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Preparation Of Biodegradable Plastic Film from *Sorghum Bicolor* (L.) Corn Starch

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Abstract

Today's challenge is to produce a biodegradable materials for packing which can partially replace traditional plastic materials. Starch-based biodegradable plastics are less harmful to the environment and breakdown faster than regular plastics. The goal of this research was to produce and characterize a biodegradable film(BF) made from Sorghum bicolor (L.) starch and glycerol plasticizer. The produced film contained two amounts of Sorghum bicolor (L.) starch (5 g and 10 g) and three percentages of glycerol (25%, 30%, and 40%). The Sorghum bicolor (L.) and biodegradable glycerol-based plastic film had the lowest density, water absorption, and thickness swelling of 0.99 g cm^{-3}, 55.72%, and 10.72%, respectively. The tensile strength is maximum at 9.97 MPa and and elongation obtained is 23.84%. The Sorghum bicolor (L.) starch and glycerol-based biodegradable film decomposed by 69.23% after biodegradability testing of one week.

Keywords: Sorghum bicolor (L.) starch, glycerol, biodegradable film, tensile strength, biodegradability

Introduction

Bioplastics are made from biomass components such as lipids, polysaccharides and proteins. [1-3]. These synthetic materials derived from renewable organic resources have been demonstrated to be efficient alternatives for petroleum-based plastics, and they are expected to reduce our dependence on fossil fuels and the amount of plastic trash generated [4]. Bioplastics have the potential to alleviate the problem of the world's ever-growing plastic waste because they are biodegradable and have applications in a range of industries, including packaging, opt-electronics, agriculture, and pharmaceuticals [5]. Overall, sustainable bio-plastics offer an excellent alternative to petroleum-based plastics [6].

Polysaccharides are one of the materials utilized to manufacture plastic film that are biodegradable and are useful in a range of industries, including the pharmaceutical and food industries [7]. Environmentally friendly polysaccharide-based bio-plastics have outstanding mechanical characteristics, resistivity, and the capacity to block the escape of O_2 and CO_2 gases at low or moderate humidity [8]. Glycerol is a byproduct of the oil or bio-diesel industries, whereas starch (polysaccharide) with thermoplastic properties is widely produced domestically. Amylose and amylopectin, two of starch's most essential components, are biopolymers.

These biopolymers are useful as barriers in raw material packaging materials. Starch is used in industrial foods and to manufacture biodegradable films that can partially or entirely replace plastic polymers since it is affordable, renewable, and has high mechanical properties [9]. Because of starch abundance, renewability, cost-effectiveness, and biodegradability, its recognized as one of the best natural polymers. [10, 11]. Nevertheless, the poor mechanical strength and ability to dissolve in water of starch biopolymers have shown to be significant limitations.

Glycerol, as viscous liquid is known as glycerin. It is the most basic trihydric alcohol with colourless, odourless, and sweet taste. It is slightly dissolved by solvent such as ether, ethyl acetate, and dioxane. It is completely soluble in both water and alcohol. Plasticizers increase brittle film flexibility while simultaneously weakening and increasing moisture permeability [12]. Glycerol has a significant impact on the mechanical properties of the bio-plastic films ($P < 0.05$). Because of the lower glycerol concentration, the tensile strength of the film and barrier qualities will be superior to films with higher concentration [13]. Biodegradable polymers based on starch are more environmentally friendly and decompose faster than ordinary plastics [14].

Biodegradable polymers based on agricultural resources have evolved in recent years [15]. Starch, a naturally occurring carbohydrate polymer, has gotten the most attention for its potential as a raw material for bioplastic manufacturing [16]. Plasticizers are widely utilized in the fabrication of starch-based polymers due to their brittleness. It ensures that the resulting plastic is not easily breakable and brittle, but rather robust and flexible [17]. Glycerol and Sorbitol are two common plasticizers used in the production of bioplastics [18, 19]. Many researchers used fillers as reinforcement to improve the mechanical and physical properties of starch-based biodegradable polymers. When a filler is added to a biodegradable plastic, its tensile strength and Young's modulus improve [20, 21].

The present challenge is to produce packaging material that are biodegradable to replace standard plastic. Biodegradable polymers based on starch are more environmentally friendly and decomposes faster than ordinary plastics. In separate investigations, Basilla [22] and Cheong et al. [23] developed biodegradable films from cassava starch, foamed disposable food containers made from nanoclay and starch, and bio-based polymers made from sago starch.

Current study focused on producing biodegradable bioplastics from natural sources, *Sorghum bicolor* (L.) starch, and increasing mechanical and physical qualities by employing glycerol as plasticizers, followed by characterization.

