Journal of Applied Agricultural Science and Technology
7(3): 272-285 (2023)
E-ISSN: 2621-2528
ISSN: 2621-4709

CHARACTERISTICS OF EDIBLE FILM FROM CORN STARCH (*Zea mays L.)* WITH ADDITIONAL GLYCEROL AND VARIATIONS OF ZINC OXIDE (ZnO) NANOPARTICLES

Ifmalinda*, Siti Azzahra Kurnia, Dinah Cherie

Department of Agricultural Engineering and Biosystem, Andalas University, Padang, Indonesia

*Corresponding author
Email: ifmalinda@ae.unand.ac.id

Abstract*. Plastic is one of the most widely used packaging materials. Plastic is made of chemicals that are highly toxic, and its use has produced a lot of waste that is bad for the environment and difficult to decompose. The global community is becoming more and more aware of the value of high-quality food, particularly when it comes to packaging that is safe for human health and the environment. Edible films can be used as an eco-friendly alternative to plastic food packaging options. As a material for packaging, edible film made of biopolymers has been created. This material can be made from biodegradable components and has qualities akin to those of ordinary plastics. When combined with zinc oxide (ZnO), a piezoelectric ceramic with anti-microbial properties, edible film degrades and decomposes readily. This study sets out to identify the effects of variations in zinc oxide nanoparticle concentration properties of edible films made from corn starch (Zea mays L.) and to establish the optimal zinc oxide nanoparticle concentration. ZnO concentrations ranging from 0% to 3% to 9% to 12% were used. The outcomes demonstrated that a concentration of 12% provided the optimal treatment for the properties of edible film. With the addition of 12% ZnO concentration, the edible film's properties improved the most in this investigation, showing 81.94% water resistance, 1.434 MPa tensile strength, and 38.46% elongation percent. The lowest biodegradability value was found in edible film with a concentration of ZnO 12%, within 14 days. The resistivity, tensile strength, and % elongation of the edible film increase with increasing ZnO content.*
Keywords: *edible films; corn starch; tensile properties; water resistance; zinc oxide (ZnO)*

1. Introduction

One of the packaging materials that is commonly utilized in daily life is plastic. Plastic is a common packaging material used in daily life to safely wrap or protect food until it is in the hands of consumers. (Rahmawati *et al.*, 2022). Plastics contain chemicals that are quite dangerous and their use has also contributed a lot of waste that is difficult to decompose and is harmful to environmental health. Along with the times, the world community increasingly understands the importance of food quality, especially with regard to healthy and safety and environmentally friendly packaging, i.e. packaging that is easily degraded and degraded by natural composer. The current situation demands research on biodegradable packaging materials. According to Nazir and Wani (2022). A recent development in the packaging industry is the use of inexpensive, biodegradable edible films. The biodegradability of edible films can effectively cut down on the global consumption of plastics. An environmentally friendly substitute for plastic food packaging is edible coatings and films (Molnar *et al.*, 2022). A thin coating that can be used is called edible

Received March 21, 2023; Accepted July 19, 2023; Published August 25, 2023
https://doi.org/10.55043/jaast.v7i3.87

film, as a coating for food or agricultural products and can be made from starch. Because of its availability, biodegradability, renewability, ability to form films, and low cost, starch generated from a variety of botanical sources (such as cassava, corn, wheat, rice, potato, and pea) is one of the most promising natural polymers for packaging applications (Sapper, 2018). Hydrocolloids like starch, which are common in nature, are an example. Corn is one of the species in West Sumatera with a comparatively high starch content.

Corn is widely known by the people of Indonesia, especially eastern Indonesia, which makes corn as a staple food substitute for rice. Corn is a grain plant that has a very high carbohydrate content. The province of West Sumatra is an area with a fairly large corn production with the type of hybrid corn grown from one of the superior corn. Statistics record that in 2018, the total production of corn plants in West Sumatra reached 925,564 tons with the largest production produced by the West Pasaman Regency area with 367,865 tons (Central Bureau of Statistics of West Sumatra Province, 2016). Most of the corn production is intended to meet the needs of making animal feed. The large amount of corn production can be used for the manufacture of corn. Edible film is an alternative packaging that is environmentally friendly because it is biodegradable in nature. Intriguing characteristics for food packaging include edible films and coatings for fruits, vegetables, and bakery goods. Starch-based films are clear, tasteless, odorless, and colorless (Basiak *et al*., 2015). To increase the mechanical qualities of the edible film, such as its tensile strength and elasticity, edible films can be created by combining natural and synthetic polymers. The plastic made from corn starch *(Zea mays L.)* was used in the research and is still stiff. The level of plastic strength that is still low can cause the resulting plastic to be less elastic so it is not flexible to use. Therefore, it is necessary to add plasticizers to make the plastic more elastic and make the edible film more flexible and not easily broken. The type of plasticizer used is glycerol. Glycerol was chosen because of its common use and low price. According to Sinaga *et al*. (2013), because it has a high boiling point and is difficult to evaporate, glycerol works to increase elasticity by decreasing the degree of hydrogen bonding and increasing the intermolecular distance from the polymer.

