Journal of Engineering and Technological Advances (JETA)
https://jeta.segi.edu.my/index.php/segi
2025 Vol. 10 No. 2

USE OF ZNO AS FILLER FOR PROPERTIES OF ARROWROOT (MARANTA ARUNDINACEA LINN) STARCH-BASED DEGRADABLE PLASTIC

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Received: 30 October 2025; Accepted: 6 November 2025; Published: 31 December 2025
doi: 10.35934/segi.v10i2.159

Highlights:

- Degradable plastic is a good option for the environment.
- The use of arrowroot tuber starch with ZnO blends to make degradable plastic.
- Plastic material exhibits complete biodegradability on day 19.

Abstract: This study explores the synthesis and characterization of arrowroot starch-based degradable plastics reinforced with zinc oxide (ZnO). The experimental design incorporated the use of arrowroot tuber starch in varying concentrations of 10, 15, 20, and 25 g, in conjunction with ZnO from 10, 20, 30, and 40%. The highest tensile strength is observed in the presence of 15 g of starch and 30% ZnO, exhibiting a value of 4.7770 MPa. The addition of ZnO fillers to degradable plastics results in enhanced mechanical strength, with increased ZnO content leading to greater strength. The mixing process exerts a significant influence on the resulting mechanical properties. Optimal mixing conditions, including appropriate speeds and times, result in a uniform distribution of particles, thereby enhancing the mechanical strength of the material. The specify which organic group present in the compound analysis of degradable plastics are characterised by a high degree of hydrophilicity, which enables them to bind to water. Thermogravimetric analysis indicates that the plastic is capable of withstanding elevated temperatures. A loss of weight is observed between 312.72°C to 344.31°C. It was observed that an improve in the percentage of ZnO used determined in a corresponding increase of water absorption value from degradable plastic. The lowest water absorption value, at 17.59%, was observed when 25 g of starch mass and 10% ZnO were used. The plastic was completely degraded on the19th day, which is substantially shorter than the 180-day biodegradation period specified in ASTM D5338.

Keywords: Arrowroot; Starch; Degradable Plastics; Reinforced; Zinc Oxide

1. Introduction

In the last decades, there continues to be a significant increase the use of petrochemicals-based synthetic plastic, which have surpassed all other synthetic materials in terms of production volume. While these materials offer a high degree of versatility, their use has had a big effect on the environment and public health concerns due to their non degradable nature and tendency to accumulate in the environment (Gamage et al, 2024). The global annual production and disposal of plastics is about 300 million tons, and the global recycling rate is only 10% to 13% (Krishnamurthy et al, 2019). The best way to reduce the impact of plastics is to develop degradable, biopolymers.

Polymers derivative from sustainable materials for example is starches, fibres, celluloses, or chitins are a great way to do this. The change from oil-based to degradable polymers is slow and inconsistent. Companies prefer to recycle plastic instead of investing in new polymers because the new polymers are weaker and don't block out moisture as well (Phelan et al, 2022) (Kan et al, 2022). Starch is a popular choice for degradable plastic because it is biodegradable, but it has limitations. Petroleum-based plastics are more water-resistant and stronger to compete with starch films. Nanomaterials such as cellulose, starch, chitin, and chitosan; metal oxides such as titanium dioxide, zinc oxide, and zirconium oxide; and essential oils such as carvacrol, eugenol, and cinnamic acid are often used to improve physical characteristics such as strength, stability, moisture resistance, oxygen barrier ability, and biodegradation rate (Muñoz-Gimena et al, 2023).

Zinc oxide (ZnO), a semiconductor material with favourable environmental properties, is non-toxic and exhibits a wide band gap; these characteristics make it suitable for use in the synthesis of degradable plastics derived from arrow root starch (Song et al, 2023) (Xu et al, 2021). Nanostructured zinc oxide is non-toxic and exhibits high stability. It has the potential to enhance the mechanical and barrier properties of polymers (Li et al, 2022). Previous studies have demonstrated that the incorporation of SiO_2–ZnO nanoparticles has the potential to enhance the properties of semi-refined ι-carrageenan (SRiC) films (Praseptiangga et al, 2021). Furthermore, the incorporation of a combination of Ag, ZnO, and CuO nanoparticles into the active starch film resulted in enhanced mechanical and antimicrobial characteristics (Peighambardoust et al., 2019). Armynah et al (2022) mixed zinc oxide into a bioplastic made from cassava starch, a type of sugar found in plants, and a natural fibre found in pineapple leaves. This made the bioplastic stronger and also showed that it could kill microbes. Sapei et al (2017) examined the impact of ZnO incorporation on the characteristics of chitosan-banana starch bioplastics.

The novel aspect of this research on degradable plastics is the utilisation of starch derived from arrowroot in combination with zinc oxide as a filler material. The tuber of arrowroot (*Maranta arundinacea*) is a member of the *Marantaceae* family and is composed of a substantial quantity of starches, fibres, carbohydrate. Arrowroot starch possesses a number of beneficial properties, including high digestibility and gel-forming ability. Additionally, it exhibits the highest amylose content (40.86%) compared to other starch sources, such as corn (28–33%), cassava (16–19%), wheat (30–32%), and potato (18–20%) (Sandoval Gordillo et al, 2014). A study was conducted on the use of zinc oxide (ZnO) reinforcement in the production of degradable plastics via the casting method. The concentrations of ZnO employed were (10, 20, 30 and 40%) with the taro tuber starch mass ranging from (10, 15, 20 dan 25 g). The objective is to optimise the mechanical and thermal characteristics, functional group contents, water resistance, biodegradability for degradable plastics through the use of different ZnO concentration variations.

