Received: 27 March 2024 | Revised: 31 May 2024 | Accepted: 12 June 2024 | Published online: 17 June 2024

RESEARCH ARTICLE

Archives of Advanced Engineering Science
2025, Vol. 3(3) 178–187
DOI: 10.47852/bonviewAAES42022946

BON VIEW PUBLISHING

A Comprehensive Study on the Production and Characterization of Eco-friendly Biodegradable Plastic Films from Dent Corn Starch

Bethel Chijioke Iheanacho[1], Hadiza Nuhu Ajoge[2], Usman Ismail[3], Fon Alain Zoum[4], Favour Okechi Ifeanyi-Nze[5,*], Favour Onasokhare Okunbi[6], Chinecherem Favour Edeh[1], Nathaniel Nwoke Chimezie[7], Esther Abigail Udoh[8], Justin Okechukwu Nworie[9], Tosin Oluwashina Oseni[10], Marian Ugonna Mark[11], George Arubi Akpowu[12], Dolapo Abidemi Kolapo[13], Augustine Oboseoye Odibo[14], Olaoluwa Joseph Edun[15], Udochukwuka Confidence Zogini[16] and Chima Ogechukwu Egwuonwu[1]

[1]*Department of Chemical Engineering, Federal University of Technology, Nigeria*

[2]*Department of Water Resources & Environmental Engineering, Nigerian Defence Academy, Nigeria*

[3]*Department of Chemical Engineering, Ahmadu Bello University, Nigeria*

[4]*Department of Mining and Mineral Engineering, University of Bamenda, Cameroon*

[5]*Department of Chemical Engineering, University of Benin, Nigeria*

[6]*Department of Microbiology, Mountain Top University, Nigeria*

[7]*Department of Environmental Management, Federal University of Technology, Nigeria*

[8]*Department of Analytical Chemistry, Imo State University, Nigeria*

[9]*Department of Metallurgical Engineering, Yaba College of Technology, Nigeria*

[10]*Department of Chemical Engineering, University of Lagos, Nigeria*

[11]*Department of Industrial Chemistry, Imo State University, Nigeria*

[12]*Department of Chemistry, Federal University of Agriculture, Nigeria*

[13]*Department of Pure and Applied Chemistry, Ladoke Akintola University of Technology, Nigeria*

[14]*Department of Pharmacy, University of Benin, Nigeria*

[15]*Department of Chemical Engineering, Ladoke Akintola University of Technology, Nigeria*

[16]*Department of Pure and Industrial Chemistry, University of Nigeria, Nigeria*

Abstract: The increasing demand for eco-conscious and sustainable biomaterials has propelled the exploration of alternatives to petroleum-derived materials. This study delves into the utilization of dent corn (Zea mays L.) starch as a renewable resource for crafting biodegradable packaging solutions. The physicochemical properties of dent corn starch were meticulously assessed through a series of preparation steps, encompassing washing, cutting, grinding, drying, and pulverizing. Despite the inherent variability in dent corn sourced from local markets, the resulting starch exhibited commendable characteristics, including a pH of 7.02, moisture content of 6.50%, ash content of 0.20%, bulk density of 0.47 g/ml, gelatinization temperature of 61.2 °C, protein content of 2%, and a yield of 64%. Subsequently, employing the casting method,

*Corresponding author: Favour Okechi Ifeanyi-Nze, Department of Chemical Engineering, University of Benin, Nigeria. Email: favour.ifeanyi-nze@eng.uniben.edu

bioplastic films were synthesized using starch powder, water, and glycerol as a plasticizer. A comprehensive evaluation of the chemical, mechanical, solubility, and biodegradability properties of the films ensued. Remarkably, the films demonstrated notable values for tensile strength (2.58 MPa), elongation at break (24%), and film thickness (1.4 mm), alongside exhibiting low absorption rates in various media and remaining insoluble in solvents, even at elevated temperatures. Notably, the influence of glycerol content on the tensile strength and biodegradability of the films was elucidated through a least squares model, underscoring its pivotal role. These findings highlight the potential of dent corn starch as a viable alternative for the development of biodegradable packaging materials, despite the variability inherent in its sourcing from local markets. The study significantly contributes to ongoing endeavors aimed at fostering sustainability and reducing reliance on petroleum-derived materials, aligning with the escalating environmental consciousness.

Keywords: corn starch, bioplastic film, biodegradable plastic

1. Introduction

The world is facing an ever-increasing need for sustainable materials that can replace traditional petroleum-based plastics [1, 2]. Biodegradable plastics are the perfect solution to this problem, as they are made from renewable sources and are environmentally friendly [3, 4]. One of the most promising sources for the production of biodegradable plastics is corn starch [5]. Corn starch is a renewable resource that is abundant and relatively inexpensive [6]. Furthermore, it has the potential to create highly durable and versatile plastics [6].

A recent and intriguing area of study is the creation of biodegradable polymers using maize starch [5, 6]. Corn starch is converted into polylactic acid (PLA) during the process [7]. The by-product of fermenting glucose is called PLA, and it is mixed with other polymers to make tough plastic [8]. Due to its superior mechanical and thermal characteristics, this material is a great option for a variety of items, including construction materials, medical equipment, and food packaging [9, 10].

In addition to being a critical step in the creation of environmentally friendly materials, the synthesis of biodegradable polymers from maize starch has several additional advantages. For instance, the procedure is reasonably straightforward and economical [10, 11], and it does not require the use of dangerous materials or poisonous chemicals [5, 6]. Additionally, the plastics made are non-toxic, odorless, light, and remarkably heat- and chemical-resistant [3].

The potential of biodegradable plastics based on corn starch is immense, and research in this area is ongoing. Future manufacture of these plastics is projected to be even more effective and economical thanks to the development of new and improved manufacturing techniques. Therefore, biodegradable plastics made from maize starch can be a key component in the creation of environmentally friendly materials that can take the place of conventional plastics made from petroleum.

Plastic pollution has emerged as a global environmental crisis, necessitating urgent action to mitigate its adverse effects on ecosystems and human health. Traditional plastic materials, derived from non-renewable sources such as petroleum, persist in the environment for centuries, contributing significantly to pollution. Conventional waste management methods, including burning and burying, are ineffective in addressing the magnitude of plastic waste accumulation, further exacerbating environmental degradation [12].