Materials and methods

Sorghum bicolor (L.) starch and glycerol (92.09% Ajax Finechem Univar ® Analytical Reagent) were used as plasticizers and film-forming agents to create a biodegradable film.

Film preparation

Sorghum bicolor (L.) starch (5 and 10 g) and glycerol (25%, 30%, and 40%) were combined. After that, 100 mL of distilled water was added to the resulting mixture. The entire solution was heated at 80°C for 15 minutes while being stirred. The heated mixture was placed on glass and petri plates and left in a 17°C temperature drop chamber for three to four days.

Characterization of the biodegradable film

The biodegradable film's density, water absorption, thickness/swelling, tensile strength, and biodegradability were all evaluated.

Density

The biodegradable film’s density was calculated using the ISO 1183 (ASTM D792) test method.

Moisture content

To determine the moisture content, a modified approach from Sanyang et al.,[24] was employed. The bioplastic samples were cut into 1.5 X 1.5 cm^2 pieces, the initial weight (W_i) of the sample was estimated, and they were then dried for 24 hours in a 90 °C oven. The final weight (W_f) was measured after drying the sample, and the moisture content was calculated using the following formula:

$$\text{Moisture content (\%)} = \frac{Wi - Wf}{Wi} \times 100 \qquad (1)$$

Water absorption

The ASTM D570-98 method was adapted to test the water absorption of bioplastics. 1.5 X 1.5 cm^2 bioplastic samples were dried in an oven at 90 °C for 24 hours to get their initial dry weight, which was then estimated gravimetrically using an electronic weighing balance (W_i). After that, the samples were immersed in 40 mL of distilled water for 24 hours at 26 ± 2 °C. After 24 hours, the residual bioplastic was recovered by filtering with filter paper and its weight was gravimetrically (Wf) measured once again. The following equation was used to determine water absorption:

$$\text{Water absorption (\%)} = \frac{Wf - Wi}{Wi} \times 100 \qquad (2)$$

Water solubility

Sanyang et al.[24] approach was used to assess the water solubility behaviour of the bioplastic sample. Samples having a surface area of 1.5 × 1.5 cm^2 were dried in a 90 °C oven for 24 hours before being gravimetrically weighed with an electronic weighing balance (Wi). The samples were then placed in beakers with 40 mL of distilled water, sealed, and stored at a temperature of 26 ± 2 °C for 24 hours. The residual bioplastics were collected after 24 hours by filtering using filter paper, dried in an oven at 90 °C for 24 hours, and their final weight was calculated using gravimetric analysis (Wf). The following equation was used to calculate the bioplastic sample solubility: water, sealed them, and stored for 24 hours at a temperature of 26 ± 2 °C.

$$\text{Water Solubiblity (\%)} = \frac{Wi - Wf}{Wi} \times 100 \qquad (3)$$

Alcohol solubility

According to Sanyang et al. [24], solubility in alcohol was assessed using the methodology as described in water solubility, with the exception that the samples were put in closed test tubes with 2 mL of ethanol rather than water. The following equation was used to determine the bioplastic sample solubility:

$$\text{Alcohol Solubiblity (\%)} = \frac{Wi - Wf}{Wi} \times 100 \qquad (4)$$

Thickness swelling

It was possible to quantify the thickness swelling of biodegradable film during the measuring of water absorption by determine and recording the thickness of the specimen before and after soaking the samples at room temperature for 24 hours.

Mechanical properties

The material's tensile strength and Young's modulus were determined using a Universal testing machine (Lloyd Instruments LF Plus) and a modified version of ASTM D882-91. The samples were cut into rectangular strips 80 mm long and 15 mm wide with scissors. The gauge was kept at 40 mm long and 15 mm wide, with the cross-head speed set at 10 mm/min. Prior to each trial, the thickness of the specimens was measured. At normal room temperature and humidity (73°F, 50%), standard operating procedures were followed. Using the instrumental data, the tensile strength and Young's modulus of the samples were calculated.