In order to create edible films, glycerol and zinc oxide (ZnO) are also added as ingredients. Zinc oxide (ZnO), a piezoelectric ceramic with anti-microbial qualities, can decrease moisture, making food more durable if it is employed as a packaging material (Erfan, 2012). The main role of antimicrobial packaging is to prohibit the bacterial and fungal growth (Abdollahzadeh *et al.*2021). In this research, the addition of zinc oxide (ZnO) will be varied to determine the effect of the addition of zinc oxide (ZnO) on the characteristics of the biodegradable plastic produced.

Research on the manufacture of edible films from starch with the addition of glycerol and zinc oxide is limited. Some previous studies using zinc oxide concentration in the production of edible films include sweet potato starch (Erfan, 2012) gadung tuber starch (Saputra *et al*., 2019), tapioca and corn ampok (Rahmatunisa, 2015), cassava starch (Ridwan, 2018) and soy protein (Putri *et al*., 2018). The authors are interested in conducting a study on "Characteristics of the Edible Film from Corn Starch (*Zea mays* L.) with Addition of Glycerol and Variation of Zinc Oxide (ZnO) Nanoparticles" because several studies show that there is an effect of changing the characteristics of each addition of concentration or amount of zinc oxide nanoparticle reinforcement used. The purpose of this study was to determine the effect of varying concentrations of zinc oxide nanoparticles on the characteristics of edible films from corn starch *(Zea mays L.)* and to determine the best concentrations of zinc oxide nanoparticles as a mechanical strengthening agent for edible films made from corn starch *(Zea mays L.)* and effect on packaging in jackfruit.

2. Methods

2.1. Tools and Materials

The research's tools and resources included: the main ingredients were 10 kg of maize with hybrid varieties, aluminum foil, aquades (H_2O), glycerol ($C_3H_8O_3$), zinc oxide (ZnO), filter paper, tissue. The zinc oxide used in this study was zinc oxide obtained from T&T Chemical. The tools used in this research are magnetic stirrer, digital oven, analytical balance, screw micrometer, Torsee's electronic system universal testing machine (COM-TEN Testing Machine 95T series 5K), spectrocolorimeter, beaker, measuring cup, erlenmeyer, dropper pipette, 100 sieve. mesh, blender, petri dish, scissors, plate and knife.

2.2. Research Method

This research was carried out with a series of processes to produce edible films with the addition of zinc oxide using variations in concentration by Ridwan (2018) with modifications of 0%, 3%, 6%, 9%, and 12% as much as 5 grams, weight of starch and the addition of 50% glycerol and then observed characteristics such as thickness, water resistance, tensile strength, elongation, and biodegradability test of the resulting edible film.

2.3. Edible Film Making

The manufacture of edible films is carried out following the work done by Ridwan (2018) with slight modifications. Making edible film from corn starch is done by weighing 5 grams of starch as the main ingredient of edible film. The concentration of glycerol used is a modification of the results of Kasmawati's research (2018) which is best for the manufacture of edible films made from corn starch, which is as much as 50% glycerol (v/corn starch) and zinc oxide (ZnO) with variations of 0%, 3%, respectively. 6%, 9% and 12% (v/vtotal) were mixed into 100 mL of distilled water and stirred until homogeneous using a magnetic stirrer for 15 minutes. After that, 5 grams of corn starch was added to a solution containing a mixture of ZnO, glycerol and aquades and then homogenized to a temperature of 80-90 ºC using a magnetic stirrer for 40 minutes. Then, it was printed on a 20 cm x 20 cm glass mold and dried at 60 ºC in the oven for 5 hours (Kasmawati, 2018). The glycerol used in this research is glycerol obtained from PT Brataco. The amount of glycerol used follows the method used by Kasmawati (2018), which is 50% of the amount of starch used.

2.4. Zinc Oxide

This study employed zinc oxide that was purchased from T&T Chemical. The zinc oxide concentration utilized was in accordance with Ridwan's (2018) methodology for the synthesis and quality test of biodegradable plastic made from cassava starch utilizing a modified form of zinc oxide (ZnO) metal reinforcement. In this investigation, ZnO concentrations of 0%, 3%, 6%, 9%, and 12% (w/vtotal), respectively, were used.