2. Materials and Methods

Arrowroot tubers are obtained from plantations in Simpang Keuramat Village, North Aceh, and the starch is produced through several processes, such as cleaning, chopping, starch extraction, settling, drying, and refining. Glycerol 99% Sigma – Aldrich and ZnO from Sigma Aldrich - Molecular Weight: 81.39. The research method was conducted in several stages. Initially, arrowroot starch was prepared; subsequently, a synthesis of degradable plastics was carried out, and the resulting plastics were tested.

2.1. Preparation of Arrowroot Starch

The arrowroot tubers are peeled and washed thoroughly. Cut into small pieces, then blended until it becomes a coarse porridge. Add water to the blended ingredients at a ratio of 1 kg of ingredients to 2 liters of water to extract the starch, then stir. The extraction process produces two layers, namely liquid (starch suspension) and pulp. The dregs and starch are separated. The starch suspension is then precipitated for 1 hour to produce to separate the liquid with starch so that wet starch is obtained. After that, it was dried 48 hours outdoors, until dry. The starch powder was pulverized with a mortar and then sieved with an 80 mesh sieve.

2.2. Degradable Plastic Preparation

Weigh a predetermined amount of material using a digital balance. Put the arrowroot tuber starch with variations of 10, 15, 20 and 25 g into a 500 ml beaker glass then add 100 ml of distilled water while stirring. Then add ZnO with variations of 10, 20, 30 and 40% from the weight of starch. While stirring. After that, add glycerol 20% of the starch weight little by little. After the solution is fully stirred, heating and stirring on a hot plate at 70°C for 40 minutes. After that, the mixture was cast into a mold, then dry using an oven at 75°C for 10 hours. After drying, it was left at room temperature for 24 hours. Degradable plastics that have been formed are then released for further analysis and testing.

2.3. Characterization and Testing

2.3.1. Mechanical Properties

The American Standard Testing and Materials (ASTM) D-638 modified plastics test for mechanical degradation was performed with five replicates. The tensile strength and elongation can be calculated using the following equations: Equation (1) for tensile strength and Equation (2) for elongation.

$$\sigma = \frac{F_{max}}{A} \quad (1)$$

σ is tensile strength (MPa), F_{max} is maximum stress (N) and A is area of film under stress (mm²).

$$\varepsilon = \frac{\triangle l}{l_0} \quad (2)$$

ε represents strain (MPa), l is gauge length (mm²), and l_0 is the initial sample length (mm²).

The Young's modulus formula is:

$$E = \frac{\sigma}{\varepsilon} \quad (3)$$

E is Young's modulus (MPa), σ is tensile strenght (MPa) and ε is strain (MPa).

2.3.2. Chemical Properties

Fourier-transform infrared spectroscopy (FTIR) is a technical employed for the identification of compounds, the detection of functional groups, and the acquisition of information regarding mixtures and samples. FTIR is a form of infrared spectroscopy that employs a Fourier transform for the detection and analysis of spectra. By utilising the FTIR tool, it is possible to ascertain the identity of the compounds that constitute the degradable plastic and the functional groups that are bound to it. The wavelength at which the sample is absorbed provides insight into its chemical composition and wave numbers ranging from 550 to 4000 cm^{-1}.

2.3.3. Thermal Properties

The thermal resistance of degradable plastics is evaluated through thermogravimetric analysis (TGA) tests. The TGA test records the change in mass of a sample undergoing dehydration, decomposition, and oxidation over time and temperature. Thermal degradation refers to the process in which a polymer is broken down due to the application of heat. The temperature at which the polymer degrades is referred to as the upper limit for operational temperature. The stability of degradable plastics is evaluated through the use of TGA (thermogravimetric analysis) apparatus, specifically model TGA50 SrC30025100553. The stability of degradable plastics is susceptible to changes resulting from the application of heat during physical changes, including glass transition and melting.

2.3.4. Water Absorption

The objective of the swell test was to analyse the resistance of degradable plastics to water absorption. In order to ascertain the swelling rate, the ASTM D2765 standard was employed. The plastic sample was weighed and then immersed in a solvent for a period of 24 hours. Subsequently, the sample was reweighed once it had undergone the aforementioned processes and reached a state of equilibrium. The final mass was recorded. The swelling rate was determined using the following Equation (3):

$$\text{Swelling Degree } \frac{\text{Weight of extended sample} - \text{Weight of initial sample}}{\text{Initial sample}} \times 100\% \quad (3)$$

2.3.5. Biodegradability Rate with Soil Burial

The rate of microbial degradation was determined by subjecting the plastic to burial in soil. In accordance with the ASTM G-21-70 standard, a biodegradability analysis was conducted by measuring the direct contact of the degradable plastic with the soil. A section of plastic measuring 5 × 2 cm was removed and the mass was recorded in grams as the initial mass (M_0). Subsequently, the sample was buried at a depths of 30 cm in soil, and inspections were conducted over a four-day period. Subsequently, the sample was weighed once more in order to ascertain its final mass (M_1). To work out how quickly the plastic was breaking down, the following equation was used:

$$\text{Biodegradabillity (\%)} = \frac{M0 - M1}{M0} \times 100\% \quad (4)$$

M_0 is the initial mass (g) and M_1 is the final mass (g).

3. Results and Discussion

3.1. Mechanical Properties Analysis

The mechanical characteristics of arrowroot starch-based degradable plastics varying from (10, 15, 20 and 25 g) with various ZnO fillers (10, 20, 30 and 40% of starch weight) were evaluated, can be seen in **Table 1**. Tensile strength showed an inverse correlation with elongation, while Young's modulus showed a direct correlation with elongation.