In response to this pressing challenge, there has been a growing interest in the development and production of biodegradable plastics as a sustainable alternative. Biodegradable plastics offer the potential to mitigate the environmental impact of plastic waste by breaking down into natural compounds through microbial action, thereby reducing long-term pollution [12].

A comprehensive understanding of the physicochemical and mechanical properties of biodegradable films is essential for their successful implementation in various applications, particularly in the food packaging industry. Several studies have focused on the characterization and evaluation of biodegradable films derived from renewable sources, such as plant starches, with the aim of elucidating their suitability for packaging perishable and cooled foods [13–15].

One such study, conducted by Krishnamurthy and Amritkumar [13], investigated the comprehensive characterization of biodegradable edible films based on potato peel starch plasticized with glycerol. The microstructure analysis revealed alterations in film properties, including increased thickness, decreased swelling power, water solubility, and vapor permeability, attributed to enhanced molecular interactions with increasing potato peel starch content. Additionally, low-starch films exhibited high transparency, good mechanical properties, thermal stability, and accelerated biodegradation in seawater and soil environments.

Another study, carried out by Nigam et al. [12], explored the formulation of biodegradable films by blending cassava starch with a synthetic biodegradable polymer, polyvinyl alcohol (PVA). The resulting film demonstrated considerable biodegradability compared to conventional polyethylene and paper, along with superior tensile strength. Specifically, the biodegradability of the film was reported as 41.27%, whereas polythene and paper showed biodegradability of 10.33% and 85.99%, respectively. Moreover, the film exhibited a tensile strength of 24.87 N/mm^2, outperforming polythene and paper, which had tensile strengths of 10.86 N/mm^2 and 8.29 N/mm^2, respectively.

Furthermore, research conducted by Keziah et al. [14] focused on the synthesis, characterization, and biodegradation of bioplastic films derived from Parthenium hysterophorus weed. The study demonstrated the feasibility of producing rapidly biodegradable films with desirable mechanical properties. The highest tensile strength (11.5 ± 0.23 MPa) and Young's modulus (170 ± 0.89 MPa) were observed for the bioplastic film with a 10% concentration of polyethylene glycol 600 (PEG600). Additionally, the film exhibited an elongation at break of 9.13 ± 0.12% and displayed biodegradability of 69.29% in natural conditions within 45 days.

Moreover, efforts have been made by Demiate et al. [15] to standardize bioplastic production using various crop sources, including banana peels, potato tubers, sweet potato tubers, maize, and sorghum seeds. The study reported promising results in terms of tensile strength, elongation, and degradation characteristics of bioplastics derived from different starch sources. For instance, maize-based bioplastics exhibited a maximum tensile strength of 4.64 MPa, while potato-based bioplastics demonstrated maximum elongation. Additionally, the degradation test indicated variations

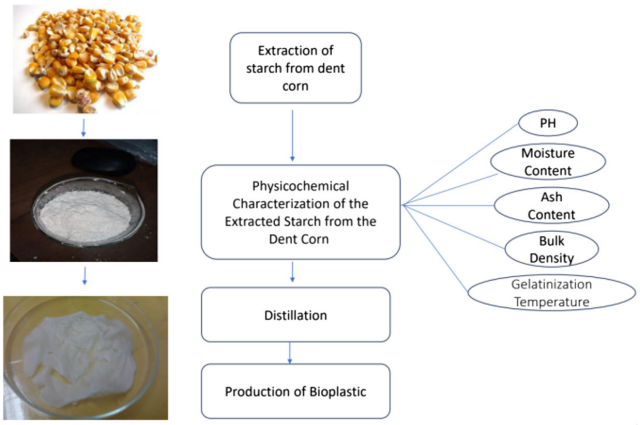
in degradation rates among different crop sources, with sorghum-based bioplastics degrading more rapidly than others.

The aim of this study was to explore the feasibility of dent corn starch-based bioplastic films and also to optimize the operating parameters and ecofriendly characteristics of dent corn starch-based bioplastic films for sustainable packaging application.

The following goals were used to achieve the study's aim:

1) Careful selection of corn species that can assure high starch content and stable starch structure.
2) Extraction and preparation of the starch for the production of plastic films by the casting method.
3) Also, the properties of the film will be assessed at different compositions, to determine the best suitable composition for biodegradable starch production.
4) Lastly, the produced plastic film will be buried in the earth to determine if it is biodegradable and the conditions for degradability.

Figure 1
Experimental process showing stages in the production of bioplastic



2. Materials and Method

2.1. Materials

This study used dent corn as a useful source for producing bioplastic film. The dent corn was obtained from the Ihiagwa market in the Owerri West district of Imo State. The necessary chemicals, such as high purity glycerol (analytical grade) and distilled water, were acquired from New Concept Laboratory, Obinze, in the same district of Imo State.

2.2. Chemicals and reagents

In this study, we employed various chemicals and reagents from reputable suppliers. Tetra oxo-sulphate (VI) acid (Sigma-Aldrich) was of analytical grade (99% purity), while selenium catalyst (Alfa Aesar) had high purity (99.9% or higher). Sodium hydroxide (Fisher Scientific) was ACS reagent grade (minimum 98% purity), and boric acid (Merck) was of high purity (99.5% or higher). Hydrochloric acid (VWR) was analytical grade (37% concentration), and glycerol (Thermo Fisher Scientific) had high purity (99.7% or higher). Distilled water was prepared in-house, and acetone (Honeywell) was analytical grade (99.5% purity). Ethanol (MilliporeSigma) and methanol (Avantor) were both commonly used with high purity levels.

2.3. Methods

Figure 1 below shows the schematic of the stages involved in the processing of dent corn to bioplastic.