2.5 Observations for Edible Film

2.5.1 Thickness

Thickness measurements were made after the edible film had been made. Film thickness was measured using a screw micrometer with an accuracy of 0.001 mm at five different points, namely in the upper right corner, lower right corner, upper left corner, lower left corner and in the middle. Measurements are averaged as a result of film thickness. The average thickness can be calculated using Equation (1).

$$\text{Average thickness} = ((1\text{ point} + 2\text{ point} + 3\text{ point} + 4\text{ point} + 5\text{ point}))/5 \quad (1)$$

2.5.2 Water Resistance (Cowd, 1991)

Measurement of water resistance was done after the film ha been made. The beaker was filled with 50 ml of distilled water. Then the edible film was cut with a size of 2 cm x 2 cm. The initial weight of the edible film was weighed. A glass filled with distilled water was prepared at room temperature, and then the edible film was put into it. After 20 minutes the sample pieces were removed and dried with paper towels, then weighing was carried out. The yield of water absorbed by the sample can be calculated using Equation (2)

$$\%\text{ Solubility} = (\text{wet sample weight} - \text{dry sample weight})/(\text{dry sample weight}) \times 100\% \quad (2)$$

Then do the calculation of water resistance on the edible film sample with Equation (3).

$$\text{Water resistance} = 100\% - \%\text{ solubility} \quad (3)$$

2.5.3 Tensile Strength (Bourtoom, 2008)

The tensile strength test was carried out after the film had been made. The tensile strength test was carried out with a sample size of 7 x 2 cm, which was clamped on both sides 1.5 cm long.

The tensile strength test was carried out using a mechanical universal testing machine. Edible film can be calculated for its tensile strength by Equation (4).

$\sigma = Fmax/Ao$ (4)

Information:
σ = tensile strength (kg/cm^2)
Fmax = maximum load (kg)
Ao = initial cross-sectional area (cm^2)

2.5.4 Percent Elongation (Bourtoom, 2008)

The percent elongation was measured after the film was made. The way to test the sample for percent elongation was by cutting the edible film sample with a size of 6cm x 2cm. After that, the sample was attached to the clamp/hook on the tool with a clamped area of 1.5 cm on both sides of the length. After that, elongation can be calculated by Equation (5).

$\varepsilon = \Delta l/Lo \times 100\%$ (5)

Information:
ε = elasticity/strain (%)
Δl = increase in length (mm)
lo = initial length of material measured (mm)

2.5.5 Edible Film Biodegradability Test

The biodegradability test was carried out to determine the time required for the edible film sample to degrade. The selected biodegradability test is controlling soil microorganisms as a helper in the degradation process or what is called the soil burial test technique. Samples measuring 5 x 1 cm were placed and planted in pots filled with soil for 6 days. Then the sample is dried in a desiccator and weighed until a constant weight is obtained (Anggarini, 2013) following the calculation used in the biogradability test (6).

% Loss of weight = (W1-W2)/W1 x 100% (6)

Note: W1 = sample weight before burial
W2 = sample weight after burial

estimated duration of overall degradation (100%) with the following calculation:

estimated degradation time = (100%)/(% loss in weight) x test time (8)

Note: the time used in this biodegradability test is 6 days.

The rate of degradability is calculated by the following Equation (9).

Degradability = (W2 - W1 g)/(6 days) (9)

3. Results and Discussion

3.1. Thickness

The final, dried-out thickness of the edible film is being measured. The average measurement data from five different areas, specifically the center and a portion of each corner, are used to determine the edible film's thickness. Film thickness is one of the physical qualities that is influenced by the size of the printing plate and the amount of dissolved particles in the film solution. Figure 1 shows the graph showing the relationship between ZnO concentration and edible film thickness.

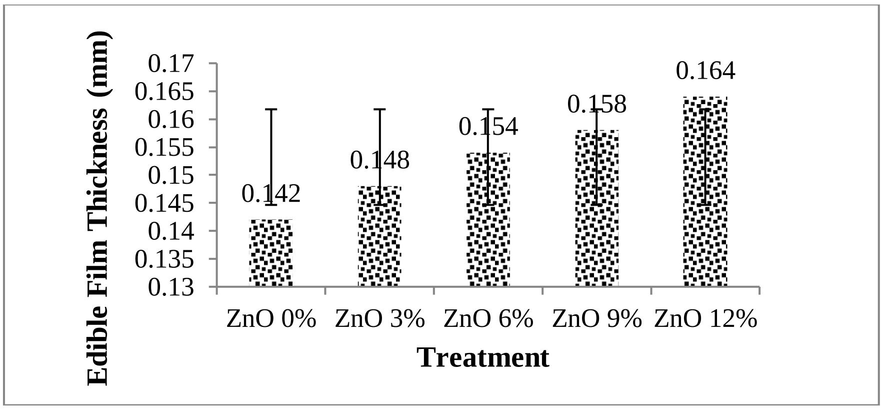

Figure 1. Analysis of edible film thickness at various concentrations of zinc oxide (ZnO)