Table 1 presents the tensile strength values associated with arrowroot starch-based degradable plastics, as influenced by the addition of ZnO. The values ranged from (2.0926 to 2.6118 MPa at 10 g starch mass), (2.0552 to 4.777 MPa at 15 g starch mass), (2.0231 to 2.5211 MPa at 20 g starch mass) and (1.1944 to 1.6064 MPa at 25 g starch mass). The table shows that the use of ZnO has an effect on the tensile strength properties of the resulting biodegradable plastic. Where it can be seen that, the greater the ZnO used, the more the tensile strength of the degradable plastic increases. Conversely, lower ZnO concentrations resulted in reduce tensile strength. The use of starch mass also affects the amount of ZnO used, where the more starch used the lower the tensile strength obtained. Starch has been shown to be a hydrophilic polymer (i.e., one with an affinity and capacity for water binding), which can be attributed to its structure's abundance of hydroxyl groups. These groups have the capacity to form hydrogen bonds with water molecules (Zarski et al, 2021).

Table 1. Effect of ZnO on mechanical properties for arrowroot starch and ZnO-based degradable plastics

Starch (g)	ZnO (%)	Tensile Strenght (MPa)	Elongation (%)	Young's modulus (MPa)
10	10	2.0926	10.90	**15.35**
	20	2.2253	7.38	24.12
	30	2.4330	6.95	28**.00**
	40	2.6118	6.54	31.94
15	10	2.0552	11.01	14.93
	20	2.3019	12.60	14.61
	30	4.7770	1.78	14.69
	40	2.956	9.22	25.64
20	10	2.0231	7.82	20.69
	20	2.2917	6.69	27.40
	30	2.4493	7.16	27.36
	40	2.5211	7.87	25.62
25	10	1.1944	5.01	19.07
	20	1.4673	5.09	22.65
	30	1.5135	5.06	23.92
	40	1.6064	5.18	24.80

In contrast, some polymer matrices or materials exhibit hydrophobic properties (water-repellent characteristics) (Vardhan et al, 2025). The use of 15 g starch mass and 30% ZnO has the highest value of 4.777 MPa. The Indonesian National Standard (SNI) sets the tensile strength range for plastics between 24.7 and 302 MPa. Degradable plastics from arrowroot starch and ZnO have not met this value. The stirring factor may also be influential in order to stabilise the tensile strength properties obtained (Dewi et al, 2024). The addition of ZnO particles makes degradable plastics stronger and more resistant to bacteria. The most effective method for achieving this objective entails subjecting the mixture to a heating and agitation process for a duration of 40 minutes, operating within a temperature range of 80 to 90°C. Glycerol solution is also needed to make degradable plastics flexible (Hendrawati et al, 2023).

Table 1 also shows the elongation values of arrowroot starch-based degradable plastics with ZnO. The elongation values obtained ranged from (6.54 - 10.9% at 10 g starch); (1.78 - 12.6% at 15 g starch); (6.69 - 7.87% at 20 g starch) and (5.01 - 5.18%). The values obtained are not stable. The highest elongation value was observed at a starch mass of 15 g and a ZnO concentration of 20%, with an elongation value of 12.6% at this point. The SNI value for bioplastic elongation is estimated between 21 to 220%. The elongation in this research has not met the SNI standard value. The elongation value is similar to PET (15 to 165%) (Tian et al, 2024). Darni et al (2024) made bioplastics from starch with chitosan filler. This bioplastic has a tensile strength 8.258 MPa, elongation 2.472%, Young's modulus 334.065 MPa, water absorption 87.500%, and density 0.762 grams/ml. Vyas et al (2025) reported that the enhanced mechanical properties were due to the uniform dispersion of ZnO nanoparticles (ZnO NPs) and the development of hydrogen bonding between ZnO and the carboxymethyl cellulose matrix. The most significant tensile strength was exhibited by the ZnO NPs 20% film, at 15.12 ± 1.28 MPa.

When pressure is removed, the material returns to its original shape. The ratio of stress to strain is kept constant and is called the Young’s modulus. In particular, it has been observed that, under certain conditions, the Young's modulus and the elongation value may be equivalent. The Young’s modulus shows how much tensile force a material can withstand. The values for the elastic modulus are presented in **Table 1**, with the following results for the specified quantities of starch: (15.35 - 31.94 MPa for 10 g starch); (14.61 - 214.69 MPa for 15 g starch); (20.69 - 27.40 MPa for 20 g starch); and (19.07 - 24.80 MPa for 25 g starch). The Young’s modulus value obtained using 15 g starch mass and 30% ZnO has a very high value of 214.69 MPa). A review of the Mat Web Material Property database for polypropylene shows that the Young's modulus is in the range of 680 - 3600 MPa. The Young's modulus value of the degradable plastics in this study has not yet met this value. The way a bioplastic material responds to mechanical forces depends on its state, especially whether it has a crystalline structure and the extent to which it is amorphous (Fabra et al, 2018).

3.2. Chemical Properties Analysis

FTIR (Fourier Transform Infrared) represents a specific instrument that employs the principles of spectroscopy. The identification of organic compounds is made possible by the very complex spectrum of infrared spectroscopy, which is characterised by a multitude of peaks. In order to analyse the samples, this study employed the use of FTIR, with measurements taken at a series of wave numbers, ranging from 550 to 4000 cm^{-1}. The results of the FTIR analysis conducted on a degradable plastic sample comprising arrowroot starch (15 g) and ZnO (30%) are presented in **Figure 1**.