2.3.1. Extraction of starch from dent corn

This study followed the method outlined by Krishnamurthy and Amritkumar [13] for the preparation of dent corn starch. The dent corn grains, weighing 5 kg, were cleaned and soaked in 5 liters of water for a day. Then, they were rinsed three times and blended. The blended mixture was strained through a cotton cloth. The strained liquid was left to stand for a day at room temperature. Then, the clear liquid was poured out, and the solid residue was collected as wet starch. It was oven-dried at 50 °C for 3 days. The dry starch mass was gently pulverized into powders using a motor and pestle and sifted with 100 mesh-size sieves. The starch powders were kept in a sealed plastic bag to avoid moisture and contamination before further analysis.

2.3.2. Physicochemical characterization of the extracted starch from the dent corn

This study followed the method of Nigam et al. [12] as well as Ezeoha and Ezenwanne [16] to measure the physicochemical properties of the starch obtained. The gelatinization temperature, ash content, pH, moisture content, bulk density, and protein content of the starch were analyzed as described by recent literatures. The test was conducted according to the analytical standards of the Institute of Professional Analysts of Nigeria (IPAN) at the new concept laboratory, in Obinze, Owerri, Nigeria.

1) **pH:** For the pH, 2 g of the dried corn starch powder was dissolved in 50 cl of distilled water, after which the PH was measured using a pH meter [14, 16].
2) **Moisture content:** For the assessment of moisture content, 5 grams of starch powder were meticulously weighed into a pristine porcelain dish. Subsequently, the dish, along with the starch, was introduced into an electric oven and subjected to a controlled temperature of 100 °C for a duration of 4 h. Following this heat treatment, the sample was carefully retrieved from the oven and transferred into a desiccator to allow for gradual cooling, thus preventing any condensation. Upon achieving ambient temperature, the weight was meticulously recorded using an analytical balance [12, 14]. The moisture content was then calculated employing the following expression, as outlined in Equation (1):

$$\text{Moisture Content } \% = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100\% \quad (1)$$

Where:
W_1 = Initial weight of empty crucible.
W_2 = Weight of empty crucible+Sample before drying.
W_3 = Weight of empty crucible+Sample after drying.

3) **Ash content:** According to Demaite et al. [15], the sample for the moisture content was further sent into the furnace and allowed to ash at a temperature of 400 °C. After the completion of the ashing

process, the sample was removed from the furnace and placed in the desiccator to cool; thereafter, the weight of the sample was determined using an analytical balance, and the % ash content was determined using the expression in Equation (2) below:

$$\text{Ash Content \%} = \frac{(w_3 - w_1)}{(w_2 - w_1)} \times 100\% \quad (2)$$

Where:
W_1 = Weight of empty crucible.
W_2 = Weight of empty crucible+sample before ashing.
W_3 = Weight of empty crucible+Ash.

4) **Bulk density:** For the bulk density, a 20 ml graduated measuring cylinder was filled with distilled water up to the10 ml mark, thereafter 2 g of corn starch was weighted and poured into the cylinder, and the increase in the volume of the water was noted [17]; the bulk density was then calculated using Equation (3) below:

$$\text{Bulk Density, g/ml} = \frac{\text{Weight}}{\text{Volume}} \quad (3)$$

5) **Gelatinization temperature:** 5 g of corn starch was weighted and poured into a beaker containing 100 ml of distilled water. The mixture was then placed on a magnetic stirrer, the stirrer was then switched on, and the temperature was gradually increased [18]. The temperature at which the mixture formed because a gel was noted as the gelatinization temperature [18].
6) **Determination of protein:** The protein determination process was done in three sections, the digestion of the sample, the distillation of the sample, and the titration of the sample [19, 20].

2.3.3. Digestion of sample

For the digestion of samples, we did the following:

Weighed 2 g of the starch sample into a 250 ml conical flask, added 20 ml of concentrated H_2SO_4, also added was 7 g of selenium catalyst (this was prepared by mixing 1 g of cupric sulfate with 7 g of potassium sulfate and a pinch of selenium metal), We then heated the mixture using a heating mantle till a yellowish, green, or greenish color was obtained and the smoke was reduced.

The digested sample was diluted to obtain the volume of digest and the dilution factor, and this was done by the following steps:

50 ml of distilled water was added to the conical flask containing the digested sample; it was then shaken well to dissolve the particles into a measuring cylinder, we took the difference in volume from the 50 ml of water added, this was the volume of the sample, we made up the measuring cylinder to 100 ml and took the dilution factor [20].

2.3.4. Distillation of sample

We carried this out using the Kjeldahl method as described by Ismail [20].

A precise volume of 10 mL of the digested and diluted sample was meticulously measured into a flask using a calibrated channel. Separately, 30 mL of boric acid solution was added to another flask, ensuring a tight seal with a funnel to prevent air ingress. To this solution, 3 drops of bromocresol green indicator were carefully introduced. Additionally, 10 mL of 40% NaOH was gradually added, via the same channel used for sample addition, to the conical flask containing the boric acid solution. The channel was promptly corked to prevent the escape of ammonia gas.

Subsequently, the heating mantle was activated and set to the highest temperature setting, initiating the distillation process. As the distillation proceeded, the color of the boric acid solution transitioned from yellow to green and eventually to blue. Concurrently, a distinct audible "pop" sound indicated the completion of the distillation process, coinciding with the boric acid solution attaining a blue hue.

Upon reaching this stage, the boric acid solution was promptly removed from the setup, and the distillate was subjected to titration. It is noteworthy that a blank distillation procedure was performed in parallel to account for any background effects.

2.3.5. Titration of sample

We titrated the distillate using 0.1 M HCL to a yellow endpoint. The above procedure identified the nitrogen content in the sample, and the protein factor was used to calculate the protein content of the sample. The expressions are given in Equations (4), (5), and (6) below:

$$\%N = \frac{1.4 \times (v_s - v_b) \times M \times D.F}{W} \quad (4)$$

N% = nitrogen content of a sample, expressed as a percentage by mass

Vs = volume in ml of the standard hydrochloric acid used for sample

Vb = volume in ml of the standard hydrochloric acid used for blank test

M = Molarity of the standard hydrochloric acid expressed to four decimal places

W = mass of test protein in g, expressed to nearest 0.1 mg

Express the nitrogen content to four decimal places.

$$\text{Protein Content \%} = N \times \text{protein factor} \quad (5)$$

Protein factor = 6.25

D.F = Dilution factor

Yield is calculated using the expression below:

$$\text{Yield\%} = \frac{\text{Weight of starch obtained after extraction}}{\text{Weight of corn before soaked in water}} \quad (6)$$

2.3.6. Production of biodegradable film using dent corn starch

A bioplastic film was produced using a formulation comprising starch powder, glycerol as a plasticizer, and distilled water. The specific method involved combining 15 g of starch powder, 8 g of glycerol, and 300 mL of distilled water in a beaker. This mixture was then subjected to heating with constant stirring using a magnetic stirrer until gelatinization commenced at 80 °C and 1 atm.