Figure 1 shows how the addition of glycerol and changes in zinc oxide alter the thickness of the edible film (ZnO). The ZnO content of the thickest edible film is 12%, while the thickness of the thinnest edible film is 0%. This illustrates that the relationship between ZnO content and edible film thickness is perfect. This is due to the fact that when component concentrations for the edible film increase, so do the total solids, which define the film's thickness. The thickness of the edible film will also rise as a result of the size of the mold plate that was utilized and the volume of suspending material that was applied. Nugroho (2013), claimed that while the volume of the solution put into each plate or mold was the same size, the rise in thickness was caused by the quantity of concentration of the film-making substance. Due to this, the amount of polymers that make up the matrix of the film and the overall amount of solids in the film after drying both rise. This study's findings support the notion that thicker films are generated at higher ZnO concentrations. The average thickness of each treatment is not drastically different, according to the data collected. The thickness of the edible film with ZnO concentrations of 0%, 3%, 6%, 9%, and 12%. Data analysis of the effect of the addition of ZnO concentration on the thickness of the edible film can be seen in Table 1.

Table 1. ANOVA analysis on changes in edible film thickness with variations in concentration of zinc oxide (ZnO)

Source of Diversity	Number of Squares	Degree of Freedom	Middle Square	F	Sig.
ZnO Treatment	.001	4	.000	3.519	.048
Error	.001	10	.000		
Total	.002	14			

A significant value of 0.048 <0.05 was obtained based on the ANOVA analysis in Table 1 meaning that H0 is rejected and H1 is accepted. So it can be concluded that the ZnO treatment affects the thickness of the edible film.

3.2. Water Resistance

Water resistance or solubility testing is one method used to determine how water-repellent edible coatings are. This test is conducted to determine whether plastic can effectively shield the product from moisture. (Lazuardi & Sari, 2013). This test was performed to find out how long the edible film will last when packaged. It is anticipated that relatively little water will be absorbed by the plastic in the final edible film, or that the material's water absorption will be minimal. The graph of the effect of ZnO concentration on air edible film resistance can be seen in Figure 2.

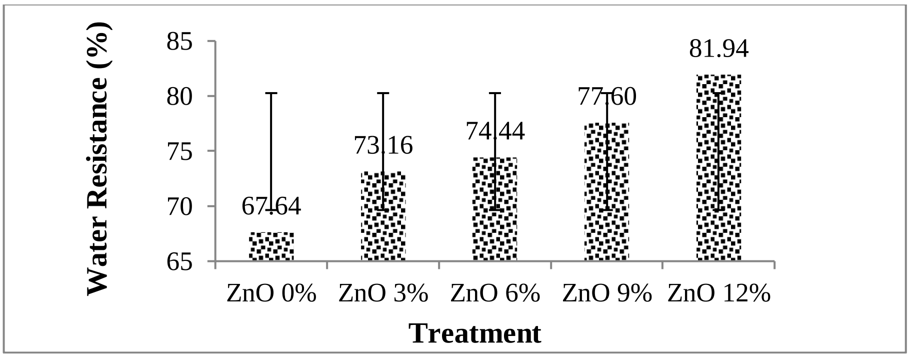

Figure 2. Analysis of water edible film resistance at various concentrations of zinc oxide (ZnO)

Table 2. ANOVA analysis on changes in edible film water resistance with variations in zinc oxide (ZnO) concentration

Source of Diversity	Number of Squares	Degree of Freedom	Middle Square	F	Sig.
ZnO Treatment	338.466	4	84.616	25.354	.000
Error	33.374	10	3.337		
Total	371.840	14			

Figure 2 shows that the addition of ZnO concentration at a concentration of 12% results in the maximum water resistance value of 81.94%. The water resistance in this study did not meet the SNI requirement because the SNI criterion for edible films' water resistance is 99%. Based on the recorded findings, it can be deduced that the edible film's resistance to water absorption increases with increasing ZnO content. Anggarini (2013), claims that a molecule's resistance to water is influenced by the fundamental characteristics of the molecules that make up that molecule. This study's starch substance is hydrophilic. The addition of glycerol also makes the resulting plastic more hydrophilic, therefore the more glycerol is added, the more water is absorbed by the plastic. Nevertheless, by adding zinc oxide (ZnO), a non-polar metal that is difficult to dissolve in water, the resulting plastic becomes soluble in water. The best ZnO concentration for the water resistance value of edible films in this study was ZnO 12%. Data analysis of the effect of the addition of ZnO concentration on the resistance of airedible films can be seen in Table 2.

H0 is rejected and H1 is approved based on the ANOVA analysis in Table 2's significant value of 0.000 0.05. The treatment of ZnO concentration had a substantial impact on the water resistance of edible films.

