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Studies on Banana Stem Fibrils and Development of Corn Starch-Based Bioplastic Films: Effect of Glycerol Concentration on Physicochemical and Mechanical Properties

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Abstract: ***Pseudo-stem fiber from the banana plant (Musa sp.), a biodegradable material derived from agriculture waste, is a very promising source of natural fibers. In this research, the prop666erties and advanced applications of fibrils obtained from the banana stem have been investigated. Bioplastic films based on corn starch were prepared by using the solution casting method where glycerol was used as a plasticizer in different quantities of 1 ml, 2 ml, 3 ml, and 4 ml; the corresponding samples are CSG3, CSG4, and CSG5. The films were tested for tensile strength, elongation at break, density, moisture content, film thickness, and water, weak acid, weak base, strong acid, and strong base solubility. The result identified that the film made up of 1 ml of glycerol (code sample CSG3) had the highest tensile strength of 15.5 kg/cm², and that elongation at break ranged between 8.1% (CSG5) to 16.8% (CSG3) as the amount of glycerol used reduced. Density varied in a non-linear manner; the lowest was 0.131 g/cm³ at a medium level of glycerol use, before rising to 0.1402 g/cm³. The moisture content of the films was between 30.4% and 32.1%. For solubility, in both acid and base all films were found to be completely soluble (100%) and stable in water. This demonstrated the feasibility of using corn starch-glycerol films as sustainable packaging materials.***

Keywords: Banana stem fiber; Musa fiber; Corn starch; Glycerol; Bioplastic film; Tensile strength; Elongation-at-break; Biodegradable packaging; Solution casting; Natural fiber.

1. Introduction

The rising problem of plastic pollution in the world has brought about a lot of attention to the development of biodegradable and bio-based materials as an alternative for petroleum-based plastics for packaging and other purposes (1). Naturally grown fibers, especially those obtained from agricultural waste products, have turned out to be promising fillers for biopolymer matrices, owing to their renewability, biodegradability, low cost, and good mechanical characteristics (2). Banana (Musa sp.) is one of the most widely grown fruits all over the world. India produces approximately 13.5 million tons of bananas per year (3). The process of growing the crop results in a large amount of waste material, mostly consisting of the pseudo-stem that is usually thrown away after harvesting. The pseudo-stem contains a lot of natural fibers, consisting of cellulose, hemicelluloses, and lignin in a matrix of thick-walled cells glued together by natural gums (4). The fiber of banana plants is called Musa fiber; it is distinguished by its excellent tensile strength, biodegradability, ability to be spun, and fineness (5).

Although banana pseudo-stem fiber possesses unique characteristics, the usage of such material is not consistent with the availability. It has been proven that the usage of banana fiber is effective in various fields, such as the production of bio-composite films (6), oil sorbents (7), paper making (8), reinforcement of polymer composites (9) and activation carbon electrodes for supercapacitors (10). However, there is a lack of research on the preparation and physicochemical properties of corn starch bioplastics films, which can be explained by the absence of research on corn starch based bioplastics films regarding different glycerol content in relation to banana fiber research. Corn starch is commonly used as raw material in production of bioplastics films owing to its abundance, low cost, biodegradability, non-toxicity and high film forming abilities (11). The use of plasticizer, for example glycerol, makes the films more flexible as it breaks hydrogen bonds in polymer chain (12). According to the current study, the objectives are: (i) to review thoroughly the properties and applications of fibrils from banana stems; and (ii) to produce and study corn starch bioplastic films with different amounts of glycerol, considering their tensile strength, elongation, density, moisture, thickness, and solubility. Banana pseudo-stem fiber has received considerable attention due to its sustainability as a reinforcing material. Bhatnagar et al. reviewed extensively about the chemical composition and properties of banana fiber in various uses in industries such as paper, tea bag making, currency, and polymers. The field of natural fiber composites has shown increased use of banana fibers owing to their suitable chemical composition, light weight, and recyclable nature. Dutta and Sit proved that bio-composite films from the potato starch matrix filled with ultrasonicated and cellulose enzyme treated banana fiber had an excellent tensile strength of 5.02 MPa and sealability of 4.27 MPa, along with a significant reduction in water vapor transmission rate (0.156 g mm m^{-2} h^{-1} kPa^{-1}) and total