Following gelatinization, the resulting starch paste was evenly poured and spread onto a large steel plate. Subsequently, the paste-coated plate was subjected to drying in a hot air oven set at 50 °C for a duration of 1 day. This drying process facilitated the formation of the bioplastic film.

Once dried, the film was manually peeled off the steel plate and carefully stored in an airtight container at room temperature. This meticulous storage approach aimed to preserve the integrity of the bioplastic film, protecting it from external factors such as humidity and potential contaminants.

By adhering to this well-defined procedure, the study ensures the reproducibility of the bioplastic film preparation, contributing to the reliability and validity of the experimental outcomes. This methodological approach aligns with established practices in the field, fostering consistency and comparability in future studies [5, 6].

2.3.7. Influence of components on the mechanical properties (tensile strength) of produced bioplastic film from starch

1) Impact of glycerol content on the properties of the produced bioplastic film

This study aimed to investigate the influence of glycerol concentration on the properties of bioplastic films, particularly focusing on its effects on biodegradability and mechanical properties.

The glycerol content, serving as a plasticizer, was systematically varied within the range of 5.5 g to 10.5 g, while keeping other parameters constant, as detailed above. Two sets of bioplastic film samples were prepared, each comprising 15 g of starch powder and 300 mL of distilled water, with differing amounts of glycerol: 5.5 g and 10.5 g.

The mechanical properties of these films, notably tensile strength, were rigorously assessed using a Shimadzu AG-Xplus Series universal tensile strength testing machine. By subjecting the samples to mechanical testing, the impact of varying glycerol concentrations on the tensile strength, elongation at break, and toughness of the bioplastic films was quantified.

Furthermore, the biodegradability of the films was evaluated through accelerated degradation studies under controlled environmental conditions. Film samples with varying glycerol concentrations were subjected to microbial degradation tests to assess the rate and extent of biodegradation over time.

2) Effect of amount of starch powder

The effect of the amount of starch powder on the tensile strength of the prepared plastic film was investigated by preparing two samples of bioplastic film with 10 g and 20 g of starch powder, respectively, 300 ml of distilled water, and 8 g of glycerol, which is the plasticizer. The effect of the amount of starch on the tensile strength of the prepared plastic film was determined by a mechanical test on the sample using a universal tensile strength testing machine [21, 22].

3) Impact of water volume on the mechanical properties of starch-based bioplastic film

This study examined the impact of water volume on the tensile strength of the bioplastic film. Two bioplastic film samples were made with the same method as above, except that the water volumes were 250 and 350 ml, respectively, while the starch and glycerol amounts were 15 and 8.0 g, respectively. The mechanical test on the sample using a universal tensile strength testing machine measured the effect of the water volume on the tensile strength of the bioplastic film [23].

2.3.8. Physicochemical and mechanical properties of bioplastic film from starch

1) Water-repellent properties of bioplastic film

This study followed the method of Varelis [24] to measure the water absorption of the bioplastic films. The bioplastic films were immersed in water at room temperature for an hour and then dried with cotton pieces and weighed. The water absorption percentage was calculated by using Equation (7).

$$\text{Water Absorption (\%)} = \frac{\textit{wet weight} - \textit{Dry weight}}{\textit{Dry weight}} \times 100 \quad (7)$$

2) Acid resistance properties of bioplastic film

This study followed the method of Varelis [24] to evaluate the acid resistance of bioplastic film. A fixed amount of bioplastic film was immersed in a 1 M hydrochloric acid solution. The weights of the bioplastic film were measured at an hourly interval. The acid absorption percentage was calculated by using Equation (8).

$$\text{Acid Absorption (\%)} = \frac{\text{wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 \quad (8)$$

3) Base resistance properties of bioplastic film

This study evaluated the base resistance of bioplastic film by immersing a fixed amount of bioplastic film in a 1 M sodium hydroxide solution. The weights of the sample were measured at an hourly interval [24–26]. The base absorption percentage was calculated by using Equation (9).

$$\text{Base Absorption (\%)} = \frac{\text{wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 \quad (9)$$

4) Moisture resistance absorption properties of bioplastic film

This study followed the method of Ben et al. [25] to measure the moisture absorption of the bioplastic film. The bioplastic film was dried in a desiccator until its weight was constant (W1). Then, the film was exposed to a normal atmosphere for a day. After that, the film was weighed (W2) again. The moisture absorption percentage was computed by using Equation (10).

$$\text{Moisture Absorption (\%)} = \frac{\text{W2} - \text{W1}}{\text{W2}} \times 100 \quad (10)$$

Where:
W1 = initial weight of film before exposure
W2 = weight of film after exposure

2.3.9. Dissolution behavior of bioplastic film in water (solubility test)

In this investigation, the solvents employed comprised acetone, ethanol, and methanol. The bioplastic film, once prepared, was sectioned into small pieces, and 0.3 g of these fragments was placed into individual test tubes, each containing 3 ml of one of the specified solvents. Subsequently, the solubility of the films was examined after an incubation period of one hour, both at a standard temperature range of (28–30 °C) and an elevated temperature of (60 °C). The experimental methodology closely follows the procedures outlined by Tafa et al. [27].

2.3.10. Mechanical behavior of biodegradable plastic film from starch

The assessment of tensile strength, film thickness, and elongation at break for the fabricated bioplastic films was conducted utilizing an AGX Series Shimadzu tensile testing

machine. The experiments were carried out at the Department of Material and Metallurgical Engineering, Federal University of Technology, Owerri, Imo State, Nigeria. The methodology involved subjecting the bioplastic films to controlled tensile strength, with measurements taken to determine film thickness, tensile strength, and elongation at break. This testing procedure adhered to established standards and protocols, ensuring the reliability and accuracy of the results obtained.