Test for biodegradability

Tensile strength and Young's modulus of the material were determined using a Universal testing machine (Lloyd Instruments LF Plus) using a modified version of ASTM D882-91. Using scissors, the samples were cut into rectangular strips 80 mm long and 15 mm wide. The gauge was fixed at a length of 40 mm and a width of 15 mm, with the cross-head speed set to 10 mm/min. Before each trial, the thickness of the specimens was measured. At typical room temperature and humidity (73°F, 50%), the standard operating procedure was used. The instrumental data was used to calculate the tensile strength and Young's modulus of the samples. After 5 days, the residual samples were removed from the soil, cleaned with distilled water, and dried in an oven at 90 °C for 24 hours before undergoing a second gravimetrical computation to determine their ultimate weight (Wf). The bioplastics' biodegradability, or percentage weight loss, was calculated using the equation below:

$$\text{Weight loss (\%)} = \frac{Wi - Wf}{Wi} \text{ X } 100 \qquad (5)$$

Fourier transform infrared spectroscopy (FTIR)

The chemical structure of the bioplastic materials were determined using a Fourier Transform Infrared Spectrophotometer (FTIR) (IRTracer-100, Shimadzu). The wavenumber spanned from 4000 to 650 cm^{-1}, with a resolution of 2 cm^{-1}.

Data analysis

The acquired data was integrated and evaluated using a 2 by 3 factorial complete randomized design. The treatment of level of significance was determined using Analysis of Variance (ANOVA). Duncan's Multiple Range Test (DMRT) was performed to determine how the means differed from one another.

Results and discussion

Description of biodegradable film

The biodegradable film is made from *Sorghum bicolor* (L.) starch, and glycerol (Figure 1). The biodegradable film was made by heating it for 15 minutes at 80°C until it gelatinized. The heated mixture was spread on glass and petri plates and allowed to sit for 3-4 days at 17°C in an air-conditioned setting.

Figure1. Biodegradable fruit bag made from *Sorghum bicolor (L.)* starch, and glycerol.

Density

Table 1 demonstrates that decreasing the amount of starch and the percentage of glycerol enhanced the mean density of the film. This is comparable with Moore et al. [25] density measurements for keratin films using varied glycerol concentrations, which ranged from 0.92 to 1.10 g cm^{-3}.

Table 1 Density of biodegradable film

Starch (g)	Glycerol (%)			
	25.0	30.0	40.0	Mean
5.0	1.73	1.02	1.15	**1.30**
10.0	1.06	0.99	1.13	**1.06**
Mean	**1.40**	**1.01**	**1.14**	

Note: Means that do not share a letter differ substantially by DMRT at the 0.05 level of significance.

Water absorption

Table 2 shows that whereas 10 g of starch with varied percentages of glycerol increased water absorption, 5 g of starch with varying percentages of glycerol decreased water absorption. This is because starch, which has a low moisture content, absorbs more water [26].As a result of glycerol's strong attraction to water molecules, plasticized samples often exhibit low water absorption values [27]. This action can be explained by glycerol forming a stronger hydrogen bond with starch, preventing water molecules from interacting with the plasticizer or starch.

Table 2 Percent water absorption of biodegradable film

Starch (g)	Glycerol (%)			
	25.0	30.0	40.0	Mean
5.0	57.48^{a}	71.32^{bc}	55.72^{a}	61.51
10.0	87.53^{c}	63.85^{b}	76.49^{c}	75.96
Mean	72.51	67.59	66.11	

Note: Means not sharing letter in common differ significantly at 0.05 level ofsignificance by DMRT

Thickness swelling

Thickness swelling (TS) is an important parameter that captures the stability performance of the composite. Because of the visco-elasticity of the polymer matrix, swelling rates for polymer matrix composites are typically low during the early stages of moisture absorption [28].

Table 3 shows that as glycerol levels increased, the percentage of thickness swelling decreased. The swelling thickness of 10 g starch with 25% glycerol was greater, but the swelling thickness of 10 g starch with 40% glycerol was the least.

Table 3 Thickness swelling of biodegradable film

Starch (g)	Glycerol (%)			
	25.0	30.0	40.0	Mean
5.0	43.29^{b}	47.45^{b}	19.26^{a}	36.66
10.0	60.54^{c}	45.83^{b}	10.72^{c}	39.03
Mean	51.92	46.64	14.99	

Note: Means not sharing letter in common differ significantly at 0.05 level ofsignificance by DMRT

Tensile strength and elongation

Table 4 displays the tensile strength (Mpa) and elongation (%) of biodegradable film. At 10 g starch and 40% glycerol, the biodegradable film had the highest tensile strength (Mpa), with a value of 9.97. This is due to the high density of cross-linking reactions in starch films between hydroxyl groups and cross-linking agents [29]. The highest % elongation, on the other hand, was attained at 5 g. Yamak [30], attributes the decrease in tensile strength to a lack of inter-facial adhesion between the starch and polymer.

