Indonesian Journal of Environmental Management and Sustainability
e-ISSN:2598-6279 *p*-ISSN:2598-6260

IJEMS

Research Paper

Sustainable Bioplastics from Sweet Corn Cob Waste: Influence of Zinc Oxide and Glycerol on Mechanical Properties and Biodegradability

Indah Nurhayati[1], Cici Tri Kurniawati[1], Muhammad Al Kholif[1*]

[1] *Department of Environmental Engineering, Faculty of Engineering, Universitas PGRI Adi Buana Surabaya, Surabaya, 60234, Indonesia*
***Corresponding author e-mail**: alkholif87@unipasby.ac.id

Abstract
The increasing environmental concerns associated with synthetic plastics have driven the search for biodegradable alternatives. This study investigates using sweet corn cob waste (*Zea mays* L. *saccharata*) for bioplastic production with varying concentrations of zinc oxide (ZnO) and glycerol as additives. The objective is to evaluate the influence of these additives on the mechanical properties, functional group composition, and biodegradability of the resulting bioplastics. The experimental procedures involved the delignification of corn cobs, bioplastic synthesis, and subsequent characterization through Fourier Transform Infrared Spectroscopy (FTIR), tensile strength and elongation tests, and biodegradability assessments. The results showed that increasing ZnO concentrations improved tensile strength, with the highest recorded at 9% ZnO and 25% glycerol. However, increased ZnO reduced elongation and biodegradability due to increased material stiffness. Conversely, higher glycerol concentrations enhanced flexibility and biodegradability but decreased tensile strength. The optimal formulation was identified at 3% ZnO and 35% glycerol, which provided a balanced combination of mechanical strength and biodegradability. This study demonstrates the potential of sweet corn cob waste as a sustainable raw material for bioplastics, contributing to environmentally friendly alternatives to conventional plastics.

Keywords
Bioplastics, Corn Cob Waste, Zinc Oxide, Glycerol, Biodegradability

Received: 11 November 2024, Accepted: 13 February 2025
https://doi.org/10.26554/ijems.2025.9.4.1-11

1. INTRODUCTION

The growing environmental concerns associated with conventional petroleum-based plastics have driven interest in developing biodegradable alternatives. Bioplastics from renewable biomass sources present a sustainable solution to plastic pollution and reduce non-degradable waste accumulation. Sweet corn cob waste (*Zea mays* L. *saccharata*) has gained attention due to its high cellulose, hemicellulose, and lignin content, which is essential for polymer formation (Chong et al., 2021). Using agricultural waste for bioplastic synthesis aligns with circular economy principles, promoting waste valorization and reducing environmental impact (Lee and Yeo, 2021). Additionally, converting agricultural by-products into valuable materials can support economic sustainability for farming communities by providing new revenue streams (Barros et al., 2014). Incorporating plasticizers and reinforcing agents can enhance Bioplastics' functionality and mechanical properties. Glycerol improves flexibility and workability by modifying intermolecular interactions within the polymer matrix (Jamal et al., 2021; Marichelvam et al., 2019; Nazree et al., 2021). Zinc oxide (ZnO) is a reinforcing filler and antimicrobial agent, offering increased rigidity and resistance to microbial degradation (Sidek et al., 2019). The synergistic effect of ZnO and glycerol in corn cob-derived bioplastics can enhance mechanical strength, flexibility, and durability, making them suitable for various industrial applications, including food packaging (Damirson et al., 2023). However, the precise impact of ZnO and glycerol concentrations on these bioplastics' mechanical, chemical, and biodegradability properties remains an area of active investigation.

The widespread use of synthetic plastics has resulted in severe environmental consequences, including non-biodegradable waste accumulation, marine pollution, and greenhouse gas emissions from plastic degradation. Despite recycling efforts, significant plastic waste remains unprocessed, exacerbating ecological damage (Lee and Yeo, 2021). Biodegradable bioplastics offer a viable alternative, yet mechanical limitations, susceptibility to degradation, and production costs constrain their commercial viability. Agricultural waste, like sweet corn cob residues, provides abundant, cost-effective

raw materials for bioplastic synthesis, but further optimization is needed to improve performance characteristics. Balancing mechanical strength and biodegradability remains a key challenge in bioplastic development (Chong et al., 2021). One promising approach is incorporating functional additives such as ZnO and glycerol. Glycerol enhances flexibility, while ZnO can improve bioplastics' mechanical integrity and antimicrobial properties, extending usability in packaging applications (Abdullah et al., 2019; Jamal et al., 2021; Sidek et al., 2019). However, the effects of different concentrations of ZnO and glycerol on bioplastic properties must be systematically examined to determine optimal formulations. By understanding these additives' influence, researchers can develop bioplastics with improved strength, durability, and environmental performance, advancing sustainable alternatives to conventional plastics (Damirson et al., 2023).

Recent studies have explored the use of cellulose-rich agricultural waste for bioplastic production. Corn cob-derived cellulose nanofibrils have been identified as promising reinforcements in bioplastic matrices, enhancing their mechanical and thermal properties (Chong et al., 2021). Incorporating lignin-containing cellulose nanofibrils (LCNF) into bioplastics has improved tensile strength and water resistance, making them more suitable for packaging applications. The addition of glycerol has been studied for improving bioplastic flexibility by disrupting polymer chain interactions and reducing brittleness (Abdullah et al., 2019; Lee and Yeo, 2021; Marichelvam et al., 2019). Studies indicate that glycerol's plasticizing effect depends on its concentration, where excessive amounts may lead to moisture absorption, potentially affecting biodegradability (Wahyuningtiyas and Suryanto, 2017). Metallic oxide nanoparticles such as ZnO have been explored for their reinforcing and functional properties in bioplastics. ZnO nanoparticles exhibit antimicrobial activity, which is advantageous in food packaging applications (Hermansyah et al., 2014; Sidek et al., 2019). ZnO in bioplastics improves mechanical strength while affecting the degradation rate due to its antimicrobial effects (Nawab et al., 2016). However, the interaction between ZnO and glycerol in bioplastics requires further investigation to ensure a balance between strength, flexibility, and biodegradability. Fourier Transform Infrared (FTIR) spectroscopy studies have shown that glycerol addition introduces hydroxyl ($-$OH) groups, contributing to increased hydrogen bonding and polymer flexibility (Jannah et al., 2021; Kartini et al., 2022). Incorporating ZnO may introduce characteristic stretching bands related to metal-oxygen interactions, indicating potential changes in bioplastic chemical composition (Xiu et al., 2023). These findings suggest optimizing ZnO and glycerol concentrations can lead to enhanced bioplastic formulations with improved mechanical properties, antimicrobial functionality, and controlled biodegradability.