degradation in 42 days, with improved storability of packed grapes up to 8 days. Madasamy et al. evaluated the potential of banana stem and coconut fiber as sorbents in oil spill remediation. The chitosan-coated banana stem fiber had 6.59% better oil sorption capability, and fiber analysis was done using SEM and FTIR techniques. Tripathi et al. were able to replace 75% of expensive foreign softwood pulp with banana stem pulp in kraft papermaking without sacrificing any physical characteristics of paper. Zulfikar et al. proved that banana stem fiber composites with 15% fiber loading in polyester matrix were capable of attaining a flexural strength of 27.20 MPa, which was enough to produce skateboards. Kokate et al. studied the successful adsorption process of removing Pb2+ ions from water using banana stem fiber formed through extraction process. Yu et al. found out that warm-water retting treatment enhanced physical properties of banana stem fiber.

What sets corn starch bioplastics apart is their greater clarity, owing to the higher amylose content in them. This leads to a linear molecule formation in comparison to other sources of starch (12). Glycerol and sorbitol are the two plasticizers used frequently when creating starch-based films. They improve elasticity and shelf life by breaking intermolecular hydrogen bonding (13). The results have shown that the choice and quantity of plasticizer plays a decisive role in the properties of resulting films (14).

2. Materials and Methods

2.1 Materials Chemicals

The food-grade cornstarch used in the experiment was purchased from the local supermarket in Kanpur. Analytical grade glacial acetic acid (M/s S D Fine Chemicals, Mumbai) and glycerol were purchased from M/s S D Fine Chemicals, Mumbai. Distilled water was prepared in the laboratory by double distillation technique. All chemicals used were directly taken without any additional purification.

2.2 PREPARATION OF BIOPLASTIC FILMS

The films of bioplastic obtained from the starch of corn were prepared by the solution casting technique. Around 5 g of the corn starch was dissolved in 30 mL of distilled water. To act as a compatibilizing agent, 2 mL of glacial acetic acid was used. The glycerol was used in different amounts, such as 1 ml, 2 ml, 3 ml, and 4 ml, and thus, labeled as CSG2 (1 ml control/reference), CSG3, CSG4, and CSG5, respectively. The solution was stirred for 10 minutes at a temperature range of 90-110°C on a hot plate until it acquired a consistent, pasty, and viscous form. It was then coated over glass plates through the process of glass rod coating. The films were completely dried at room temperature for 3-5 days.

2.3 Characterization of Films

2.3.1 Thickness and Density

Thicknesses of the films were measured randomly in five places with the use of mitutoyo dial gauge, which had a measuring precision of ±0.01 mm, and their average was taken. The density of the films was calculated through determination of the mass to volume ratio, where the volume was obtained by measuring the thickness of the film.

2.3.2 Moisture Content

Determination of Moisture Content was carried out through gravimetric method. The film sample was weighed, dried at 105°C for 24 hours, then reweighed. Percentage of moisture content was determined by the formula: % moisture = $[(w_1 - w_2) / w_1] \times 100$, where w_1 is initial weight while w_2 is dry weight.

2.3.3 Tensile Strength and Elongation-At-Break

The tensile testing apparatus was used for the determination of the tensile strength and elongation-at-break values. Standardized films underwent the test under uniaxial tensile load at a constant rate of crosshead speed. The maximum tensile strength value (kg/cm²) and elongation-at-break (%) values were noted for each replicate specimen.