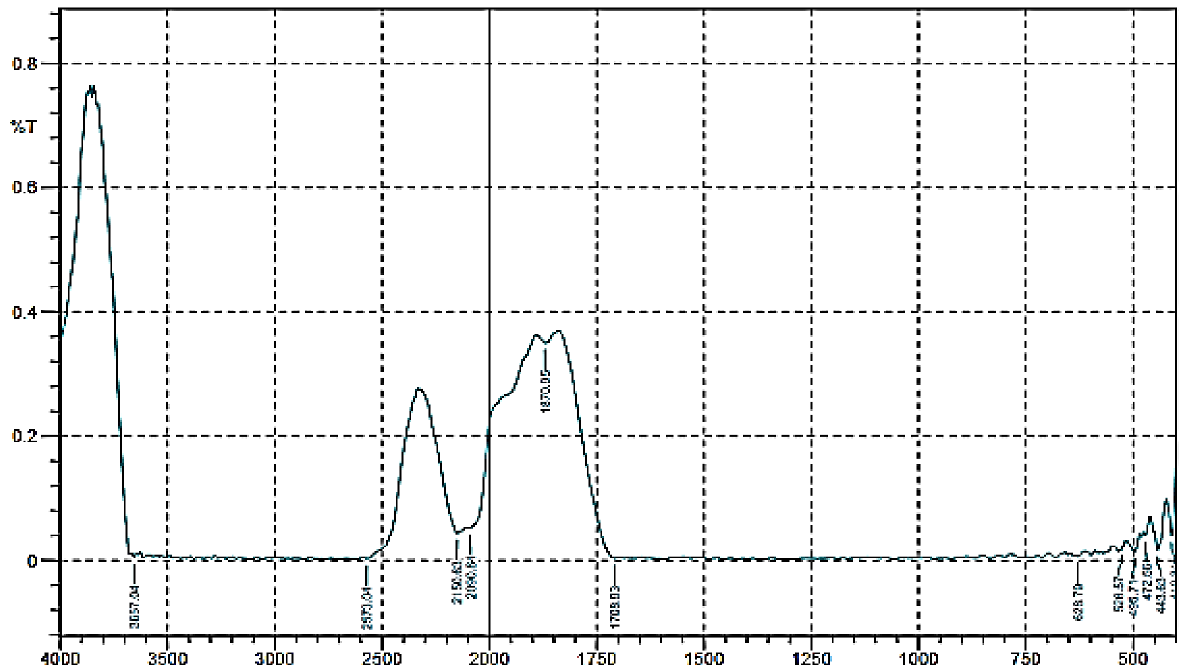

Figure 1. FTIR results on arrowroot starch and ZnO-based degradable plastics

Figure 1 shows that the wave number 3657.04 cm^{-1} (the peak is not significant) likely indicates the existence of O-H vibrations in the NaOH bond present the starch. Wavenumbers between 2100 and 2500 cm^{-1} are indicative of hydroxyl groups present in the starch. Conversely, wave numbers 2573.04 cm^{-1}, 2150.63 cm^{-1} and 2090.84 cm^{-1} are indicative of a CH_2 bond, which is a characteristic of glucose content in arrowroot starch. Jiménez et al (2022) on the production of Hass avocado seed starch bioplastics, a peak wavelength of 2919 cm^{-1} was observed, which is indicative of CH bonds associated with methyl groups. Furthermore, the observed vibration range around 528.57 cm^{-1}, 496.71 cm^{-1}, 472.66 cm^{-1} and 443.63 cm^{-1} is indicative of the Zn-O bond of the inorganic nanomaterial. The addition of glycerol to the starches resulted in a reduction of the O-H stretching band, indicating that the films containing glycerol formed stronger hydrogen bonds with water (Aghazadeh et al, 2018). The characteristic peak at 3298 cm^{-1} (associated with the O–H bond) was observed to shift to 3300 cm^{-1} for the films comprising 10–30% glycerol. These shifts indicated that the addition of glycerol facilitated hydrogen bonding interactions between starch and glycerol (Sirbu et al, 2024).

Navasingh et al (2023) made bioplastics from rice starch and tapioca with $CaCO_3$ and plasticisers. The presence of C-H groups is indicated by the appearance of peaks at 2883 cm^{-1} and 3000 cm^{-1}. The starch makes these groups appear. This looks like a sample made with glycerol. At 1500, an N-H group of amines makes a reaction between maleic anhydride and NaOH to make degradable plastics. The researcher says that the substances interact and dissolve with each other, as shown by the shift in peaks on the FTIR spectrum. The FTIR analysis of arrowroot starch-based plastic with ZnO filler shows organic groups. The plastic is hydrophilic, binds to water, and has ester groups. These groups make it susceptible to soil degradation (Srihanam et al, 2023).

3.3. Thermal Properties Analysis

The thermal stability of degradable plastics can be evaluated through a thermogravimetric analysis (TGA), which assesses the effects of polymer heating during physical transitions, including those associated with the glass transition and melting of the polymer. The TGA test employed starch (15 g) and ZnO (30%) in the degradable plastic, generating a curve that depicts the change in mass versus temperature (**Figure 2**).