2.3.11. Bioplastic film biodegradability property

The evaluation of biodegradability was conducted through the soil burial method, a procedure previously conducted by Varelis [24] as well as Ben et al. [25], with minor adjustments. The bioplastic film, post-preparation, was cut into dimensions of 3 inches in length and 3 inches in width, and its initial weight was recorded as W1. Subsequently, the weighed film was buried in the soil at a depth of 3 inches for a duration of one week at ambient room temperature. Following this incubation period, the film was carefully unearthed and re-weighed (W_2).

The degradation process is attributed to soil microorganisms consuming the starch content, resulting in the fracture of the polymer chain and subsequent biodegradation. The percentage weight loss of the film was calculated using Equation (11).

This methodology, while influenced by the soil burial method as detailed by previous researchers, was adapted to suit the specific requirements of the study, ensuring a standardized and controlled assessment of biodegradability. The modifications made were in accordance with best practices in the field, contributing to the reliability and validity of the experimental outcomes.

$$\text{Weight Loss } \% = \frac{W1 - W2}{W1} \tag{11}$$

Where:
W1 = weight of film before burying,
W2 = weight of film after burying.

3. Results

3.1. Physicochemical characteristics of corn starch

Although the pH values, moisture content, and gelatinization temperature of the corn starch differed by being lower than the values reported in the literature, other attributes such as ash content, protein content, and yield percentage fell within the range specified in the literature, as presented in Table 1. This discrepancy suggests variations in specific characteristics of the corn starch utilized in the study compared to the literature, underscoring the importance of considering multiple parameters for a comprehensive understanding of starch quality and composition. The results highlight noteworthy distinctions in certain aspects while reinforcing alignment with literature values for other key characteristics.

3.2. Composition and effect of amount of glycerol, starch, and water content

The influence of varying quantities of glycerol, starch powder, and water volume on the tensile strength of the fabricated bioplastic film is detailed in Tables 2 and 3. These tables present a comprehensive depiction of the experimental outcomes, illustrating the impact of different amounts of key components on the mechanical property of tensile strength in the developed bioplastic films.

From the model developed using the least square method, where we consider the effect of starch content, glycerol content, and water content on the tensile strength of the film, the model is

$$Y = 2.61 + 0.01\,X_1 + 0.02\,X_2 + (2.22\times10\text{^}{-}16)X_3$$

where Y is the tensile strength in Mpa
X_1 is starch content in gram (g)
X_2 is the glycerol content in gram (g)
And X_3 is the water content in (ml)

In the obtained results, it was determined that the combination of 8 g of glycerol, 15 g of starch content, and 300 ml of water demonstrated the highest tensile strength compared to other quantities and volumes tested. This particular set of conditions emerged as the most favorable, as it consistently yielded superior tensile strength in the prepared bioplastic films.

3.3. Biodegradability test

To determine if the composition of the film affects the degradation rates, a least squares analysis was used on the degradation results for two weeks, after which a model was formed. The model is

$$Y = 49.001 + 0.051\,X_1 + 0.108\,X_2 + 0.0031\,X_3$$

where Y is the degradation rate in %
X_1 is the starch content in gram (g)
X_2 is the glycerol content in gram (g)
X_3 is the water content in (ml)

3.4. Discussion

The results obtained indicate notable disparities in the pH value, moisture content, and gelatinization temperature of dent corn starch

Table 1
Result of physicochemical characteristics of corn starch

S/N	Characteristics	Corn starch from experiment	Corn starch [28]
1	Moisture content %	6.52	6.50
2	Gelatinization temperature ˚C	64.3	61.2
3	Ash content %	0.15	0.1–0.3
4	Bulk density (g /ml)	0.43	0.47
5	Ph	7.14	7.02
6	Protein content %	1.17	1.1–2.00
7	Yield percent %	67.0	50–70

Table 2
Composition of various samples

Sample	Starch content (g)	Glycerol content (g)	Water content (ml)
1	15	8.0	300
2	10	8.0	300
3	20	8.0	300
4	15	5.5	300
5	15	10.5	300
6	15	8.0	250
7	15	8.0	350

Table 3
Mechanical testing results for samples

Sample	Films thickness (mm)	Tensile strength (Mpa)	Elongation at break (%)
1	1.3	2.58	24
2	1.1	2.35	20
3	1.4	2.45	22
4	1.0	2.30	21
5	1.1	2.40	19
6	1.3	2.50	20
7	1.3	2.50	23

compared to the literature values. However, it is noteworthy that ash content, protein content, and yield percentage align closely with the literature range. This variation may be attributed to factors such as the cultivation region and prevailing climatic conditions. The distinct environmental parameters of the cultivation region could play a significant role in influencing the composition of dent corn starch. The observed discrepancies emphasize the need for a nuanced understanding of the impact of geographical and climatic factors on starch characteristics, shedding light on the intricacies of starch composition and properties in different agricultural contexts. Further investigations and comparative studies considering regional variations are warranted to enhance the comprehension of these disparities and their implications on starch quality.

We noticed that the composition affects the properties of the films. For the tensile strength, we observed that with an increase in plasticizers, the tensile strength increases proportionately. The sample with the highest tensile strength is sample 1, followed by sample 6 and sample 7. It showed that the best composition for tensile strength is sample 1, which also had the best elongation. From the pieces of literature that were reviewed, samples with 20–35% plasticizers have an excellent balance in mechanical properties and absorption rates. Our results also followed that trend. The biodegradability rate showed that compositions with high starch contents decayed faster than those with relatively lower starch contents. This is consistent with the findings of the papers reviewed in the literature review.

The analysis of tensile strength and elongation at the breaking point, as outlined in Table 3, revealed significant insights into the mechanical properties of the bioplastic film samples. Notably, the incorporation of glycerol as a plasticizer was observed to enhance the film's flexibility by reducing intermolecular bonds between polymer chains, thereby modifying its mechanical characteristics. This aligns with the findings of Ibrahim et al. [29], who detailed how the mechanical resistance of films against rupture improved with the impregnation of rice starch, resulting in a nearly 1.5 times greater strength compared to non-impregnated counterparts.