3.3. Tensile Strength

A test for tensile strength is performed to establish the extended edible film's maximum tensile strength in order to calculate the force at which it will break during the measurement. Tensile strength testing is used to figure out how much force is needed to get the maximum tension in each film area. The graph of the effect of ZnO concentration on the tensile strength of edible films can be seen in Figure 3.

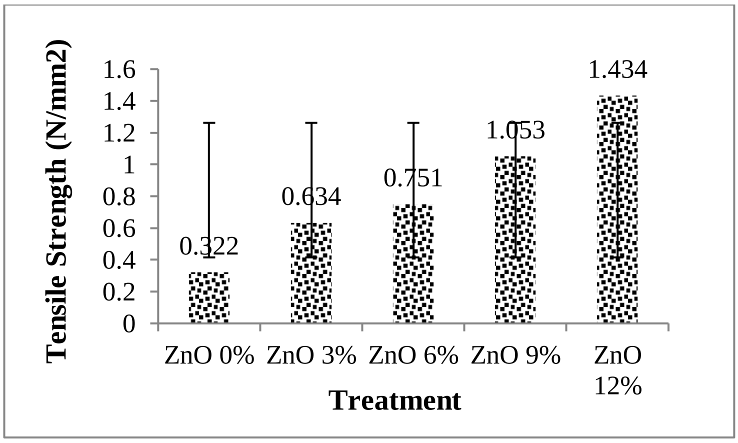

Figure 3. Analysis of edible film tensile strength at various concentrations of zinc oxide (ZnO)

Figure 3 shows a graph of the tensile strength of edible films after adding concentrations of ZnO. The analysis's findings reveal that the average value of edible films' best tensile strength (1.434N/mm2) is at a concentration of ZnO12% and that their lowest tensile strength is (0.322 N). /mm2) has a ZnO content of zero. The findings indicate that the tensile strength will rise with increasing ZnO content. This is brought on by variations in zinc oxide (ZnO) concentration, which might result in variations in the mechanical characteristics of the created edible film since the mechanical characteristics of the film are influenced by the substantial amount of content that makes up the film. (Anggarini, 2013). As the amount of zinc oxide filler rises, the tensile strength also rises. This is so that when starch and glycerol are added to form complex bonds that increase the tensile strength of bioplastics, intermolecular hydrogen bonds that are lost will be replaced by the Zn2+ ion, which will act as a bridge. (Saputra *et al.*, 2019). The data obtained from this study did not meet the SNI value of 24.7-302 N/mm^2. The graph demonstrates that adding additional ZnO increases the edible film's tensile strength value. Hence, the tensile strength of the maize starch edible film increases with increasing ZnO content. If the ratio of starch, glycerol, and zinc oxide is right, the tensile strength of the edible film might meet the SNI criteria. The small amount of attained tensile strength is also affected by the 50% glycerol content. This is in accordance with the results of Kasmawati's research (2018) which uses glycerol concentrations of 10%, 20%, 30%, 40%, 50% and the lowest tensile strength value is found at a concentration of 50%. Because more plasticizers are added, the intermolecular tensions between the components that make up the polymer are reduced, making the polymer flexible rather than stiff. This results in a decrease in the tensile strength. (Kasmawati, 2018). The best concentration of ZnO for the tensile strength of edible films in this study was ZnO 12%. Data analysis of the effect of the addition of ZnO concentration on the tensile strength of edible films can be seen in Table 3.

Table 3. ANOVA analysis on changes in tensile strength of edible films with variations in concentration of zinc oxide (ZnO)

Source of Diversity	Number of Squares	Degree of Freedom	Middle Square	F	Sig.
ZnO Treatment	2.152	4	.538	50.532	.000
Error	.106	10	.011		
Total	2.258	14			

H0 is rejected and H1 is approved based on the ANOVA analysis in Table 3's significant value of 0.000 0.05. The treatment of ZnO concentration, it can be inferred, has an impact on the tensile strength of edible films.

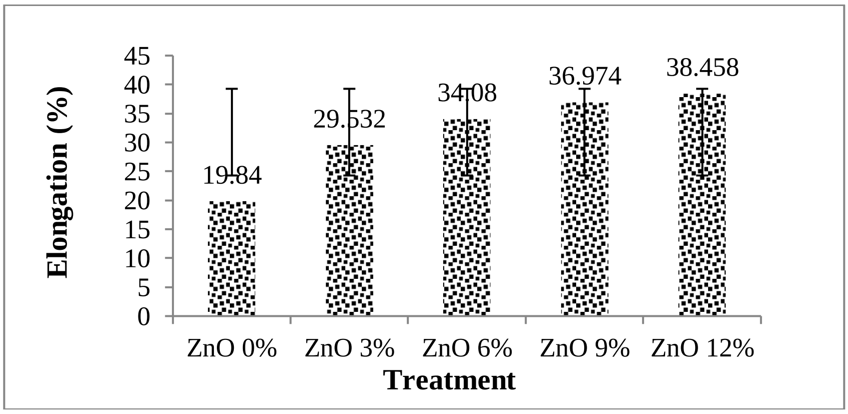

Figure 4. percentage elongation analysis of edible film at various concentrations of zinc oxide (ZnO)

3.4. Percent Elongation

The edible film's percent elongation is measured using a tensile strength tester. The percent elongation value, which is determined from the edible film's physical properties, shows the extent to which the extended edible film can attain tensile strength before breaking. Figure 4 shows the graph showing the relationship between ZnO concentration and the percentage of elongation of edible film.