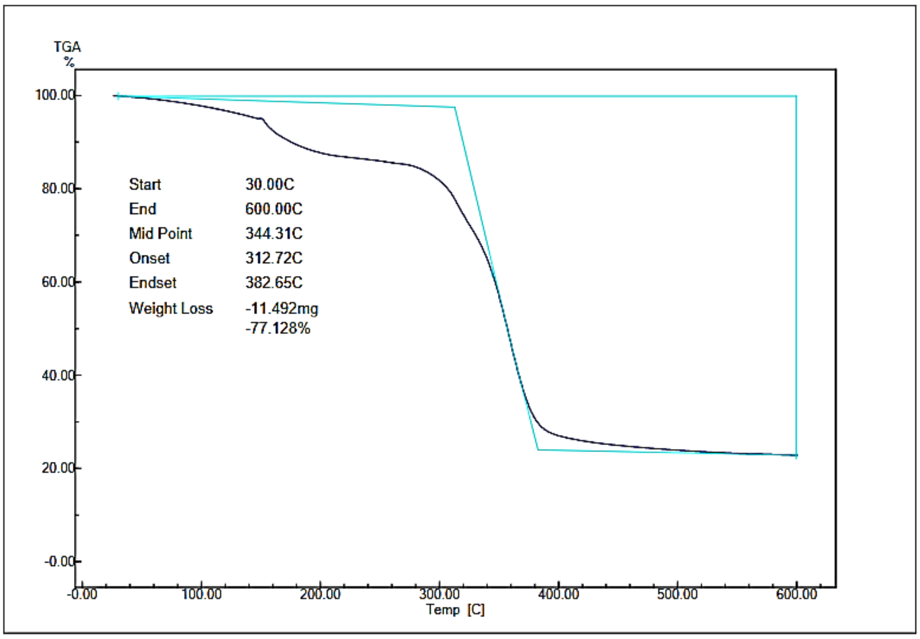

Figure 2. TGA results on arrowroot starch and ZnO-based degradable plastics

The thermogravimetric analysis (TGA) of arrowroot starch-based and ZnO degradable plastic are presented in **Figure 2**. It is evident that weight loss occurs in the case of degradable plastic. The rate of mass loss of the specimen is relatively slow at 30°C. It can be attributed to the presence of contaminants and other substances added to the degradable plastic at this temperature. The extreme weight loss commences at temperatures between 312.72°C to 344.31°C, resulting in the loss of ZnO, glycerol and starch (Sirbu et al, 2021). Mass loss was observed for the degradable plastic samples, which showed mass loss between 77.128% and 11.492 mg. The majority of the raw undergoes decomposition and is fully exhausted at 600°C.

This research, the samples of degradable plastic were subjected to a significant degree of thermal degradation. Thermal analysis of the TGA reveals that the change in thermogram is a consequence of the transfer of heat to the degradable plastic, which then initiates a series of structural and phase changes within the material. The notable loss in weight within the temperature range of 250-300°C is attributed to the degradation of gelatine and starch. It can therefore be concluded that the prepared sample is suitable for use in applications that operate at high temperatures (Marichelvam et al, 2019). Plasticisers make it easier for the OH groups in the starch molecules to form new hydrogen bonds with the plasticisers. This leads to the formation of homogenous thermoplastic starch with increased chain mobility, decreased glass transition temperature, and consequently improved ductile and extension properties (Narancic et al, 2020). It can be concluded that the higher the residual weight of arrowroot starch and ZnO-based degradable plastics that have undergone decomposition, the greater the thermal resistance.

3.4. Water Absorption Analysis

The term'water absorption is used in the field of degradable plastics to describe the process by which water is absorbed into the material. This is an important characteristic to assess as it determines the extent to which the material will resist the ingress of water. **Figure 3** shows how the water resistance test of arrowroot starch-based degradable plastics (10, 15, 20 and 25 g) with various ZnO fillers (10, 20, 30 and 40% of starch weight) by swelling test.

Figure 3 shows the swelling values obtained in arrowroot starch-based degradable plastics with ZnO fillers at 10 g starch (17.59 - 41.48%); 15 g (40.96 - 73.82%); 20 g (25.35 - 63.21%) and 25 g starch (17.59 - 59.45%). From the results obtained, the mass of starch and ZnO used affects the value of water absorption produced. The greater the percentage of ZnO used, the greater the water absorption value of the degradable plastic. When using 25 g of starch mass and 25% ZnO, the lowest water absorption value was 17.59%. The hydrophilic nature and high moisture flexibility of the starch facilitate the movement of water into the starch-soaked area during the soaking process. Furthermore, the incorporation of plasticisers influences the water resistance of degradable plastics (Abidin et al, 2020). As in previous research, the production of bioplastic films from taro starch with the addition of bentonite demonstrated enhanced resilience to saline and acidic environments; however, it exhibited reduced resistance to alkali and minimal expansion. The results of the soil degradability tests demonstrated that the film was biodegradable and could be employed as a substitute for conventional plastics (Mohd Zain et al, 2019).

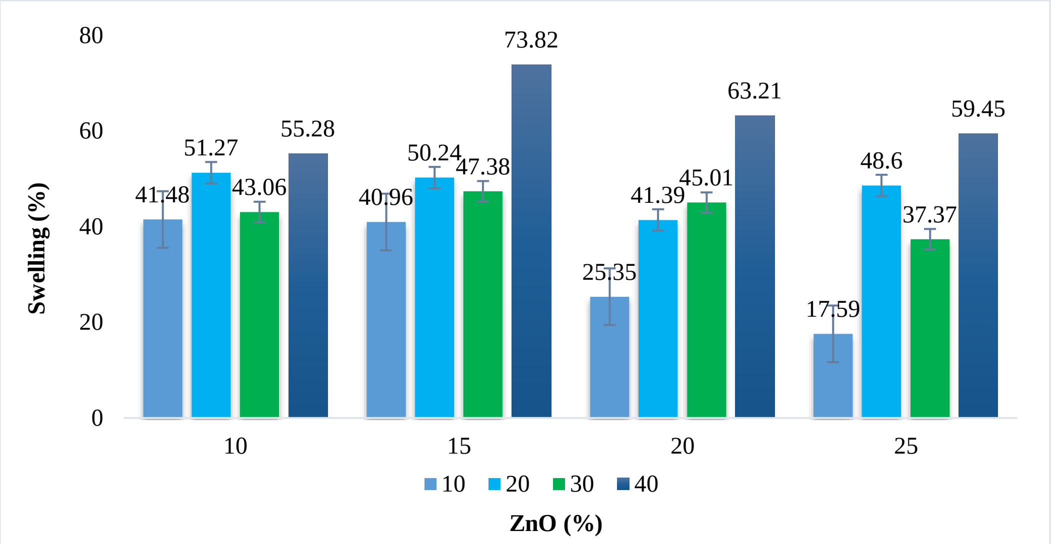

Figure 3. Water absorption results on arrowroot starch and ZnO-based degradable plastics

A study on bioplastics from the cocoyam plant showed that adding gelatin and glycine increased water absorption to 60.41%. The sample with vegetable oil absorbed the least, at 10.49%. This is because oil is hydrophobic, which means it repels water. This is good for products that need to be water-resistant (Enwere et al, 2024).