Previous studies on bioplastics from agricultural waste have focused on optimizing mechanical properties and biodegradability by incorporating plasticizers and reinforcing agents. Research on bioplastics from corn cob cellulose has shown their potential as sustainable alternatives to petroleum-based plastics, with improvements in mechanical performance through lignin-containing cellulose nanofibrils (Chong et al., 2021). However, the effects of ZnO and glycerol concentrations on corn cob-derived bioplastics' mechanical, functional, and biodegradability aspects remain underexplored. While glycerol is a well-studied plasticizer, its interaction with reinforcing agents like ZnO in bioplastics needs further investigation (Jamal et al., 2021). The balance between glycerol-induced flexibility and ZnO-induced rigidity is not fully established, causing uncertainties in the material formulation. Additionally, ZnO's antimicrobial properties are well-documented (Sidek et al., 2019), but its impact on bioplastic biodegradation due to potential microbial resistance remains a critical research gap (Nawab et al., 2016). Functional group analysis through FTIR is widely used in bioplastic studies (Kartini et al., 2022). However, limited research exists on how ZnO and glycerol variations specifically alter the chemical composition of corn cob-derived bioplastics. Understanding these interactions is essential for optimizing bioplastic performance for practical applications. Addressing these gaps will provide insights into developing high-performance, biodegradable bioplastics from agricultural waste

This study introduces a new approach to making bioplastics from sweet corn cob waste by optimizing the balance between strength and biodegradability using ZnO and glycerol. While previous research focused on improving mechanical properties or enhancing biodegradability, this study examines both aspects. ZnO strengthens the bioplastic but reduces its biodegradability, while glycerol improves flexibility but lowers tensile strength. FTIR analysis shows how these additives interact at the molecular level. Furthermore, the study identifies an optimal formulation of 3% ZnO and 35% glycerol, achieving durability and environmental friendliness. On the other hand, this study highlights the potential of agricultural waste for sustainable bioplastic production, providing a practical alternative to conventional plastics. The objective is to investigate the effect of varying ZnO and glycerol concentrations on mechanical properties, functional group composition, and biodegradability of sweet corn cob waste-derived bioplastics. Specifically, this research aims to analyze these additives' influence on tensile strength and elongation, examine their impact on functional groups using FTIR, and evaluate the bioplastics' biodegradability under different ZnO and glycerol formulations.

2. EXPERIMENTAL SECTION

2.1 Materials

This study uses sweet corn cob waste (*Zea mays* L. *saccharata*) as the main ingredient in the manufacture of bioplastics. In addition, additional materials used include Zinc Oxide (ZnO) with concentration variations of 3%, 6%, and 9%, and glycerol as a plasticizer with concentration variations of 25%,

30%, and 35%. For the delignification process, 10% Sodium hydroxide (NaOH) and 5% Sodium hypochlorite (NaOCl) solutions were used as bleaching agents. Distilled (DI) water was used as a solvent in all process stages. Some of the tools used in this research include a hot plate stirrer, analytical balance, measuring cup, glass stirrer, thermometer, petri dish, beaker glass, iron spatula, 10 × 20 cm plexiglass mold, oven, 60 mesh sieve, filter cloth, filter paper, and glass funnel. All the highest quality chemical materials and equipment are obtained from UD. Sentausa Kimia.

2.2 Analysis Data of Methods

2.2.1 Preparation of Corn Cob powder

Sweet corn cob waste was washed to remove impurities and dried in the sun until the moisture content was reduced. After drying, the corn cobs were ground using a grain grinder and then sieved using a 60-mesh sieve to obtain a fine powder. The powder was dried in an oven at 60°C for 1 hour to free it from moisture.

2.2.2 Pulp Production (Delignification Process)

Sweet corn cob powder was soaked in 10% NaOH solution in a ratio of 1:10 and stirred for 24 hours to remove lignin content. Afterward, the mixture was filtered using a filter cloth to separate the residue from the filtrate. The residue was then re-soaked in 5% NaOCl solution for 3 hours for bleaching. After bleaching, the residue was washed with boiling DI water until the hypochlorite odor disappeared, then dried in an oven at 60°C until constant weight. The resulting powder from the delignification process was ground using a grinder and sieved with a 60-mesh sieve.

2.2.3 Bioplastic Synthesis

100 mL DI water was mixed with ZnO and glycerol according to the predetermined concentration variations. The solution was then stirred until homogeneous. Next, 5 grams of sweet corn cob powder was added to the solution and heated at 70 - 83°C for 22 minutes until the gelatinization process occurred. After that, the mixture was poured into a 10 × 20 cm plexiglass mold and left for a few minutes until the air bubbles disappeared. The molded bioplastics were then dried in the sun for 5 days until completely dry.

2.2.4 Bioplastic Characterization

- Fourier Transform Infrared Spectroscopy (FT-IR) Analysis

FT-IR analysis was conducted to identify the functional groups contained in the bioplastics. The sample was cut into a circular shape with a diameter of 10 mm and inserted into the FT-IR device (Tensor 27, Shimadzu). Furthermore, the radiation source is heated at 1500-2000 K to produce an infrared spectrum. Compounds in the sample will absorb the resulting infrared radiation, and the results are converted into an infrared spectrum showing absorption peaks at certain wavelengths, which are then analyzed to identify functional groups in bioplastics.

- Mechanical Properties (Tensile Strength and Elongation)

Tensile strength and elongation tests were conducted using an IMADA brand tensile machine following the Standar Nasional Indonesia (SNI), the International Organization for Standardization (ISO) - SNI ISO 527-4:2016 (Badan Standarisasi Nasional, 2016). Before testing, the samples were conditioned in a room with a temperature of 23°C and 50% relative humidity for 48 hours. The tensile strength test was carried out by clamping the end of the sample on the tensile machine and pulling it at a speed of 500 mm/minute until the sample broke. The tensile strength value is obtained from the maximum load to break the sample and then divided by the initial cross-sectional area.

- Biodegradability

The biodegradability test used Effective Microorganism 4 (EM4) as the soaking medium. Bioplastic samples were weighed before testing and immersed in 1% EM4 liquid medium for 3 days. After the soaking process, the samples were dried in an oven until the weight was constant. The degradation percentage was calculated based on the difference between the initial and final weights of the sample after the biodegradability test was conducted.

3. RESULT AND DISCUSSION

This study aims to assess the characteristics of bioplastics made from sweet corn cob waste with varying concentrations of ZnO reinforcement and glycerol plasticizer. The resulting bioplastics were tested through a functional group test using FT-IR, a mechanical test (tensile strength and elongation), and a biodegradability test.