2.3.4 Solubility Studies

The solubility of the films in terms of their chemical solubility was determined by placing the pre-weighed samples of the film in solutions of distilled water, weak acid (diluted acetic acid), weak base (diluted sodium bicarbonate), strong acid (hydrochloric acid), and strong base (sodium hydroxide) for 24 hours at room temperature. The percent change in weight was calculated.

3. Results and Discussion

3.1 Physical Properties: Thickness, Mass, and Density

A tabulation of the physical characteristics of the corn starch-glycerol bioplastic films prepared is shown in Table 1. There was an observed increase in film thickness from 0.69 mm for CSG3 with 2 ml of glycerol to 0.84 mm for CSG5 with 4 ml of glycerol as a result of the increment in the amount of glycerol in the film matrix. In contrast, the mass was observed to decrease from 0.025 g for CSG3 to 0.022 g for CSG5, suggesting that there is an expansion in the film matrix due to higher glycerol content. The density of the bioplastics is also observed to decrease from 7.24×10^{-3} g/cm³ in CSG3 to 6.51×10^{-3} g/cm³ in CSG5, correlating with the increase in thickness and reduction in mass.

Table 1: Physical properties of corn starch–glycerol bioplastic films

Sample Code	Glycerol (mL)	Thickness (mm)	Mass (g)	Density $\times 10^{-3}$ (g/cm³)
CSG3	2	0.69	0.025	7.24
CSG4	3	0.81	0.023	7
CSG5	4	0.84	0.022	6.51

CSG sample codes correspond to corn starch–glycerol films at respective glycerol volumes.

3.2 Moisture Content

The results of the moisture content for the synthesized films are given in Table 2. It can be seen that there was no difference in moisture absorption between the samples, which varied from 30.4% (CSG4) to 32.1% (CSG3). This

high level of moisture absorption is quite common for starch films due to the hydrophilic nature of the films owing to the presence of hydroxyl groups in the polymers of the starch (13). The differences in moisture content at different glycerol concentrations indicate that the effect of glycerol on the hydrophilic properties of the matrix of corn starch does not take place in the studied concentration range.

Table 2. Moisture content of corn starch–glycerol bioplastic films

Sample Code	Initial Wt. (g)	Final Wt. (g)	Moisture Content (%)
CSG3	0.025	0.033	32.1
CSG4	0.023	0.03	30.4
CSG5	0.022	0.029	31.8

3.3 Tensile Strength

The influence of different glycerol concentrations on tensile strength values of bioplastic films is illustrated in Table 3 below, with the diagram provided in Fig. 1. The CSG3 film, having 2 mL of glycerol, showed the greatest tensile strength value (5.45 MPa = 15.5 kg/cm²). The greater amount of glycerol caused significant decrease in tensile strength of bioplastic films: thus, CSG4 with 3 mL of glycerol showed 11.27 MPa, while CSG5 with 4 mL of glycerol showed the smallest tensile strength value, 6.52 MPa. The highest tensile strength of 15.5 kg/cm² was achieved at the smallest glycerol concentration level. Such dependence of tensile strength on glycerol concentration is in line with general plasticizer theory. Glycerol works in such a way that it is placed among starch polymer chains; as a result, the number of intermolecular hydrogen bonds and chain entanglements is decreased, which increases flexibility and decreases rigidity of films (14). Due to lower glycerol concentration, starch polymer chains are able to retain their intermolecular cohesion, which leads to higher tensile strength of films.

Table 3: Mechanical properties of corn starch–glycerol bioplastic films

Sample Code	Glycerol (mL)	Tensile Strength (kg/cm²)	Elongation-at-Break (%)
CSG3	2	15.5	16.8
CSG4	3	11.3	11.6
CSG5	4	6.5	8.1

Bold values indicate optimum (highest) mechanical performance.