3.5. Biodegradability Rate with Soil Burial Analysis

Microorganisms represent a key factor in the degradation of degradable plastics. Biodegradation breaks down carbon at the end of the useful lives of degradable polymers, without releasing harmful compounds (Folino et al, 2020). **Table 2** shows the results of a biodegradability test of arrowroot starch-based plastic with different concentrations of ZnO filler.

This research employed arrowroot starch and varying quantities of ZnO, with a view to ascertaining the impact of the resulting degradation rate on the material in question. From the results obtained, the average degradable plastic decomposed completely on the 19th day. Furthermore, the use of (10 g starch; 10% ZnO), (15 g starch; 10% ZnO), (20 g starch; 10% ZnO) took less time to fully degrade. From the results obtained it is also evident that the use of ZnO has an effect on the rate of plastic decomposition. The more ZnO used, the faster the degradable plastic decomposes, the less ZnO used, the longer the degradable plastic takes to decompose. For example, the combination of chitosan and starch-based bioplastics with PP showed complete biodegradation in 28 days, which demonstrates the efficacy of synthetic polymers as reinforcing materials in facilitating the biodegradation of bioplastics (Jangong et al, 2019).

Table 2. Biodegradability rate results on arrowroot starch and ZnO-based degradable plastics

Starch (g)	ZnO (%)	Weight Loss (%)							
		Day 3	Day 6	Day 9	Day 12	Day 15	Day 18	Day 19	Day 20
10	**10**	15.14	28.30	42.55	54.45	70.79	83.49	97.24	100.00
10	**20**	16.18	29.51	44.12	57.60	73.68	87.15	100.00	100.00
10	**30**	17.65	31.03	46.43	59.90	75.97	89.85	100.00	100.00
10	**40**	18.94	33.09	50.21	62.81	79.65	94.28	100.00	100.00
15	**10**	16.10	27.14	45.24	53.16	70.86	83.16	96.72	100.00
15	**20**	17.17	30.43	48.92	55.88	73.93	86.96	100.00	100.00
15	**30**	18.53	33.55	51.75	59.81	77.94	91.84	100.00	100.00
15	**40**	18.94	35.96	52.94	62.75	81.86	96.27	100.00	100.00
20	**10**	16.51	29.11	46.71	54.56	72.78	85.33	99.13	100.00
20	**20**	17.72	32.34	48.86	57.82	75.85	89.05	100.00	100.00
20	**30**	16.60	34.14	51.70	59.78	78.98	93.36	100.00	100.00
20	**40**	18.87	36.34	52.95	62.94	82.90	97.19	100.00	100.00
25	**10**	16.80	32.21	45.95	58.53	75.45	88.88	100.00	100.00
25	**20**	17.80	34.42	48.54	59.78	79.56	92.69	100.00	100.00
25	**30**	18.14	35.85	51.96	61.90	81.76	95.91	100.00	100.00
25	**40**	18.80	36.72	53.92	63.89	83.74	98.53	100.00	100.00

Other studies have shown that the use of bentonite in taro starch bioplastics affects how quickly it decomposes. The more bentonite used, the slower the decomposition. How much filler is added affects how biodegradable it is (Post et al, 2021). The degradation rate of biodegradable plastics is influenced by a number of factors, including the composition of the polymer, soil moisture levels and the surrounding environmental conditions (Elgharbawy et al, 2024). The ASTM D5338 standard serves as a assessment guidelines of compostability in degradable plastics, in conjunction with the ASTM D-20.96 standard on environmentally degradable plastics. The criteria for degradable plastics are defined within this standard. In order to meet the standard, products comprising a single polymer (either a homopolymer or a random copolymer) must undergo a conversion of at least 60% organic carbon to carbon dioxide within a period of 180 days (Dewi et al, 2023).

5. Conclusion

The strength of arrowroot starch plastic can be increased by adding ZnO. The values ranged from 2.09 to 2.61 MPa at 10 g starch mass, 2.06 to 4.77 MPa at 15 g starch mass, 2.02 to 2.52 MPa at 20 g starch mass and 1.19 to 1.61 MPa at 25 g starch mass. The incorporation of ZnO into the plastic matrix is directly proportional to the resulting mechanical strength. The amount of ZnO used is directly proportional to the weakness of the plastic. The incorporation of a greater quantity of starch into a given plastic composition is directly proportional to the observed reduction in its tensile strength. The FTIR analysis shows that the wave number 3657.04 cm^{-1} is the O-H bond. Wavenumbers 2100-2500 cm^{-1} show the hydroxyl group of starch. The 1723 C=O, 1290 C-O-C bond, which is a type of glucose found in arrowroot starch. Also, there are vibrational ranges around 528.57, 496.71, 472.66 and 443.63 cm^{-1} that show the presence of Zn-O bonds from inorganic nanomaterials. In TGA analysis, the most extreme weight loss happens at temperatures between 312.72°C and 344.31°C. The aforementioned factors result in the loss of ZnO, glycerol, and starch. The plastic samples loss mass, with the majority decomposing fully at 600°C. The amount of starch and ZnO affects how much water the substance absorbs. The more ZnO, the greater the water absorption. The lowest water absorption value is 17.59% when 25 g of starch and 25% ZnO are used. In biodegradability analysis, degradable plastics decompose completely on average by day 19. The use of ZnO affects the rate of plastic degradation. More ZnO means faster decomposition. Less ZnO means longer decomposition times.