Based on Figure 4, it can be seen that the percentage of elongation obtained was highest at

12% ZnO concentration and the lowest at 0% ZnO concentration. The highest percentage of elongation was found in the addition of 12% ZnO, which was 38.46%. This refers to the Indonesian National Standard (SNI) in determining the percent elongation of edible films, which is 21-220%. From the data obtained, the edible film without zinc oxide (ZnO 0%) did not meet the SNI standard. ZnO-treated edible film has a value that complies with SNI. The percent elongation value increased with increasing ZnO concentration. According to Kanmani & Rhim (2014), using zinc oxide nanoparticles as nanofillers can improve color, UV barrier, moisture content, hydrophobicity, elongation, and thermal stability in packaging films made of agar, carrageenan, and carboxymethyl cellulose (CMC). In this investigation, ZnO 12% was the optimal ZnO concentration for the percent elongation value of edible film. Table 4 displays the outcomes of the SPSS study of the edible film's elongation.

Table 4. ANOVA analysis on changes in percentage elongation of edible films with variations in concentration of zinc oxide (ZnO)

Source of Diversity	Number of Squares	Degree of Freedom	Middle Square	F	Sig.
ZnO Treatment	672.826	4	168.206	34.207	.000
Error	49.174	10	4.917		
Total	721.999	14			

H0 is rejected and H1 is approved based on the ANOVA analysis in Table 4's significant value of 0.000 0.05. Therefore, it was determined that the ZnO concentration treatment had an impact on the message value of the edible film's elongation.

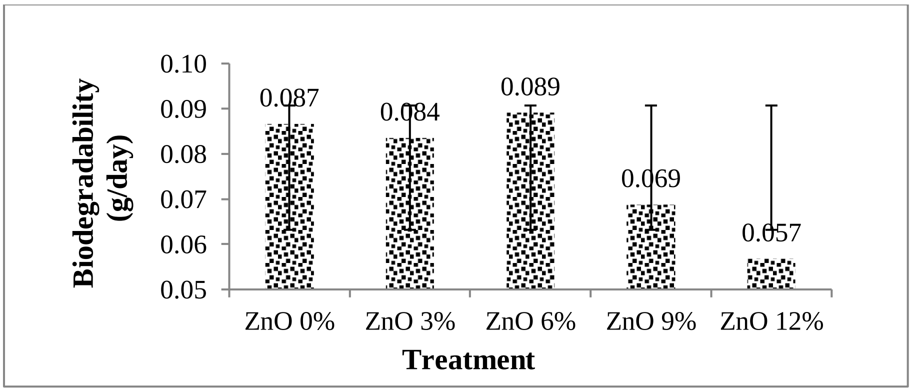

Figure 5. biodegradability analysis of edible filmat various concentrations of zinc oxide (ZnO)

3.4. Biodegradability Test

This biodegradability test was carried out to find out whether soil-dwelling microorganisms might break down edible films. By burying the sample in the soil and comparing its weight before and after burial, the soil burial test method is used to conduct this test. The graph of the effect of ZnO concentration on the degradability of edible film can be seen in Figure 5.

Figure 5 it can be seen that the weight of the sample before and after being buried on the first day until the 6th day experienced a significant decrease in weight. This is because the sample has undergone partial degradation indicated by changes in the shape of the intact plastic sheet changing into partially crushed plastic. From the data presented, it can be seen that the higher the concentration of ZnO given, the lower the biodegradability of edible film. This is because ZnO is a metal particle so it will be difficult to be degraded by microorganisms in the soil. According to Wang (2008) The frequency of attacks on microorganisms that are disintegrating increases with a larger ZnO concentration because ZnO particles act as agents of assault on microorganisms. The goal is that ZnO can be converted into particles that can stop bacterial development. Estimated degradation time of edible film can be seen in Figure 6.