Additionally, the starch crosslinking through ether or ester linkages among hydroxyl (OH^-) clusters, as described by Nigam et al. [12], was found to enhance mechanical properties by increasing density through crosslinking. The observations from Table 3 suggest that Sample 1 exhibited favorable tensile properties, implying that the specific formulation or processing conditions associated with Sample 1 resulted in superior mechanical characteristics.

These findings collectively showed the influence of plasticizers and starch crosslinking on the mechanical properties of bioplastic films, emphasizing the importance of formulation variables in tailoring film characteristics. The comparison with existing literature further contextualizes the outcomes and contributes to the understanding of how specific modifications impact the mechanical performance of starch-based films.

From the model developed using the least square method, where we consider the effect of starch content, glycerol content, and water content on the tensile strength of the film, the model is:

$$Y = 2.61 + 0.01\ X_1 + 0.02\ X_2 + (2.22\times10\text{^}{-}16)X_3$$

where Y is the tensile strength in Mpa
X_1 is starch content in gram (g)
X_2 is the glycerol content in gram (g)
And X_3 is the water content in (ml)

It was observed that starch content and glycerol content have a very large effect on the tensile strength, with glycerol having the greatest effect on the tensile strength of the film.

The assessment of bioplastic film thickness involved measurements at ten different locations using a thickness gauge and the subsequent calculation of the average thickness for each sample. The results indicated an average thickness of (1.3 mm, 1.1 mm, 1.4 mm, 1.0 mm, 1.1 mm, 1.3 mm, and 1.3 mm) for samples 1 through 7, respectively. In accordance with the regulations of the federal government of Nigeria, which stipulates a minimum thickness of 50 microns for plastic bags, the prepared bioplastic films in this study surpass the regulatory requirement. This implies their suitability for use in the production of carrying bags.

However, a comparison with existing literature reveals variations in the reported thickness of starch films [30]. Observed a thickness value of approximately 0.15 mm for corn starch films, whereas Bilo et al. [31] investigated various starch films from sources such as potatoes, rice, wheat, gelatine, and sorghum, reporting thickness within the range of 53 to 63 microns. The findings of the present study indicate a higher thickness, potentially attributed to differences in processing methodologies.

This discrepancy underscores the significance of processing techniques in influencing the physical properties of bioplastic films. The variations in thickness may be a consequence of specific procedures employed in the current study, emphasizing the need for a nuanced understanding of processing parameters and their implications on film characteristics. Further exploration of processing methods and their effects on film thickness is warranted to enhance the comprehension of these variations and guide future applications of bioplastic films.

The absorption of the bioplastic films was tested in water and was found to be (24, 26.67, 25, 15.67, 31, 23.67, and 29 all in %) for samples 1, 2, 3, 4, 5, 6, and 7, respectively, from the result,

Table 4
Results of absorption test on plastic films

Samples	Water absorption resistance %	Moisture absorption resistance %	Acid absorption resistance %	Base absorption resistance %
1	24.00	15.83	30.54	Soluble
2	26.67	36.59	12.50	Soluble
3	25.00	32.78	17.18	Soluble
4	15.67	27.81	32.71	Soluble
5	31.00	25.22	17.65	Soluble
6	23.67	33.44	33.85	Soluble
7	29.00	41.91	17.52	Soluble

Table 5
Solubility test result on plastic films

Sample	Acetone 30 °C	Ethanol 30 °C	Methanol 30 °C	Acetone 60 °C	Ethanol 60 °C	Methanol 60 °C
1	Insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble
2	Insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble
3	Insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble
4	Insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble
5	Insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble
6	Insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble
7	insoluble	Insoluble	insoluble	Insoluble	Swell	insoluble

Table 6
Results of biodegradability test on plastic film samples

Sample	Time (weeks)	Initial mass (g)	Final mass (g)	Weight loss (%)
1	1	3.10	2.00	35.48
1	2	3.10	1.40	54.84
1	3	3.10	0.50	83.87
1	4	3.10	0.00	100
2	1	3.20	2.30	28.13
2	2	3.20	1.60	50.00
2	3	3.20	0.70	78.00
2	4	3.20	0.00	100
3	1	2.97	2.13	28.28
3	2	2.97	1.47	50.51
3	3	2.97	0.74	75.08
3	4	2.97	0.00	100
4	1	3.00	2.10	30.00
4	2	3.00	1.42	52.67
4	3	3.00	0.61	79.67
4	4	3.00	0.00	100
5	1	2.80	2.00	28.57
5	2	2.80	1.31	53.21
5	3	2.80	0.53	81.07
5	4	2.80	0.00	100
6	1	3.20	2.33	27.19
6	2	3.20	1.61	49.69
6	3	3.20	0.80	75.00
6	4	3.20	0.00	100
7	1	3.00	2.17	27.67
7	2	3.00	1.51	50.00
7	3	3.00	0.68	77.33
7	4	3.00	0.00	100

sample 4 had the lower water absorption rate of 15.67%, which means sample 4 will have a longer shelf life when immersed in water.

The absorption of the films was also checked when exposed to moisture in the environment for 1 day. The result is shown in Table 4; from the result, sample 1 has the lowest moisture absorption rate of 15.83% meaning it will have the longest shelf life should the sample be exposed to moisture. Tables 5 and 6 show the solubility and biodegradability test results.

A similar test was carried out using an acid and a base. It was observed that the samples were completely soluble in the base, but the acid absorption resistance percentage revealed sample 2 to have the lower acid resistance rate.

The samples were found to be insoluble in acetone, ethanol, and methanol at a temperature of 28–30 °C. When the temperatures were increased to 60 °C, the samples were also found to be insoluble in acetone and methanol but swelled in ethanol.