Acknowledgement

The present study was performed within the Chemical Engineering Research Lab at the Faculty of Engineering, Malikussaleh University, Aceh.

Credit Author Statement

Conceptualization, D.R. and A.A.; methodology, S.N. and S.M.; validation, R.M., C.T. and S.P.J.; formal analysis, A.A.; investigation, S.N. and S.M.; resources, D.R. and R.M.; data curation, D.R.; writing—original draft preparation, A.A.; writing—review and editing, D.R. and S.P.J.; visualization, R.M.; supervision, C.T. and S.M.; project administration, D.R.

Conflict of Interest

The authors declare no conflict of interest.

Artificial Intelligence (AI) Transparency Statement

Artificial intelligence tools, such as ChatGPT were used only to enhance grammar, clarity, and manuscript readability. They were not used to generate, analyze, or interpret data, nor to create scientific hypotheses, conclusions, or literature reviews. All content remains the intellectual product of the authors. Any AI-assisted text was carefully checked, revised, and validated to ensure compliance with research integrity and publisher guidelines.

References

Abidin, N. D. Z., Azhar, N. S., Sarip, M. N., Hamid, H. A., & Nasir, N. A. H. A. (2021). Production of bioplastic from cassava peel with different concentrations of glycerol and $CaCO_3$ as filler. *AIP Conference Proceedings, 020004*. https://doi.org/10.1063/5.0043482

Aghazadeh, M., Karim, R., Rahman, R. A., Sultan, M. T., Johnson, S. K., & Paykary, M. (2018). Effect of glycerol on the physicochemical properties of cereal starch films. *Czech Journal of Food Sciences*, *36*(5), 403–409. https://doi.org/10.17221/41/2017-CJFS

Armynah, B., Anugrahwidya, R., & Tahir, D. (2022). Composite cassava starch/chitosan/pineapple leaf fiber/ZnO bioplastics with high mechanical properties and faster degradation. *International Journal of Biological Macromolecules*, *213*, 814–823. https://doi.org/10.1016/j.ijbiomac.2022.06.038

Darni, Y., Lesmana, D., Puspita, W. P., Lismeri, L., Utami, H., & Ginting, S. B. (2024). Enhancing mechanical and physical properties of bioplastics: Impact of starch/chitosan mass ratio and corn stem cellulose nanofiber filler. In A. Zakaria et al. (Eds.), *Proceedings of the 1st International Conference on Industry Science Technology and Sustainability (IConISTS 2023)* (Vol. 235, pp. 315–334). Atlantis Press. https://doi.org/10.2991/978-94-6463-475-4_27

Dewi, R., Sylvia, N., & Riza, M. (2023). Characterization of degradable plastics from sago and breadfruit starch with zinc oxide catalyst and polyvinyl alcohol. *Jurnal Kimia Sains dan Aplikasi*, *26*(11), 427–436. https://doi.org/10.14710/jksa.26.11.427-436

Dewi, R., Sylvia, N., Zulnazri, Z., Fithra, H., Riza, M., Siregar, J. P., Cionita, T., Fitriyana, D. F., & Anis, S. (2024). Optimization of avocado seed starch-based degradable plastic synthesis with PLA blend using response surface methodology. *Polymers*, *16*(16), 2384. https://doi.org/10.3390/polym16162384

Elgharbawy, A. S., El Demerdash, A.-G. M., Sadik, W. A., Kasaby, M. A., Lotfy, A. H., & Osman, A. I. (2024). Synthetic degradable polyvinyl alcohol polymer and its blends with starch and cellulose: A comprehensive overview. *Polymers*, *16*(10), 1356. https://doi.org/10.3390/polym16101356

Enwere, C. F., Okafor, I. S., Adeleke, A. A., Petrus, N., Jakada, K., Olosho, A. I., Ikubanni, P. P., Paramasivam, P., & Ayuba, S. (2024). Production of bioplastic films from wild cocoyam (*Caladium bicolor*) starch. *Results in Engineering*, *24*, 103132. https://doi.org/10.1016/j.rineng.2024.103132

Fabra, M. J., Martínez-Sanz, M., Gómez-Mascaraque, L. G., Gavara, R., & López-Rubio, A. (2018). Structural and physicochemical characterization of thermoplastic corn starch films containing microalgae. *Carbohydrate Polymers*, *186*, 184–191. https://doi.org/10.1016/j.carbpol.2018.01.039

Folino, A., Karageorgiou, A., Calabrò, P. S., & Komilis, D. (2020). Biodegradation of wasted bioplastics in natural and industrial environments: A review. *Sustainability*, *12*(15), 6030. https://doi.org/10.3390/su12156030

Gamage, A., Thiviya, P., Liyanapathiranage, A., Wasana, M. L. D., Jayakodi, Y., Bandara, A., Manamperi, A., Dassanayake, R. S., Evon, P., Merah, O., & Madhujith, T. (2024). Polysaccharide-based bioplastics: Eco-friendly and sustainable solutions for packaging. *Journal of Composites Science*, *8*(10), 413. https://doi.org/10.3390/jcs8100413

Hendrawati, Liandi, A. R., Ahyar, H., Maladi, I., Azhari, A., & Cornelia, M. (2023). Influence of rice husk cellulose, PVA, and ZnO fillers on cassava biodegradable plastic. *Case Studies in Chemical and Environmental Engineering*, *8*, 100520. https://doi.org/10.1016/j.cscee.2023.100520

Jangong, O. S., Gareso, P. L., Mutmainna, I., & Tahir, D. (2019). Fabrication and characterization of starch/chitosan reinforced polypropylene as biodegradable material. *Journal of Physics: Conference Series*, *1341*(8), 082022. https://doi.org/10.1088/1742-6596/1341/8/082022