Table 4 Tensile strength and percent elongation at break ofbiodegradable film

Level of Starch	Level of glycerol	Max. stress, Mpa	% Elongation
5 g Starch	25%	4.13	19.85
	30%	3.09	21.73
	40%	3.17	23.84
10 g Starch	25%	3.16	20.07
	30%	6.13	16.83
	40%	9.97	13.98

Test of biodegradability

After one week of biodegradability testing, the *Sorghum bicolor* (L.) starch and glycerol-based biodegradable film decomposed by 71.13%. Current biodegradation results for *Sorghum bicolor* (L.) starch-based bioplastics are consistent with those reported by Mohan et al., [31]. The biodegradability of a bioplastic is determined by physical and chemical properties such as surface area, hydrophilicity or hydrophobicity, chemical structure, and molecular weight [32].

Fourier transform infrared spectroscopy

Fourier transform infrared spectroscopy (FTIR) was used to investigate the functional groups present in the bio-plastic samples to see if the addition of plasticizers resulted in the production of any new functional groups. In all of the samples studied, the bio-plastics were found to have distinctive peaks ranging from 2610 to 3490 cm^{-1} (Fig 2). The addition of plasticizer resulted in the formation of additional peaks at 3032-3416 cm^{-1}. In unplasticized materials, three to four distinctive peaks in the 890-1412 cm^{-1} range were found.

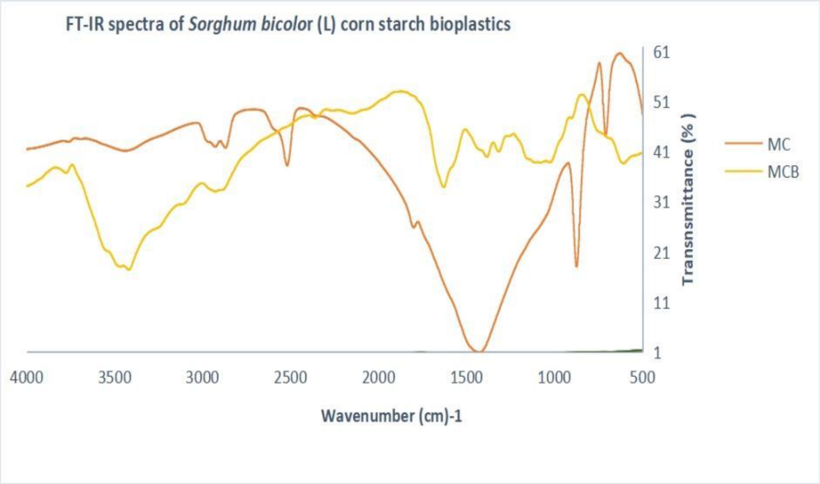

Figure 2: FTIR of Sorghum bicolor (L.) starch bioplastic without plasticizer (MC) and Plasticized Sorghum bicolor (L.) starch bioplastic (MCB)

FTIR is a commonly used analytical technique for analyzing molecular structures, determining component interactions, and detecting functional groups in a substance [33]. The presence of starch was responsible for the usual peaks in the samples analyzed, which ranged from 2900-3010 cm^{-1} (=C-H stretching). Kumirska et al. [34] investigated characteristic peaks within this range previously. As previously reported, the addition of plasticizer resulted in the formation of additional peaks at 3216-3419 cm^{-1}, which are indicative of the O- H functional group. The presence of these peaks can be attributed to the presence of a large number of hydroxyl groups in both glycerol and polyols, resulting in a broad peak ranging between 3600 and 3200 cm^{-1} [35]. This shows that adding a plasticizer to bio-plastics can result in the addition of new functional groups. Three to four typical peaks in the range of around 970-1034 cm^{-1}, showing the C-O-C functional group, and 1025-1145 cm^{-1}, indicating the C-O-H functional group, were found in all unplasticized and plasticized samples of all types. Many previous studies have reported the occurrence of distinctive peaks due to C-O bond stretching between 990 and 1200 cm^{-1} [36].

The FTIR spectra can be used to study interactions between bioplastic components. If the bioplastic components do not blend effectively, no changes may be noticed in the spectra, however some changes can be seen if the components blend properly.

Conclusion

Corn starch from *Sorghum bicolor* (L.) is a viable component in the manufacturing of biodegradable films. The biodegradable film based on *Sorghum bicolor* (L.) maize starch and glycerol had the lowest density, water absorption, and thickness swelling of 0.99 g cm^{-3}, 55.72%, and 10.72%, respectively. The maximum tensile strength and elongation obtained are 9.97MPa and 23.84%, respectively. The amount of glycerol used influences the film's elasticity. A higher glycerol level increases tensile strength while decreasing elongation. The *Sorghum bicolor* (L.) starch and glycerol-based biodegradable film decomposed by 69.23% after one week of biodegradability testing.

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Conflict of Interest

The authors do not have any conflict of interest.

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