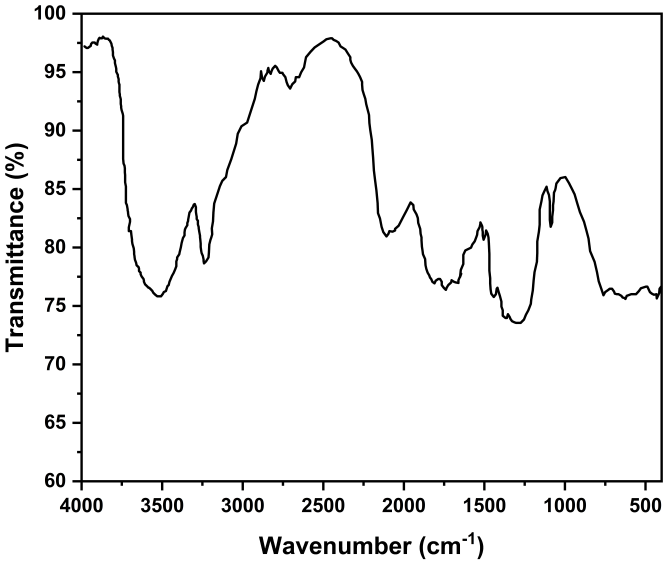

Figure 1. FT-IR Testing Results of Sweet Corn Cobs

3.1 FTIR analysis

3.1.1 Sweet Corn Cob Powder Sample

The FTIR spectrum of corn cob showed several absorption bands, indicating the presence of major functional groups in the lignocellulosic material, as shown in Figure 1. A strong absorption band was detected in the region around 3300 cm^{-1}, representing the stretching of hydroxyl (O−H) groups, possibly derived from cellulose and hemicellulose components. In addition, the band at 2900 cm^{-1} indicates the presence of aliphatic C−H stretching, characteristic of hydrocarbon structures. In the region around 1700 cm^{-1}, there is a typical absorption band for carbonyl groups (C=O), which can be derived from ester or ketone groups, common components in lignin. In the 1000-1200 cm^{-1} region, an absorption band shows C−O vibrations, indicating the presence of alcohol or ether groups. This supports the presence of polysaccharide compounds such as cellulose and hemicellulose. Overall, these FTIR spectra confirm that corn cobs have a major component of lignocellulose, which consists of cellulose, hemicellulose, and lignin. This identification is relevant for understanding the potential of this material in various applications, such as bioethanol production, adsorbents, or composite materials.

These results are consistent with previous studies reporting that the absorption bands at 3459 cm^{-1} (O−H axial deformation), 2943 cm^{-1} (C−H deformation), and 1743 cm^{-1} (C=O stretching), indicate the presence of phenolic groups, alcohols, carboxylic acids, and polysaccharides (Padilla et al., 2019). In addition, FTIR has been used to understand the changes in the chemical structure of corn cobs during thermal treatment. Another study highlighted the importance of FTIR in analyzing functional group transformations during the co-pyrolysis process of corn cobs, providing insight into the reactivity of biomass for energy production (Reddy, 2024). Thermal treatment affects the chemical properties of biomass, which are detected through changes in FTIR absorption bands (Kanwal et al., 2019). The chemical changes during corn cob pyrolysis in raw biomass and charcoal products highlight the varying degrees of chemical decomposition among the samples (Domazetovska et al., 2023). In the context of environmental applications, FTIR is used to study the role of corn cobs in biological processes. The research used FTIR to assess chemical changes in corn cobs as carbon substrates in biological denitrification processes (Hidalgo, 2024). These results demonstrate the ability of FTIR to evaluate biomass surface changes during biological processes. Awosusi et al. (2017) demonstrated the potential of corn cobs in producing commodities by using FTIR to analyze their thermal and chemical properties.

The three-step hydro-depolymerization process of corn cobs, involving hemicellulose, lignin, and cellulose, has also been studied using FTIR. Research by Yang et al. (2023) showed that this technique helps characterize the chemical changes during biomass conversion, with hemicellulose conversion efficiency reaching 78.48% and cellulose 76.97% after five cycles. These results confirm the role of FTIR in supporting the optimized use of corn cobs for agricultural and industrial applications. Beyond biomass analysis, FTIR has also shown versatility in various other applications. For instance, Inman et al. (2024) used FTIR to detect radiation exposure in mouse ear pinna, while Barrera-Patiño et al. (2023) applied FTIR to analyze bacterial profiles in detecting antibiotic resistance. This technique was also used by Bilamjian et al. (2024) to identify adulteration in food products, such as maple syrup.

3.1.2 ZnO Concentration at 3, 6, and 9 % with Glycerol

FTIR is an important method for analyzing the chemical interactions and structural properties of materials such as starch and glycerol-based bioplastics by adding ZnO. In this study, FTIR was used to evaluate changes in the chemical structure of glycerol by adding ZnO at different concentrations (3%, 6%, and 9%), as shown in Figure 2. The analysis results showed changes in the intensity and position of the characteristic peaks, which provided insight into the interaction between ZnO and glycerol. At 3% ZnO concentration, the FTIR spectrum showed a major absorption band at 3410 cm^{-1} associated with stretching hydroxyl (O-H) groups. Other absorption bands were detected at 2929 cm^{-1} for aliphatic C−H stretching, 1642 cm^{-1} for H−O−H deformation, and 1027-1152 cm^{-1} for C−O vibrations of alcohol groups. Adding ZnO at 3% produced a change in intensity in the hydroxyl band, indicating a weak interaction between ZnO and glycerol. At 6% ZnO concentration, the intensity of the hydroxyl band at 3415 cm^{-1} was reduced, indicating increased interaction with ZnO. The C−H absorption band remained at 2924 cm^{-1} , while the C−O band in the 1024-1155 cm^{-1} range showed higher intensity, reflecting more significant interaction with the alcohol group. At 9% ZnO concentration, the intensity of the hydroxyl band at 3400 cm^{-1} decreased dramatically, indicating a strong interaction between ZnO and glycerol hydroxyl groups. In addition, the C=O or C−O vibrational bands in the 1000-1200 cm^{-1} range showed a significant increase in intensity, indicating the formation of a new chemical complex between ZnO and glycerol.