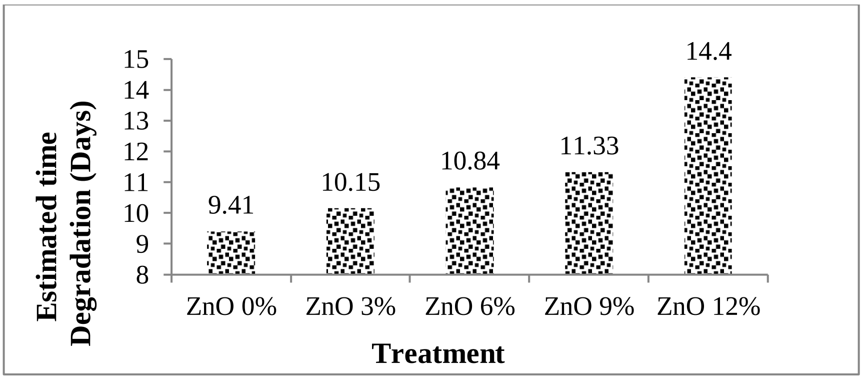

Figure 6. Estimated degradation time of edible film

Table 5. ANOVA analysis on changes in biodegradability of edible films with variations in concentration of zinc oxide (ZnO).

Source of Diversity	Number of Squares	Degree of Freedom	Middle Square	F	Sig.
ZnO Treatment	.002	4	.001	4.879	.019
Error	.001	10	.000		
Total	.003	14			

The lowest biodegradability value was found in edible film with a concentration of ZnO 12%, and the highest was ZnO 0% and ZnO 6%. The values obtained from this study mostly showed a decrease with increasing ZnO concentration. However, the value obtained at 3% ZnO concentration was lower than 0% ZnO, this was due to the factor that the number of microorganisms in the edible film was buried less than other places and caused a decrease in the value of biodegradability. Shakina *et al.* (2012) who also researched the capacity of plastic breakdown using soil burial tests came to the conclusion that a variety of factors, including soil type, microbial type, and humidity, affected the degradation ability of synthetic plastics. The best ZnO concentration for edible film degradability value in this study was 6% ZnO. From the data obtained, it can be concluded that the addition of ZnO as an edible film material does not give a good effect considering the purpose of edible films that are easily decomposed in the soil or are degradable. Data analysis of the effect of the addition of ZnO concentration on the biodegradability of edible films can be seen in Table 5.

According to Table 5 Anova analysis, the significant value is 0.019<0.05, rejecting H0 and accepting H1. It is clear from the data that the treatment of ZnO concentration has an impact on the biodegradability of edible films.

4. Conclusions

Zinc oxide (ZnO) nanoparticle application affects the properties of corn starch-based edible films, including thickness, water resistance, tensile strength, percent elongation, and biodegradability. With the addition of 12% ZnO concentration, the edible film's properties improved the most in this investigation, showing 81.94% water resistance, 1.434 MPa tensile strength, and 38.46% elongation percent. Based on the research that has been done, the authors suggest optimizing the methods used in making edible films such as changing the type of plasticizer or using a glycerol concentration with a concentration <50%, as well as increasing the concentration of zinc oxide used in the hope of perfecting the characteristics of edible films according to standards so that can be used on a large scale.

References

Abdollahzadeh, E., Nematollahi, A., & Hosseini H. (2021). Composition of antimicrobial edible films and methods for assessing their antimicrobial activity. *Food Science & Technology*, 1(10). https://doi.org/10.1016/j.tifs.2021.01.084.

Anggarini, F. (2013). *Application of Glycerol Plasticizer in Making Biodegradable Plastics from Jackfruit Seeds* [Thesis]: Semarang: Universitas Negeri Semarang. http://lib.unnes.ac.id/id/eprint/17845

Basiak, E., Galus, S., & Lenart A. (2015). Characterisation Of Composite Edible Films Based On Wheat Starch And Whey-Protein Isolate. *Int. J. Food Sci. Technol.*, 50 pp. 372-380 https://doi.org/10.1111/ijfs.12628

Bourtoom T. (2008). *Review Article Edible Films and Coatings: Characteristics and Properties. J. International Food Research*. 15(3):237-248. https://www.researchgate.net/publication/228397700_Edible_films_and_coatings_Characteristics_and_properties

Central Bureau of Statistics of West Sumatra Province. (2016). *Indonesian Corn Production Statistics 2018*. Central Statistics Agency of West Sumatra Province. Padang. https://www.bps.go.id/

Cowd, M. A. (1991). *Kimia Polimer*. Translated By J. G. Stark. ITB. Bandung.

Erfan, A. (2012). *Synthesisof Bioplastic from Sweet Potato Starch Using ZnO Metal Reinforcement and Chitosan Natural Reinforcement*. [Thesis]:Jakarta: Universitas Indonesia. https://lib.ui.ac.id/detail?id=20308134&lokasi=lokal

Kanmani, P., & Rhim, J. (2014). Properties and Characterization of Bionanocomposite Films Prepared With Various Biopolymers and ZnO Nanoparticles. *J. Carbohydrate Polymer*, 106, 190-199. https://doi.org/10.1016/j.carbpol.2014.02.007.

