibers Polym.*, vol. 18, no. 1, pp. 162–171, Jan. 2017, doi: 10.1007/s12221-017-6251-7.

[42] R. Datta, "Enzymatic degradation of cellulose in soil: A review," *Heliyon*, vol. 10, no. 1, p. e24022, Jan. 2024, doi: 10.1016/j.heliyon.2024.e24022.

[43] E. N. Fitri, "Pembuatan plastik biodegradabel menggunakan selulosa jerami padi dengan penambahan gliserol dan carboxy methyl cellulose (CMC)," B.S. thesis, Malikussaleh Univ., Lhokseumawe, Indonesia, 2024.

[44] S. Paudel, S. Regmi, and S. Janaswamy, "Effect of glycerol and sorbitol on cellulose-based biodegradable films," *Food Packag. Shelf Life*, vol. 37, p. 101090, Jun. 2023, doi: 10.1016/j.fpsl.2023.101090.

Authors information

Sahasika Sean Putra is a biology teacher at SMA Negeri 1 Ngawi. He earned his bachelor's degree in biology education from Universitas Muhammadiyah Surakarta. His academic interest includes microbiology, food technology, biomaterial engineering, and development of environmentally friendly educational innovations.

Ariki Zainulmuttaqin is a student of SMA Negeri 1 Ngawi, Indonesia. Currently in his final year of high school. He is interested in environmental science, biomaterial engineering, science especially physics and chemistry, as well as research, and wants to explore further in this field through research and collaboration in the future

Gavin Viryateja Effendi is a high school student at SMA Negeri 1 Ngawi, Indonesia. Who is currently in the final year of high school. He is interested in environmental science, biomaterial engineering, software engineering, robotics, and is eager to explore more in the field through future research and collaboration.

Triastuti Rahayu is an Associate Professor in the Biology Education Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Surakarta. She earned her doctoral degree in the Biotechnology Program, Graduate School, Universitas Gadjah Mada, Yogyakarta. Her research focuses on metagenomics, microbiology, and plastic degradation.