The results of this study are consistent with previous findings showing the important role of glycerol as a plasticizer in bioplastic materials. Glycerol reduces intermolecular forces in polymer chains, increases molecular mobility, and produces more flexible materials (Anugrahwati et al., 2022; Kandah, 2022; Nazree et al., 2021). The addition of ZnO is also reported to improve bioplastics' mechanical strength and water absorption characteristics, although it decreases their biodegradability (Muharam et al., 2022; Saputra et al., 2019; Sasria, 2024). The FTIR spectra in this study showed a shift in the characteristic peaks of hydroxyl (O−H) and carbonyl (C=O) groups, which is consistent with the findings of Jannah et al. (2021) and Abdullah et al. (2019). These

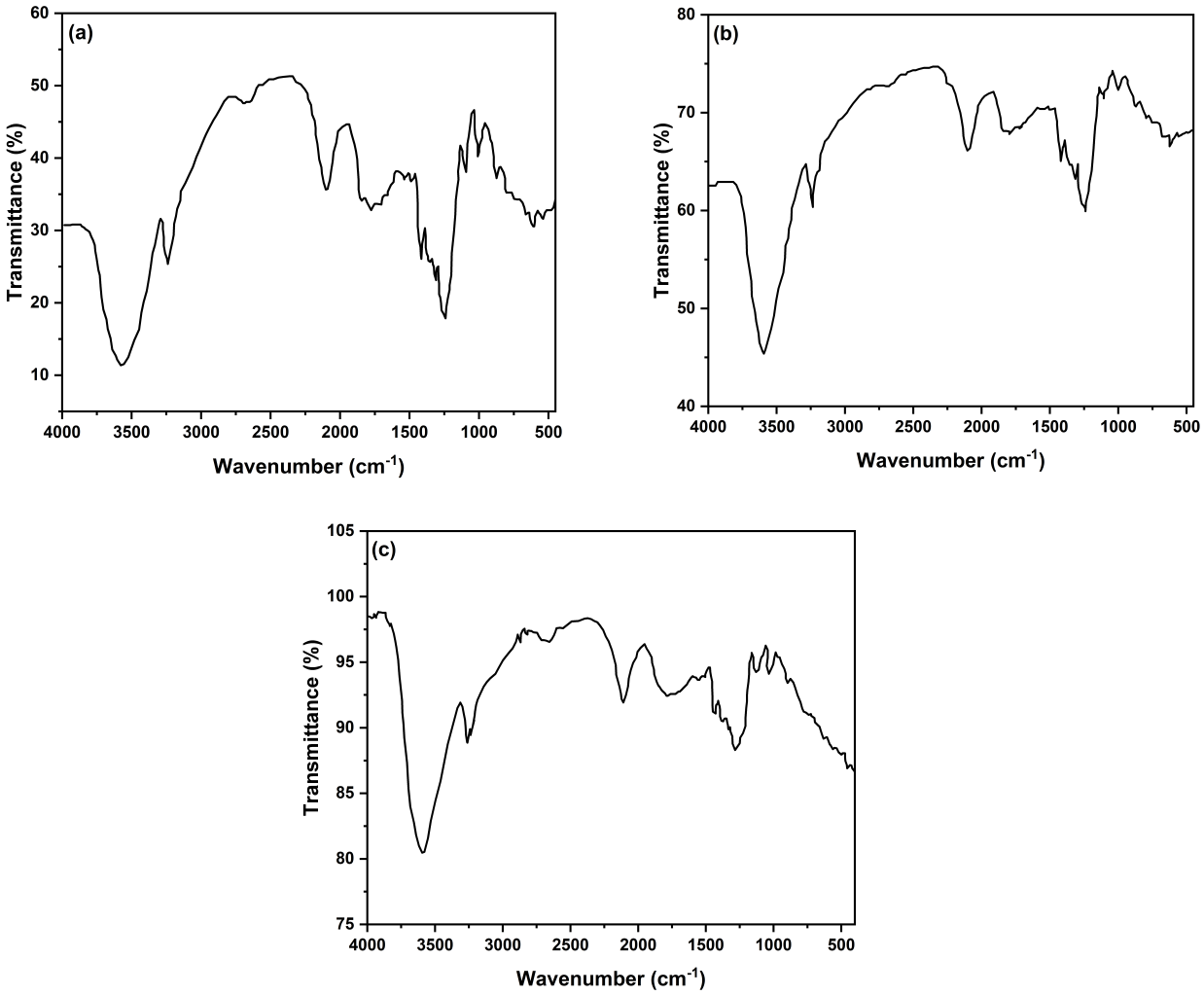

Figure 2. FT-IR Testing Results of ZnO with Glycerol: (a) ZnO 3% with Glycerol, (b) ZnO 6% with Glycerol, and (c) ZnO 9% with Glycerol

shifts reflect the formation of new bonds or modification of existing bonds due to the interaction between ZnO and glycerol. Optimization of glycerol concentration proved to be important in producing materials with an optimal balance between mechanical strength and flexibility (Abdullah et al., 2019; Mukuze et al., 2019). Previous research on cassava starch-based bioplastics also showed that optimal glycerol concentration can increase tensile strength and elongation at the break of the material (Inman et al., 2024). In addition, these results align with research using FTIR to characterize the interaction of ZnO in nanocomposites. Mehta et al. (2023) observed a characteristic band for the Zn−O stretching mode in ZnO nanoparticles around 439-481 cm^{-1}, which reflects the structure of ZnO. Other studies have also shown that the vibrational frequency of Zn-O can differ depending on the synthesis method and particle size (Ahmed et al., 2023). The study by Song et al. (2023) showed that the basic structure of ZnO remains intact during the formation of nanocomposites, as observed in this study.

3.2 Tensile Strength Analysis Elongation Analysis

Figure 3 shows the relationship between ZnO concentration (%), glycerol percentage (25%, 30%, and 35%), and bioplastic tensile strength (MPa). This data illustrates how variations in material composition affect the mechanical properties of bioplastics, particularly in terms of tensile strength. In general, increasing ZnO concentration from 3% to 9% increased the tensile strength of bioplastics for all glycerol variations. At 3% ZnO concentration, the tensile strength was relatively low, with the highest value of 1.67 Mpa in bioplastics with 25% glycerol and the lowest value of 1.20 MPa at 35% glycerol. At 6% ZnO concentration, the tensile strength experienced a moderate increase compared to 3% ZnO. The highest tensile strength was achieved at 25% glycerol at 3.17 MPa, while 30% and 35% glycerol

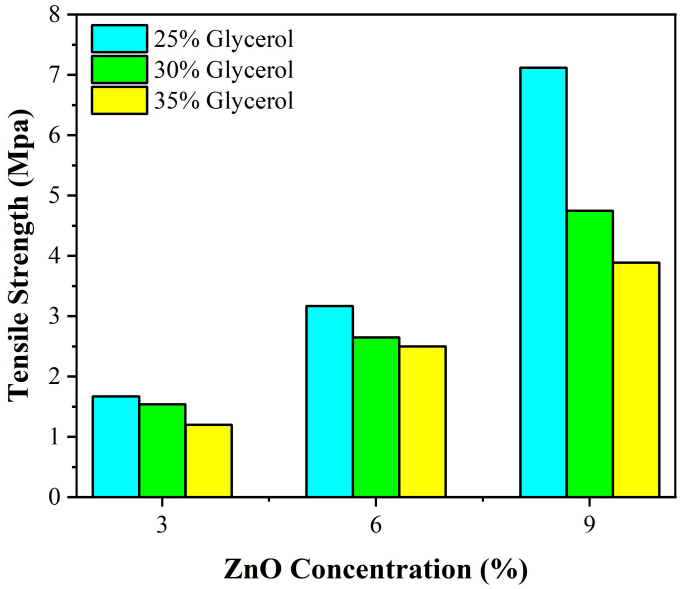

Figure 3. The Effect of ZnO Concentration and Glycerol on the Bioplastic Tensile Strength