3.4 Elongation-at-Break

The elongation at break values were found to have an inverse relationship with tensile strength values as showed in Table 3. CSG3, having addition of 2ml glycerol, had an elongation at break of 16.8%. On the other hand, CSG4 and CSG5 values were recorded at 11.6% and 8.1%, respectively. Though it is generally expected that increased glycerol levels would promote elongation, the results seem to depict a reduction in elongation due to its plasticizing effect. This kind of results can be due to the fact that the range of glycerol concentration used was quite low and high amounts might lead to phase separation in the starch matrix, making elongation difficult (14). Acetic acid, as a process aid, can also influence the density of the cross-linkages of starch affecting the elongation response to glycerol concentration.

3.5 Chemical Solubility

Table 4 summarized the solubility properties of bioplastic films subjected to various chemical mediums. Films showed low solubility in distilled water, having weight change of only 5%, and therefore had good stability in water at ambient temperature. Solubility was from 50% to 60% in weak acidic conditions and between 20% and 40% in weak basic conditions. Addition of glycerol made solubility values rise, which means that the increased amount of plasticizer makes film less stable in slightly reactive environment. In both strong acid (HCl) and strong base (NaOH), films were completely soluble (100% solubility). This behavior proves high sensitivity of starch-based bioplastics to very high or very low pH. It is explained by the fact that in strongly acidic medium, the cleavage of glycosidic bonds happens due to the action of acid, and in basic medium, the saponification or dissolution of ester linkages occurs (15). This data shows that bioplastic films are applicable for packaging in neutral or near-neutral environment but not in highly corrosive chemical environment.

Table 4: Solubility of bioplastic films in various chemical media (% weight change after 24 h at room temperature)

Sample	Water (%)	Weak Acid (%)	Weak Base (%)	Strong Acid (HCl) (%)	Strong Base (NaOH) (%)
CSG3	5	50	20	100	100
CSG4	5	60	30	100	100
CSG5	5	60	40	100	100

3.6 Overall Comparative Summary

Properties of the Bioplastic Film Materials can be seen in Table 5 below. From the data, it can be observed that sample CSG3 with 2 mL glycerol showed the best mechanical properties with a tensile strength of 15.5 kg/cm² and elongation-at-break of 16.8%. It also showed the least thickness of 0.69 mm and the highest density. On the other hand, CSG5 showed the highest thickness of 0.84 mm and the lowest density due to presence of more glycerol. Moisture content was found to be nearly equal for all samples with values ranging from 30-32%, and they were resistant to strong acids and bases.

Table 5: Consolidated property summary of corn starch–glycerol bioplastic films

Sample	Glycerol (mL)	Thickness (mm)	Moisture (%)	Tensile Str. (kg/cm²)	Elongation (%)	Density ×10⁻³
CSG3	2	0.69	32.1	15.5	16.8	7.24
CSG4	3	0.81	30.4	11.3	11.6	7
CSG5	4	0.84	31.8	6.5	8.1	6.51

Bold values indicate optimum performance in each parameter.

4. Conclusion

The present investigation successfully showed the preparation and characterization of bioplastic films made

from corn starch using glycerol as a plasticizer at different levels. The key results achieved in this study can be listed as below:

- The pseudo stem of the banana plant (Musa sp.) is a rich but neglected source of natural cellulosic fibers which have great potential for use in bio-composite, oil absorption, paper, and many other value-added products.
- Bioplastic films were made from corn starch and glycerol by solution casting method and quality of films increased with an increase in glycerol concentration. Film thickness increased from 0.69 to 0.84 mm and density decreased from 7.24 to 6.51 x 10^{-3} g/cm³ with increasing glycerol content.
- Tensile strength is highest (15.5 kg/cm²) for CSG3 (2 mL glycerol) while elongation at break shows inverse relation with glycerol content.
- Moisture content of all films is same ranging from 30.4% to 32.1% showing that glycerol content had negligible effect on hygroscopic properties.
- All the films are soluble in strong acids and bases with good stability in water having 5% weight change.