The evaluation of the biodegradability properties of the sample involved studying the weight loss of the specimens, providing insights into the process of biodegradation facilitated by microorganisms. Notably, all buried samples exhibited comparable degradation rates. This uniformity in degradation rates across the buried specimens suggests a consistent susceptibility to biodegradation, emphasizing the effectiveness of the material in undergoing natural decomposition by microorganisms. It was above 30% for the first week, 52% for two weeks, 80% for three weeks, and 100% for four weeks, which means the samples were completely degraded at four weeks.

Also, to determine if the composition of the film affects the degradation rates, a least squares analysis was used on the degradation results for two weeks, after which a model was formed. The model is:

$$Y = 49.001 + 0.051\ X_1 + 0.108\ X_2 + 0.0031\ X_3$$

where Y is the degradation rate in %
X_1 is the starch content in gram (g)
X_2 is the glycerol content in gram (g)
X_3 is the water content in (ml)

The molecular model shows that glycerol content has the highest contribution to the degradation rate. I can say that the plasticizer content, to a very large extent, determines the degradation rate of plastic.

4. Conclusion

This study showed that bioplastic film produced from different compositions with different ratios has better biodegradability than the existing plastic materials. Moisture absorption changes with environmental temperature, but the results obtained were not significant. The glycerol addition improves the shelf life of the products and improves their mechanical strength. The average thickness of the bioplastic is 1.2 mm. The average moisture content is 30.51%. The biodegradability of the sample is 100%, which is achieved in 4 weeks. According to these effects, the obtained bioplastics can be used as substantiation for non-biodegradable plastics. Hence, it can be concluded that it is very possible to make plastic from the above biomaterials as raw materials, and this can facilitate the mitigation of the environmental problem.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Bethel Chijioke Iheanacho: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Hadiza Nuhu Ajoge:** Conceptualization, Methodology, Software, Formal analysis. **Usman Ismail:** Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Fon Alain Zoum:** Visualization, Supervision. **Favour Okechi Ifeanyi-Nze:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Visualization, Supervision, Project administration. **Favour Onasokhare Okunbi:** Resources, Data curation, Project administration. **Chinecherem Favour Edeh:** Writing – original draft, Visualization, Supervision. **Nathaniel Nwoke Chimezie:** Validation, Formal analysis. **Esther Abigail Udoh:** Resources, Data curation, Writing – review & editing. **Justin Okechukwu Nworie:** Resources. **Tosin Oluwashina Oseni:** Investigation. **Marian Ugonna Mark:** Investigation. **George Arubi Akpowu:** Writing – review & editing. **Dolapo Abidemi Kolapo:** Writing – review & editing. **Augustine Oboseoye Odibo:** Data curation. **Olaoluwa Joseph Edun:** Validation. **Udochukwuka Confidence Zogini:** Validation. **Chima Ogechukwu Egwuonwu:** Writing – original draft.

References

[1] Bhat, R. (2022). Emerging trends and sustainability challenges in the global agri-food sector. In R. Bhat (Ed.), *Future foods: Global trends, opportunities, and sustainability challenges* (pp. 1–21). Academic Press. https://doi.org/10.1016/B978-0-323-91001-9.00041-4

[2] Ahmad, F., Saeed, Q., Shah, S. M. U., Gondal, M. A., & Mumtaz, S. (2022). Environmental sustainability: Challenges and approaches. In M. K. Jhariya, R. S. Meena, A. Banerjee, & S. N. Meena (Eds.), *Natural resources conservation and advances for sustainability* (pp. 243–270). Elsevier.

[3] Moshood, T. D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M. H., & AbdulGhani, A. (2022). Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution? *Current Research in Green and Sustainable Chemistry*, *5*, 100273. https://doi.org/10.1016/J.CRGSC.2022.100273

[4] Döhler, N., Wellenreuther, C., & Wolf, A. (2022). Market dynamics of biodegradable bio-based plastics: Projections and linkages to European policies. *EFB Bioeconomy Journal*, *2*, 100028. https://doi.org/10.1016/J.BIOECO.2022.100028

[5] do Val Siqueira, L., la Fuente Arias, C. I., Maniglia, B. C., & Tadini, C. C. (2021). Starch-based biodegradable plastics: Methods of production, challenges and future perspectives. *Current Opinion in Food Science*, *38*, 122–130. https://doi.org/10.1016/J.COFS.2020.10.020

[6] Jiang, T., Duan, Q., Zhu, J., Liu, H., & Yu, L. (2020). Starch-based biodegradable materials: Challenges and opportunities.

Advanced Industrial and Engineering Polymer Research, *3*(1), 8–18. https://doi.org/10.1016/J.AIEPR.2019.11.003

[7] Chen, M., Yan, X., Cheng, M., Zhao, P., Wang, Y., Zhang, R., . . . , & Chen, M. (2022). Preparation, characterization and application of poly(lactic acid)/corn starch/eucalyptus leaf essential oil microencapsulated active bilayer degradable film. *International Journal of Biological Macromolecules*, *195*, 264–273. https://doi.org/10.1016/J.IJBIOMAC.2021.12.023

[8] Swetha, T. A., Ananthi, V., Bora, A., Sengottuvelan, N., Ponnuchamy, K., Muthusamy, G., & Arun, A. (2023). A review on biodegradable polylactic acid (PLA) production from fermentative food waste – Its applications and degradation. *International Journal of Biological Macromolecules*, *234*, 123703. https://doi.org/10.1016/J.IJBIOMAC.2023.123703

[9] Yaashikaa, P. R., Senthil Kumar, P., & Karishma, S. (2022). Review on biopolymers and composites – Evolving material as adsorbents in removal of environmental pollutants. *Environmental Research*, *212*, 113114. https://doi.org/10.1016/J.ENVRES.2022.113114

[10] Udayakumar, G. P., Muthusamy, S., Selvaganesh, B., Sivarajasekar, N., Rambabu, K., Banat, F., . . . , & Show, P. L. (2021). Biopolymers and composites: Properties, characterization and their applications in food, medical and pharmaceutical industries. *Journal of Environmental Chemical Engineering*, *9*(4), 105322. https://doi.org/10.1016/J.JECE.2021.105322

[11] Charles, A. L., Motsa, N., & Abdillah, A. A. (2022). A comprehensive characterization of biodegradable edible films based on potato peel starch plasticized with glycerol. *Polymers*, *14*(17), 3462. https://doi.org/10.3390/polym14173462

[12] Nigam, S., Das, A. K., & Patidar, M. K. (2021). Synthesis, characterization and biodegradation of bioplastic films produced from *Parthenium hysterophorus* by incorporating a plasticizer (PEG600). *Environmental Challenges*, *5*, 100280. https://doi.org/10.1016/J.ENVC.2021.100280

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

[14] Keziah, V. S., Gayathri, R., & Vishnu Priya, V. (2018). Biodegradable plastic production from corn starch. *Drug Invention Today*, *10*(7), 1315–1317.