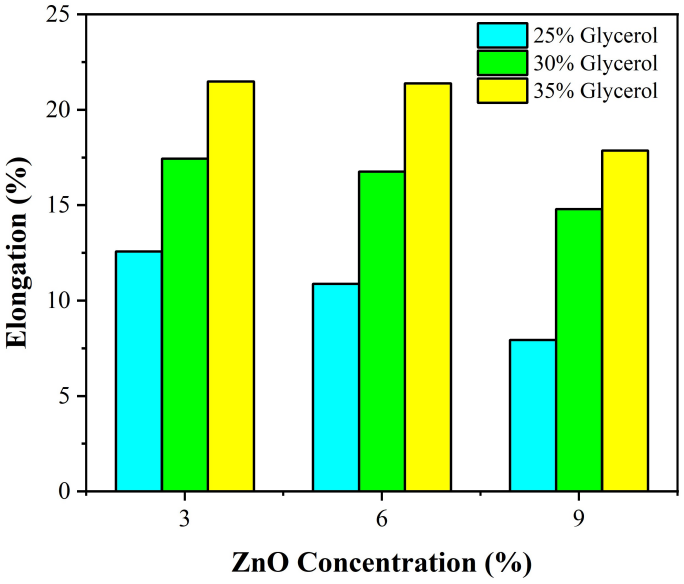

Figure 4. The Effect of ZnO Concentration and Glycerol on The Bioplastic Elongation

produced tensile strengths of 2.63 MPa and 2.50 MPa, respectively. The tensile strength increased significantly at 9% ZnO concentration compared to the previous concentrations. The highest value was recorded at 25% glycerol at 7.12 MPa, followed by 30% glycerol at 4.75 MPa and 35% at 3.89 MPa. Increasing glycerol resulted in a more flexible bioplastic but with a lower tensile strength. In contrast, adding ZnO reinforced the bioplastic matrix, thus increasing the overall tensile strength. A ZnO concentration of 9% with 25% glycerol provided optimal results, producing bioplastics with the highest tensile strength.

This result is consistent with the findings of previous studies. The addition of glycerol as a plasticizer tends to increase the flexibility of bioplastics but reduces their tensile strength. Glycerol causes disruption of hydrogen bonds in the polymer matrix, which increases the mobility of the polymer chains and thus decreases the tensile strength. A decrease in the tensile strength of bioplastics due to the addition of glycerol, although the material's flexibility increased (Dianursanti et al., 2018). The increasing glycerol concentration caused elongation to increase but tensile strength to decrease (Basiak et al., 2018; Farahnaky et al., 2013). Budiman et al. (2022) supported these results by stating that higher glycerol content increased flexibility but decreased the mechanical strength of bioplastics.

In contrast, the addition of ZnO was shown to increase the tensile strength of bioplastics. At the optimum ZnO concentration, ZnO acts as a reinforcement that improves the bioplastic structure by increasing the interaction between ZnO and polymer chains. A ZnO concentration of 3% resulted in a tensile strength of about 5.9966 MPa, which showed a significant improvement in the mechanical properties of the bioplastics (Maslahah et al., 2021). Another study revealed that ZnO strengthens the bioplastic matrix by forming strong interactions with the polymer chains (Hidayat et al., 2019). However, a concentration of too high ZnO can cause agglomeration, reducing mechanical properties, as Takribiah et al. (2022) reported. These results also support the work of Zhao et al. (2024), who showed that the optimal ZnO concentration at 3% can increase the tensile strength to 32 MPa in PBAT/PLA-based bioplastic blends. In addition, Yu et al. (2023) noted that glycerol can improve tensile strength early. However, environmental factors such as hydrothermal aging can negatively affect the material's mechanical properties.

3.3 Elongation Analysis

The effects of ZnO concentration and glycerol on the elongation properties of bioplastics are critical for optimizing their mechanical performance. Glycerol, a common plasticizer, plays a significant role in enhancing the flexibility and elongation of bioplastics. Incorporating ZnO and glycerol in bioplastic composites has significantly affected their elongation properties.

Figure 4 shows that the elongation of bioplastics is affected by the variation of ZnO and glycerol concentrations. Increasing the percentage of glycerol from 25% to 35% increases the elongation value while increasing the ZnO concentration from 3% to 9% tends to decrease the elongation of bioplastics. At 3% ZnO concentration, the highest elongation was recorded at 35% glycerol at 21.48%, followed by 30% glycerol at 17.44% and 25% at 12.58%. A similar trend was seen at 6% ZnO concentration, where the highest elongation remained recorded at 35% glycerol at 21.38%, while 30% and 25% glycerol produced elongations of 16.78%

Table 1. Comparison of The Result of Previous Study with This Study

Study	Tensile Strength (MPa)	Elongation (%)	Biodegradability (%)	Discussion
(Maslahah et al., 2021)	5.99 (3% ZnO, Arrowroot starch)	Increased with glycerol	ZnO reduces the degradation rate	ZnO enhances mechanical strength but slows degradation. Arrowroot starch bioplastics exhibited moderate tensile strength.
(Hidayat et al., 2019)	Improved with ZnO addition	Decrease at higher ZnO	Biodegradability drops with ZnO	ZnO reinforced the bioplastic matrix, improving strength but reducing flexibility and biodegradability.
(Zhao et al., 2024)	32 (3% ZnO in PBAT/PLA blend)	Higher with low ZnO	ZnO influences microbial resistance	PBAT/PLA blends with 3% ZnO reached high tensile strength but had unknown biodegradability impacts.
(Nawab et al., 2016)	Reduction due to plasticizer	70% glycerol leads to high elongation	Glycerol increases degradation time	Plasticizer addition (glycerol) greatly influenced flexibility, but too much-reduced strength and increased moisture sensitivity.
(Budiman et al., 2022)	Decreased with increased glycerol	More glycerol increases flexibility but lowers strength	Higher glycerol accelerates biodegradability	Glycerol increased flexibility and biodegradability but led to reduced mechanical properties.
This study	7.12 (9% ZnO, 25% glycerol)	21.48 (3% ZnO, 35% glycerol)	31.74 (3% ZnO, 35% glycerol)	This study showed that increasing ZnO increases tensile strength but reduces elongation and biodegradability. Higher glycerol improves flexibility and biodegradability but lowers tensile strength.

and 10.88%, respectively. At 9% ZnO concentration, elongation was still highest at 35% glycerol at 17.86%, while 30% and 25% glycerol recorded 14.80% and 7.94%, respectively. The addition of glycerol was shown to increase the elongation of bioplastics due to the plasticizing properties of glycerol, which can reduce intermolecular forces in the polymer matrix and increase the material's flexibility. However, increasing ZnO concentration tends to decrease the elongation value, especially at 25% and 30% glycerol, due to an increase in material stiffness caused by the role of ZnO as a filler that strengthens the bioplastic matrix. Overall, the best combination to produce the highest elongation was 35% glycerol with 3% ZnO concentration, which reached 21.48%. These results indicate that the balance between