Kasmawati. (2018). *Characteristics of Corn Starch Edible Film (Zea mays L.) with Addition of Glycerol and Extract of Temu Putih (Curcuma Zedoaria)*. [Thesis]: Makassar: Universitas Islam Negeri Alauddin Makassar. http://repositori.uin-alauddin.ac.id/id/eprint/8932

Lazuardi, G. P. & Sari, E. C. (2013). Manufacture and Characterization of Chitosan-Based Bioplastics and Cassava Starch with Glycerol Plasticizer. Unesa *Journal Of Chemistry*, 2(3), 161-166. https://jurnalmahasiswa.unesa.ac.id/index.php/unesajournalofchemistry/article/view/4495/2137

Molnar, D., Novotni, D., Kurek, M., Galić, K., Iveković, D., Bionda, H., & Ščetar, M. (2023). Characteristics of Edible Films Enriched With Fruit By-Products And Their Application On Cookies. *Food Hydrocolloids*, 1(5), 115-129. https://doi.org/10.1016/j.foodhyd.2022.108191.

Nazir, S., & Wani, I. A. (2022), Development And Characterization of An Antimicrobial Edible Film From Basil Seed *(Ocimum Basilicum* L.*)* Mucilage and Sodium Alginate. *Biocatalysis and Agricultural Biotechnology*, 4(4), 132-145. https://doi.org/10.1016/j.bcab.2022.102450.

Nugroho, A. A., Basito, & Anandito, R. B. K. (2013). Study of Tapioca Edible Film Production With the Effect of Pectin Addition of Several Types of Banana Peel on Physical and Mechanical Characteristics. *Teknosains Pangan*, 2(1), 73-80. https://jurnal.uns.ac.id/teknosains-pangan/article/view/4276

Putri, I. E., Nugaraha, E. S., & Harsi, D. K. (2018). Soy Protein Isolate Based Antibacterial Edible Film with Turmeric Extract and Zinc Oxide Nanoparticles. *J. Teknologi dan Industri Pangan*, 29(1), 85-92. https://doi.org/10.6066/jtip.2018.29.1.85

Rahmatunisa, R. (2015). *Effect of Addition of ZnO and Ethylene Glycol Nanoparticles on Functional Properties of Biodegradable Foam Packaging from Tapioca and Corn Ampok*. [Thesis]. Institut Pertanian Bogor. Bogor. https://inlislite.ipb.ac.id/opac/detail-opac?id=74523

Rahmawati, S., Pathuddin, Nuryanti, S., Sangkota, V. D. A., Afadil, Anggraini, & Syawaliah, N. (2022). Characteristics and Antioxidants of Edible Film from Durian Seeds *(Durio Zibethinus)* with Additions to Rosella Flower Extract *(Hibiscus sabdariffa L.)*, *Materials Today*, 65(7). https://doi.org/10.1016/j.matpr.2022.07.162.

Ridwan, M. (2018). *Synthesisand Quality Test of Biodegradable Plastic from Cassava Starch Using Variations of Zinc Oxide (ZnO) Metal Reinforcing and Plasticizer Glycerol*. [Thesis]: Makassar: UIN Alauddin Makassar. http://repositori.uin-alauddin.ac.id/id/eprint/13884

Sapper, M., Talens, P., Chiralt, A. (2019). Improving functional properties of cassava starch-based films by incorporating xanthan, gellan, or pullulan gums. *International Journal of Polymer Science*, 2019, 1-8. https://doi.org/10.1155/2019/5367164

Saputra, W., Hartiati, A., & Harsojuwono, B. A. (2019). Effect of Concentration of Zinc Oxide (ZnO) and Addition of Glycerol on Bioplastic Characteristics of Gadung Tuber Starch (Dioscorea hispida Deenst). *J. Rekayasa dan Manajemen Agroindustri*. 7(4), 531-540. https://doi.org/10.24843/JRMA.2019.v07.i04.p05

Shakina J., Sathiya Lekshmi K., & Allen Gnana Raj G. (2012). Microbial Degradation of Synthetic Polyesters from Renewable Resources. *Indian Journal of Science*, 1(1), 21-28. https://doi.org/10.1155/2012/195674

Sinaga, L. L., Rejekina, M. S., & Sinaga, M. S. (2013). Characteristics of Edible Film from Soybean Extract with Addition of Tapioca Starch and Glycerol as Food Packaging Materials. *J. Teknik Kimia. 2*(4), 12-16. https://doi.org/10.32734/jtk.v2i4.1485

Wang, Z. L. (2008). Toward Self-Powere Nanosystem: From Nanogenerators to Nanopiezotronics. *Journal of Advanced Fucntional Materials*, 18(2), 3553-3567. https://doi.org/10.1002/adfm.200800541