Jiménez, R., Sandoval-Flores, G., Alvarado-Reyna, S., Alemán-Castillo, S. E., Santiago-Adame, R., & Velázquez, G. (2022). Extraction of starch from Hass avocado seeds for biofilm preparation. *Food Science and Technology*, *42*, e56820. https://doi.org/10.1590/fst.56820

Kan, M., & Miller, S. A. (2022). Environmental impacts of plastic food packaging. *Resources, Conservation and Recycling*, *180*, 106156. https://doi.org/10.1016/j.resconrec.2022.106156

Krishnamurthy, A., & Amritkumar, P. (2019). Synthesis and characterization of eco-friendly bioplastic from low-cost plant resources. *SN Applied Sciences*, *1*(11), 1432. https://doi.org/10.1007/s42452-019-1460-x

Li, J., Zhang, G., & Zhang, D. (2022). Structural optimization of sorghum straw/ZnO/PVA nanocomposite films. *Coatings*, *12*(8), 1226. https://doi.org/10.3390/coatings12081226

Marichelvam, M. K., Jawaid, M., & Asim, M. (2019). Corn and rice starch-based bioplastics as alternative packaging materials. *Fibers*, *7*(4), 32. https://doi.org/10.3390/fib7040032

Mohd Zain, A. H., Ab Wahab, M. K., & Ismail, H. (2019). Effect of calcium carbonate on LLDPE/thermoplastic starch blends. *Journal of Engineering Science*, *15*(2), 97–108. https://doi.org/10.21315/jes2019.15.2.7

Muñoz-Gimena, P. F., Oliver-Cuenca, V., Peponi, L., & López, D. (2023). Reinforcements and additives in starch-based composites for food packaging. *Polymers*, *15*(13), 2972. https://doi.org/10.3390/polym15132972

Narancic, T., Cerrone, F., Beagan, N., & O'Connor, K. E. (2020). Recent advances in bioplastics: Application and biodegradation. *Polymers*, *12*(4), 920. https://doi.org/10.3390/polym12040920

Navasingh, R. J. H., Gurunathan, M. K., Nikolova, M. P., & Królczyk, J. B. (2023). Sustainable bioplastics for food packaging from renewable resources. *Polymers*, *15*(18), 3760. https://doi.org/10.3390/polym15183760

Peighambardoust, S. J., Peighambardoust, S. H., Pournasir, N., & Mohammadzadeh Pakdel, P. (2019). Active starch-based films incorporating Ag, ZnO, and CuO nanoparticles. *Food Packaging and Shelf Life*, *22*, 100420. https://doi.org/10.1016/j.fpsl.2019.100420

Phelan, A., Meissner, K., Humphrey, J., & Ross, H. (2022). Plastic pollution and packaging: Corporate commitments and actions. *Journal of Cleaner Production*, *331*, 129827. https://doi.org/10.1016/j.jclepro.2021.129827

Post, W., Kuijpers, L. J., Zijlstra, M., Van der Zee, M., & Molenveld, K. (2021). Effect of mineral fillers on biodegradable polymers. *Polymers*, *13*(3), 394. https://doi.org/10.3390/polym13030394

Praseptiangga, D., Widyaastuti, D., Panatarani, C., & Joni, I. M. (2021). Development of carrageenan/SiO_2–ZnO bionanocomposite film. *Foods*, *10*(11), 2776. https://doi.org/10.3390/foods10112776

Sandoval Gordillo, C. A., Ayala Valencia, G., Vargas Zapata, R. A., & Agudelo Henao, A. C. (2014). Physicochemical characterization of arrowroot starch and membranes. *International Journal of Food Engineering*, *10*(4), 727–735. https://doi.org/10.1515/ijfe-2014-0122

Sapei, L., Padmawijaya, K. S., Sijayanti, O., & Wardhana, P. J. (2017). Influence of ZnO on chitosan–banana starch bioplastics. *IOP Conference Series: Materials Science and Engineering*, *223*, 012044. https://doi.org/10.1088/1757-899X/223/1/012044

Sirbu, E.-E., Dinita, A., Tănase, M., Portoacă, A.-I., Bondarev, A., Enascuta, C.-E., & Calin, C. (2024). Influence of plasticizer concentration on starch films. *Processes*, *12*(9), 2021. https://doi.org/10.3390/pr12092021

Song, D., Ma, L.-W., Pang, B., An, R., Nie, J.-H., Guo, Y.-R., & Li, S. (2023). Active bio-based packaging using ZnO. *International Journal of Molecular Sciences*, *24*(2), 1577. https://doi.org/10.3390/ijms24021577

Srihanam, P., Thongsomboon, W., & Baimark, Y. (2023). Mechanical and thermal properties of $CaCO_3$-reinforced bioplastics. *Polymers*, *15*(2), 301. https://doi.org/10.3390/polym15020301

Tian, J., Kong, Y., Qian, S., Zhang, Z., Xia, Y., & Li, Z. (2024). Robust starch films reinforced with nanofibrillated cellulose. *Composites Part B: Engineering*, *275*, 111339. https://doi.org/10.1016/j.compositesb.2024.111339

Vyas, A., Ng, S., Fu, T., & Anum, I. (2025). ZnO-embedded carboxymethyl cellulose bioplastic film from sugarcane bagasse. *Polymers*, *17*(5), 579. https://doi.org/10.3390/polym17050579

Xu, J., Huang, Y., Zhu, S., Abbes, N., Jing, X., & Zhang, L. (2021). Green synthesis of ZnO nanoparticles and applications. *Journal of Engineered Fibers and Fabrics*, *16*, 15589250211046242. https://doi.org/10.1177/15589250211046242