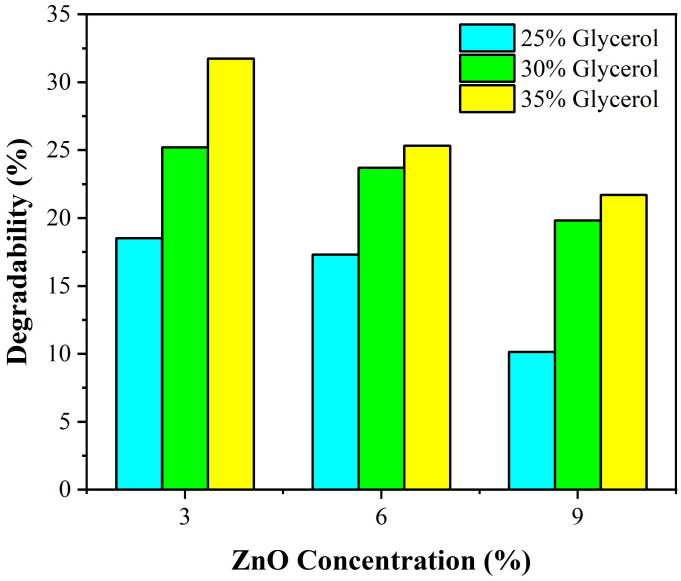

Figure 5. The Effect of ZnO Concentration and Glycerol on The Bioplastic Biodegradability

ZnO and glycerol concentrations is crucial to optimizing the flexibility and stretchability of bioplastics.

These results are in line with previous studies showing that glycerol increases elongation by reducing intermolecular forces in the polymer matrix, thus allowing greater movement of polymer chains when subjected to stress (Islamiyah et al., 2022; Jamal et al., 2021; Nawab et al., 2016). Increasing glycerol concentration from 40% to 70% can substantially increase the elongation of bioplastics due to the plasticizing effect of glycerol (Nawab et al., 2016). This study showed a similar pattern, where higher glycerol concentration resulted in greater elongation at all ZnO concentrations. However, the addition of ZnO had the opposite effect on elongation. ZnO can improve certain mechanical properties, such as tensile strength and Young's modulus, at low concentrations, but higher concentrations tend to decrease elongation as it interferes with the flexibility of the polymer matrix (Hasna et al., 2022; Saputra et al., 2019). This is consistent with the results of this study, where an increase in ZnO concentration from 3% to 9% caused a decrease in elongation value, especially at 25% glycerol.

The interaction between ZnO and glycerol is also important. The optimal combination of 10% ZnO with 1 gram of glycerol resulted in good mechanical properties, including significant elongation (Saputra et al., 2019). The decrease in elongation at higher ZnO concentrations, as seen in this study, indicates that excess ZnO can reduce the flexibility of the bioplastic and shows a trade-off between strength and elongation at high ZnO concentrations (Hasna et al., 2022). In addition, PBAT/PLA blends with tetrapod-zinc oxide (T-ZnO) whiskers showed that an optimal ZnO concentration of 3% could provide the best mechanical properties, including tensile strength up to 32 MPa (Zhao et al., 2024). This finding supports the results of this study, where a low ZnO concentration (3%) resulted in higher elongation than higher concentrations. Interestingly, the reprocessing effect also affects the elongation of the biocomposites. Titone et al. reported that the elongation in biocomposites increased by about 90% after the first extrusion process, suggesting reprocessing can improve the material's flexibility (Titone et al., 2023). Although this study did not evaluate the effects of reprocessing, the findings are relevant in modifying the elongation properties of materials through processing techniques.

3.4 Biodegradability Analysis

The biodegradability of bioplastics is significantly influenced by the concentration of glycerol and the incorporation of materials such as ZnO. Glycerol is a plasticizer, enhancing bioplastics' flexibility and mechanical properties and affecting their degradation rates. Figure 5 shows the effect of ZnO and glycerol concentration on the biodegradability of bioplastics. The results showed that increasing the percentage of glycerol from 25% to 35% increased the biodegradability value while increasing the ZnO concentration from 3% to 9% tended to decrease it. At 3% ZnO concentration, the highest biodegradability was recorded at 35% glycerol with a value of 31.74%, followed by 30% glycerol at 25.21% and 25% glycerol at 18.52%. A similar pattern was seen at 6% ZnO concentration, where the highest biodegradability value remained at 35% glycerol at 25.32%, while 30% and 25% glycerol produced biodegradability values of 23.70% and 17.30%, respectively. The biodegradability values decreased overall at 9% ZnO concentration but remained highest at 35% glycerol at 21.70%, while 30% and 25% glycerol produced 19.82% and 10.14% values, respectively. The addition of glycerol was shown to increase the biodegradability of bioplastics. This is due to the plasticizing properties of glycerol, which increases flexibility and reduces the density of the polymer matrix, making it easier for microorganisms to access and degrade the material. Conversely, an increase in ZnO concentration reduces biodegradability as ZnO increases the stiffness of the polymer matrix, which slows down degradation by microorganisms. These findings indicate the importance of balancing ZnO and glycerol concentrations to produce environmentally friendly bioplastics with good biodegradability.

3.5 Comparison of This Study with Other Study

In This section, Table 1 shows the comparison and presents the tensile strength, elongation, and biodegradability results of this study alongside findings from previous research, highlighting the impact of ZnO and glycerol concentrations on bioplastic properties. It demonstrates that while ZnO enhances tensile strength, it reduces elongation and biodegradability, whereas glycerol increases flexibility and biodegradability but lowers mechanical strength. The find-

ings align with other studies, confirming the trade-offs between strength, flexibility, and environmental degradation and emphasizing the need for an optimal balance of additives for improved bioplastic performance.

4. CONCLUSIONS

This study successfully demonstrated the potential of sweet corn cob waste (*Zea mays* L. *saccharata*) as a raw material for bioplastic production, with the addition of ZnO and glycerol significantly influencing the mechanical properties, functional group composition, and biodegradability of the resulting bioplastics. The FTIR analysis confirmed the presence of key functional groups, including hydroxyl (−OH) and carbonyl (C=O), essential for polymer interactions. Incorporating ZnO led to structural modifications in the polymer matrix, enhancing its mechanical properties, while glycerol acted as an effective plasticizer, improving flexibility. The mechanical testing results showed that increasing ZnO concentration improved the tensile strength of bioplastics, with the highest value recorded at 9% ZnO and 25% glycerol. However, elongation decreased with higher ZnO concentrations due to increased stiffness. Conversely, higher glycerol concentrations enhanced elongation but reduced tensile strength, highlighting the trade-off between flexibility and mechanical strength. The biodegradability analysis revealed that increasing glycerol concentration improved the degradation rate, while higher ZnO concentrations reduced biodegradability due to their antimicrobial properties. The optimal formulation was identified at 3% ZnO and 35% glycerol, which provided a balanced combination of mechanical performance and biodegradability. Future studies should optimize processing conditions and explore additional reinforcing agents to enhance bioplastic performance and sustainability.