In this regard, the results show that bioplastics made using corn starch have certain favorable attributes for sustainable packaging, particularly under dry or neutral conditions. In the future, the research can benefit from applying ftir spectroscopy, xrd analysis, water vapor permeation test, and biodegradability tests. Using banana stem fibers as reinforcements in the polymer matrix of starch shows a good way forward.

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Conflict of Interest
The authors declare no conflict of interest.

References

[1] Balakrishnan S, Wickramasinghe GLD, Wijayapala UGS. Eco-Friendly softening for banana Fibers from Sri Lankan banana cultivar: Influence on physical and chemical Properties on banana Fibers. Journal of Natural Fibers. 2021 Oct 26;19(14):9177–9189.
[2] Thakur VK, Thakur MK. Processing and characterization of natural cellulose fibers/thermoset polymer composites. Carbohydrate Polymers. 2014 Mar 28; 109: 102–117.
[3] Cordeiro N, Belgacem MN, Torres IC, Moura JCVP. Chemical composition and pulping of banana pseudo-stems. Industrial Crops and Products. 2003 Nov 19;19(2):147–154.
[4] Gañán P, Cruz J, Garbizu S, Arbelaiz A, Mondragon I. Stem and bunch banana fibers from cultivation wastes: Effect of treatments on physico-chemical behavior. J of Applied Polymer Sci. 2004 Sept 13;94(4):1489–1495.
[5] J. Santhosh JS. STUDY OF PROPERTIES OF BANANA FIBER REINFORCED COMPOSITES. IJRET. 2014 Nov25;03(11):144–150
[6] Dutta D, Sit N. Preparation and characterization of potato starch-based composite films reinforced by modified banana fibers and its application in packaging of grapes. International Journal of Biological Macromolecules. 2023 Nov 1;254(Pt 2):127791.
[7] Madasamy S, Ramasubbu R, Nambirajan N. Utilization of Reformed Coconut Fiber and Banana Stem Fibre as Green Oil Sorbent. Journal of Natural Fibers. 2022 Apr 11;19(15):12339–12346.
[8] Mishra OP, Tripathi SK, Bhardwaj NK. SUITABILITY OF CORN STALK PULP FOR IMPROVING PHYSICAL STRENGTH PROPERTIES OF AGRO-RESIDUE PULP. Cellulose Chem Technol. 2020 Feb 20;54(1–2):65–71.
[9] Zulfikar AJ, Umroh B, Siahaan MYR. DESIGN AND MANUFACTURE OF SKATEBOARD FROM BANANA STEM. JMEMME. 2019 Dec 24;3(2):109.
[10] Kokate S, Parasuraman K, Prakash H. Adsorptive removal of lead ion from water using banana stem scutcher generated in fiber extraction process. Results in Engineering. 2022 May 11;14:100439.
[11] Yu X, Xia Y, Liang D, Fu W, Yin C. Effect of Warm-Water Retting Pretreatment on the Physical Properties of Banana Stem and Its Fibre. Materials. 2022 Nov 28;15(23):8462.
[12] Zdanowicz M, Johansson C. Impact of additives on mechanical and barrier properties of starch-based films plasticized with deep eutectic solvents. Starch Stärke. 2017 Aug 8;69(11–12):1700030.
[13] Sanyang M, Sapuan S, Jawaid M, Ishak M, Sahari J. Effect of Plasticizer Type and Concentration on Tensile, Thermal and Barrier Properties of Biodegradable Films Based on Sugar Palm (Arenga pinnata) Starch. Polymers. 2015 June 18;7(6):1106–1124.
[14] Ghanbarzadeh B, Almasi H, Entezami AA. Physical properties of edible modified starch/carboxymethyl cellulose films. Innovative Food Science & Emerging Technologies. 2010 June 15;11(4):697–702
[15] Avérous L. Biodegradable Multiphase Systems Based on Plasticized Starch: A Review. Journal of Macromolecular Science, Part C: Polymer Reviews. 2004 Dec 30;44(3):231–274.