[15] Demiate, I. M., Bet, C. D., Ito, V. C., & Lacerda, L.G. (2023). Laboratory methods for starch extraction. In M. P. Cereda & O. F. Vilpoux (Eds.), *Starchy crops morphology, extraction, properties and applications: Vol 1: Underground starchy crops of South American origin: Production, processing, utilization and economic perspectives* (pp. 165–187). Academic Press.

[16] Ezeoha, S. L., & Ezenwanne, J. N. (2013). Production of biodegradable plastic packaging film from cassava starch. *IOSR Journal of Engineering*, *3*(10), 14–20. https://doi.org/10.9790/3021-031051420

[17] Obadi, M., & Xu, B. (2021). Review on the physicochemical properties, modifications, and applications of starches and its common modified forms used in noodle products. *Food Hydrocolloids*, *112*, 106286. https://doi.org/10.1016/J.FOODHYD.2020.106286

[18] Chen, J., Wang, Y., Liu, J., & Xu, X. (2020). Preparation, characterization, physicochemical property and potential application of porous starch: A review. *International Journal of Biological Macromolecules*, *148*, 1169–1181. https://doi.org/10.1016/J.IJBIOMAC.2020.02.055

[19] Jung, H. W., & Kim, H. S. (2023). Impact of pH on physicochemical properties of corn starch by dry heat treatment. *Food Science and Biotechnology*, *32*, 1901–1911. https://doi.org/10.1007/s10068-023-01353-7

[20] Ismail, B. P. (2017). Ash content determination. In S. S. Nielsen (Ed.), *Food analysis laboratory manual* (pp. 117–119). Springer. https://doi.org/10.1007/978-3-319-44127-6_11

[21] Deb, P. K., Abed, S. N., Jaber, A. M. Y., & Tekade, R. K. (2018). Particulate level properties and its implications on product performance and processing. In R. K. Tekade (Ed.), *Dosage form design parameters: Volume II: A volume in advances in pharmaceutical product development and research* (pp. 155–220). Academic Press. https://doi.org/10.1016/B978-0-12-814421-3.00005-1

[22] Sandhu, K. S., & Singh, N. (2007). Some properties of corn starches II: Physicochemical, gelatinization, retrogradation, pasting and gel textural properties. *Food Chemistry*, *101*(4), 1499–1507. https://doi.org/10.1016/J.FOODCHEM.2006.01.060

[23] Mæhre, H. K., Dalheim, L., Edvinsen, G. K., Elvevoll, E. O., & Jensen, I. J. (2018). Protein determination—Method matters. *Foods*, *7*(1), 5. https://doi.org/10.3390/FOODS7010005

[24] Varelis, P. (2016). Food chemistry and analysis. *Reference Module in Food Science*. https://doi.org/10.1016/B978-0-08-100596-5.03341-2

[25] Ben, Z. Y., Samsudin, H., & Yhaya, M. F. (2022). Glycerol: Its properties, polymer synthesis, and applications in starch based films. *European Polymer Journal*, *175*, 111377. https://doi.org/10.1016/J.EURPOLYMJ.2022.111377

[26] Tarique, J., Sapuan, S. M., & Khalina, A. (2021). Effect of glycerol plasticizer loading on the physical, mechanical, thermal, and barrier properties of arrowroot (*Maranta arundinacea*) starch biopolymers. *Scientific Reports*, *11*(1), 13900. https://doi.org/10.1038/s41598-021-93094-y

[27] Tafa, K. D., Satheesh, N., & Abera, W. (2023). Mechanical properties of tef starch based edible films: Development and process optimization. *Heliyon*, *9*(2), e13160. https://doi.org/10.1016/J.HELIYON.2023.E13160

[28] Gabriel, A. A., Solikhah, A. F., & Rahmawati, A.Y. (2021). Tensile strength and elongation testing for starch-based bioplastics using melt intercalation method: A review. *Journal of Physics: Conference Series*, *1858*, 012028. https://doi.org/10.1088/1742-6596/1858/1/012028

[29] Ibrahim, M. I. J., Sapuan, S. M., Zainudin, E. S., & Zuhri, M. Y. M. (2019). Physical, thermal, morphological, and tensile properties of cornstarch-based films as affected by different plasticizers. *International Journal of Food Properties*, *22*(1), 925–941. https://doi.org/10.1080/10942912.2019.1618324

[30] Shanmathy, M., Mohanta, M., & Thirugnanam, A. (2021). Development of biodegradable bioplastic films from Taro starch reinforced with bentonite. *Carbohydrate Polymer Technologies and Applications*, *2*, 100173. https://doi.org/10.1016/J.CARPTA.2021.100173

[31] Bilo, F., Pandini, S., Sartore, L., Depero, L. E., Gargiulo, G., Bonassi, A., . . . , & Bontempi, E. (2018). A sustainable bioplastic obtained from rice straw. *Journal of Cleaner Production*, *200*, 357–368. https://doi.org/10.1016/J.JCLEPRO.2018.07.252

How to Cite: Iheanacho, B. C., Ajoge, H. N., Ismail, U., Zoum, F. A., Ifeanyi-Nze, F. O., Okunbi, F. O., . . . , & Egwuonwu, C. O. (2025). A Comprehensive Study on the Production and Characterization of Eco-friendly Biodegradable Plastic Films from Dent Corn Starch. *Archives of Advanced Engineering Science*, *3*(3), 178–187. https://doi.org/10.47852/bonviewAAES42022946