5. ACKNOWLEDGEMENT

The Environmental Engineering Laboratory of Universitas PGRI Adi Buana Surabaya fully supports this research, providing research facilities and funding assistance.

REFERENCES

Abdullah, A., O. D. Putri, and W. Sugandi (2019). Effects of Starch-Glycerol Concentration Ratio on Mechanical and Thermal Properties of Cassava Starch-Based Bioplastics. *Jurnal Sains Materi Indonesia*, **20**; 162

Ahmed, N., S. C. Dey, N. Mustary, and M. Ashaduzzaman (2023). pH Regulated Lactose Inspired Fabrication of Zinc Oxide Nanoparticles for Insulin Sensing by LSPR Absorption. *Heliyon*, **9**; e18153

Anugrahwati, M., M. D. P. Nasution, and F. I. Fajarwati (2022). Characteristic Comparison of Cornstarch-Based Bioplastics Using Kaolin, Microcrystalline Cellulose and Chitosan as Fillers. *Jurnal Pijar MIPA*, **17**; 73–78

Awosusi, A. A., A. O. Ayeni, R. Adeleke, and M. O. Daramola (2017). Biocompositional and Thermodecompositional Analysis of South African Agro-Waste Corncob and Husk Towards Production of Biocommodities. *Asia-Pacific Journal of Chemical Engineering*, **12**; 960–968

Badan Standarisasi Nasional (2016). *Standar Nasional Indonesia (SNI), The International Organization for Standardization (ISO) - SNI ISO 527-4:2016*. Indonesia

Barrera-Patiño, C. P., J. M. Soares, K. C. Branco, N. M. Inada, and V. S. Bagnato (2023). Spectroscopic Identification of Bacteria Resistance to Antibiotics by Means of Absorption of Specific Biochemical Groups and Special Machine Learning Algorithm. *Antibiotics*, **12**; 1502

Barros, J., A. Romaní, G. Garrote, and B. Ordás (2014). Biomass, Sugar, and Bioethanol Potential of Sweet Corn. *GCB Bioenergy*, **7**; 153–160

Basiak, E., A. Lenart, and F. Debeaufort (2018). How Glycerol and Water Contents Affect the Structural and Functional Properties of Starch-Based Edible Films. *Polymers (Basel)*, **10**; 412

Bilamjian, S., M. Bahadi, A. Ismail, C. Tremblay, and S. Bayen (2024). Development of a Method Based on ATR-FTIR Spectroscopy to Detect Maple Syrup Adulterated with Added Syrups. *Journal of the Science of Food and Agriculture*, **104**; 1768–1776

Budiman, M. A. K., U. Uju, and K. Tarman (2022). A Review on the Difference of Physical and Mechanical Properties of Bioplastic From Seaweed Hydrocolloids With Various Plasticizers. In *IOP Conference Series: Earth and Environmental Science*, volume 967. page 012012

Chong, T. Y., Y. S. Chan, M. Law, and J. K. U. Ling (2021). The Thermo-Mechanical Properties of Corn Cob Lignin-Containing Cellulose Nanofibril Reinforced Bioplastics

Damirson, A. C., L. A. T. Bañaga, D. M. M. D. Concha, D. C. Mariano, and C. L. S. Reyes (2023). The Garden Battle: A Comparative Study on the Tensile Properties Between Corn-Based and Cassava-Based Bioplastics

Dianursanti, G., M. Gozan, and C. Noviasari (2018). The Effect of Glycerol Addition as Plasticizer in *Spirulina platensis* Based Bioplastic. In *E3S Web of Conferences*, volume 67. page 03048

Domazetovska, S., V. Strezov, R. V. Filkoski, and T. Kan (2023). Exploring the Potential of Biomass Pyrolysis for Renewable and Sustainable Energy Production: A Comparative Study of Corn Cob, Vine Rod, and Sunflower. *Sustainability*, **15**; 1–14

Farahnaky, A., B. Saberi, and M. Majzoobi (2013). Effect of Glycerol on Physical and Mechanical Properties of Wheat Starch Edible Films. *Journal of Texture Studies*, **44**; 176–186

Hasna, T., C. A. Lestari, W. D. R. Putri, and V. Fathuroya (2022). The Effect of ZnO (Zinc Oxide) and Glycerol Concentrations on the Mechanical Properties of Bioplastics Made From Canna Tuber (*Canna edulis*) Starch. *Advances in Food Science Sustainable Agriculture and Agroindus-*

trial Engineering, **5**; 21–28

Hermansyah, H., R. Carissa, M. B. Faiz, and P. Deni (2014). Food Grade Bioplastic Based on Corn Starch With Banana Pseudostem Fibre/Bacterial Cellulose Hybrid Filler. *Advanced Materials Research*, **997**; 158–168

Hidalgo, G. C. S. (2024). Enhanced Biological Nitrate Removal From Groundwater in Humid Tropical Regions Using Corn Cob-Based Permeable Reactive Barriers: A Case Study From Panama. *Water (Basel)*, **16**; 1668

Hidayat, S., A. Abdullah, R. F. Septiyanto, Y. R. Denny, and I. Affifah (2019). Perbandingan Sifat Mekanik Bioplastik Terhadap Penambahan Zinc Oxide (ZnO). *Gravity: Jurnal Ilmiah Penelitian Dan Pembelajaran Fisika*, **5**

Inman, J. L., Y. Wu, L. Chen, E. Brydon, D. Ghosh, K. H. Wan, J. D. Chant, L. Obst-Huebl, K. Nakamura, C. Y. Ralston, S. E. Celniker, J.-H. Mao, P. H. Zwart, H.-Y. N. Holman, H. Chang, J. B. Brown, and A. M. Snijders (2024). Long-term, Non-invasive FTIR Detection of Low-dose Ionizing Radiation Exposure. *Scientific Reports*, **14**; 6119

Islamiyah, H. S., M. A. Alamsjah, and D. Pujiastuti (2022). Application of Modified Starch in the Carragenan-Based Biodegradable Packaging From *Eucheuma cottonii* on Biodegradability and Mechanical Properties. In *IOP Conference Series: Earth and Environmental Science*, volume 1036. page 012072

Jamal, T., S. M. Sapuan, and K. Abdan (2021). Effect of Glycerol Plasticizer Loading on the Physical, Mechanical, Thermal, and Barrier Properties of Arrowroot (*Maranta arundinacea*) Starch Biopolymers. *Scientific Reports*, **11**

Jannah, N. R., N. Jamarun, and Y. E. Putri (2021). Production of Starch-Based Bioplastic From *Durio zibethinus* Murr Seed Using Glycerol as Plasticizer. *Jurnal Riset Kimia*, **12**

Kandah, M. I. (2022). Production of Biodegradable Bioplastics Filled With Jordanian Olive Tree Leaves. *Chemical Engineering & Technology*, **45**; 755–761

Kanwal, S., S. Munir, N. Chaudhry, and H. Sana (2019). Physicochemical Characterization of Thar Coal and Torrefied Corn Cob. *Energy Exploration & Exploitation*, **37**; 1286–1305

Kartini, I., M. Masuda, and B. Ishartono (2022). Incorporation of Urea Fertilizer and Activated Carbon in Carboxymethyl Cellulose-Based Bioplastics. *Materials Science Forum*, **1061**; 75–80

Lee, C. L. Y. and W. S. Yeo (2021). A Basic Characterisation Study of Bioplastics via Gelatinization of Corn Starch. *Journal of Applied Science & Process Engineering*, **8**; 820–833

Marichelvam, M. K., M. Jawaid, and M. Asim (2019). Corn and Rice Starch-Based Bio-Plastics as Alternative Packaging Materials. *Fibers*, **7**; 32

Maslahah, N. U., D. Alisaputra, and E. Sedyadi (2021). Biodégradation Bioplastic Based on Arrowroot Starch With Glycerol Plasticizer and ZnO Fillers. *Journal of Physics: Conference Series*, **1788**; 012007

Mehta, M., C. Chopra, S. Sistla, and I. Bhushan (2023). Potential of Biosynthesized Silver and Zinc Oxide Nanoparticles from *Carissa opaca* Extracts for Antimicrobial Activity and Wastewater Treatment. *Sustainability*, **15**; 8911

Muharam, T., D. Fitriani, D. F. M. Jannah, M. Z. A. Ghifari, and R. P. Sihombing (2022). Karakteristik Daya Serap Air Dan Biodegradabilitas Pada Bioplastik Berbasis Pati Singkong Dengan Penambahan Polyvinyl Alcohol. *Prosiding Snast*, **8**; D35–D49

Mukuze, S., M. Hillary, and F. L. Mkandawire (2019). Comparison of Fructose and Glycerol as Plasticizers in Cassava Bioplastic Production. *Advanced Journal of Graduate Research*, **6**; 41–52

Nawab, A., F. Alam, M. A. Haq, and A. Hasnain (2016). Biodegradable Film From Mango Kernel Starch: Effect of Plasticizers on Physical, Barrier, and Mechanical Properties. *Starch - Stärke*, **68**; 919–928

Nazree, A. A., N. Adrus, Z. A. Muis, H. Hashim, N. Baharulrazi, S. H. C. Man, M. N. H. Z. Alam, R. A. Majid, E. Johnson, A. R. Abdullah, B. R. Chuprat, F. Ali, and J. Jamaluddin (2021). Mechanical and Biodegradation Properties of Fresh and Rotten Jicama Starches Based Bioplastics. *Environmental Quality Management*, **32**; 355–364

Padilla, E. R. D., G. T. Nakashima, A. L. S. Hansted, L. R. O. Santos, J. L. d. Barros, A. C. De Conti, and F. M. Yamaji (2019). Thermogravimetric and FTIR analyzes of corn cob pyrolysis. *Química Nova*, **42**(5); 566–569

Reddy, A. K. (2024). Co-Pyrolysis and Pyrolysis of Corn-Cob Biomass and Waste Plastic: Comprehensive Study Based on Kinetic and Thermodynamic Approach. *ChemistrySelect*, **9**(32); e202402177

Saputra, W., A. Hartiati, and B. A. Harsojuwono (2019). Pengaruh Konsentrasi Seng Oksida (ZnO) dan Penambahan Gliserol Terhadap Karakteristik Bioplastik Dari Pati Umbi Gadung (*Dioscorea hispida* Deenst). *Jurnal Rekayasa dan Manajemen Agroindustri*, **7**; 531

Sasria, N. (2024). Bioplastic Properties of Cassava Peel Starch (*Manihot esculenta*) Influenced by the Addition of Crab Shell Chitosan and Zinc Oxide (ZnO). *Materials Science Forum*, **1140**; 75–84

Sidek, I. S., S. F. S. Draman, S. R. S. Abdullah, and N. Anuar (2019). Current Development on Bioplastics and Its Future Prospects: An Introductory Review. *Inwascon Technology Magazine*; 03–08

Song, T., J. Li, Q. Deng, and Y. Gao (2023). Preparation, Characterization, Photochromic Properties, and Mechanism of PMoA/ZnO/PVP Composite Film. *Molecules*, **28**; 7605

Takribiah, F., H. Harunsyah, Z. Amalia, R. Fauzan, and M. Sami (2022). Pembuatan Bioplastik Dengan Penguat ZnO Dan Penambahan Minyak Atsiri Sebagai Anti Mikroba. *Jurnal Teknologi*, **22**; 37

Titone, V., F. P. La Mantia, and L. Botta (2023). Recy-

clability of a Bio-Based Biocomposite Under Different Reprocessing Conditions. *Journal of Materials Science*, **58**; 17459–17469

Wahyuningtiyas, N. E. and H. Suryanto (2017). Analysis of Biodegradation of Bioplastics Made of Cassava Starch. *Journal of Mechanical Engineering Science and Technology*, **1**; 24–31

Xiu, W., X. Wang, S. Yu, Z. Na, C. Li, M. Yang, and Y. Ma (2023). Structural Characterization, In Vitro Digestion Property, and Biological Activity of Sweet Corn Cob Polysaccharide Iron (III) Complexes. *Molecules*, **28**; 2961

Yang, X., X. Li, L. Zhu, J. Liang, and J. Zhu (2023). Production of Hemicellulose Sugars Combined with the Alkaline Extraction Lignin Increased the Hydro-Depolymerization of Cellulose from extitCorn Cob. *Sustainability*, **15**; 9041

Yu, W., L. Sun, M. Li, Y. Peng, C. Wei, W. Lei, R. Qiu, and Y. Ge (2023). Effect of Modification and Hydrothermal Ageing on Properties of 3D-Printed Wood Flour–Poly(Butylene Succinate)–Poly(Lactic Acid) Biocomposites. *Polymers*, **15**; 3697

Zhao, Z., R. Balu, S. Gangadoo, N. K. Duta, and N. R. Choudhury (2024). Poly(Butylene Adipate-co-Terephthalate)/Polylactic Acid/Tetrapod-Zinc Oxide Whisker Composite Films with Antibacterial Properties. *Polymers*, **16**; 1039

