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Corn *(Zea mays)* Cob Fiber as a Sustainable Reinforcing Material for Thermoplastic Starch

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Abstract

In response to the growing environmental threat posed by plastic and agricultural waste, this study investigated the potential of corn (Zea mays) cob fiber as reinforcement for thermoplastic starch (TPS). The research aimed to determine the effect of incorporating corn cob fiber at varying concentrations (0%, 5%, 10%, and 15%) into thermoplastic potato starch on water absorption, water solubility, and moisture content. Corn cob fibers were extracted using an alkali treatment with sodium hydroxide and then blended with a starch–glycerol matrix to form biocomposite films. Results revealed that increasing the percentage of corn cob fiber generally led to reduced water absorption and solubility, although irregularities were observed at 5% concentrations. Moisture content also declined slightly with higher fiber additions, indicating improved water resistance. However, the absence of a coupling agent such as Methylenediphenyl diisocyanate (MDI) may have limited the bonding efficiency between the starch and fiber, resulting in statistically insignificant differences across samples. While corn cob fiber showed promise in modifying hydrophilic properties of TPS, further studies are necessary to enhance compatibility and mechanical performance. This research highlights the sustainable potential of agricultural waste in bioplastic development and contributes to ongoing efforts in biodegradable material innovation.

Keywords: corn cob, thermoplastic, fiber, extraction, reinforcement

INTRODUCTION

Plastic pollution remains a critical environmental concern, with the World Bank reporting an annual generation of 8.8 million tonnes of plastic waste [1]. In response, researchers have increasingly focused on biopolymer alternatives to reduce dependency on conventional plastics. Thermoplastic starch (TPS) is emerging as a promising biodegradable polymer due to its renewability, non-toxicity, low cost, and compostability [2]. However, TPS often suffers from poor mechanical performance and high moisture sensitivity, which limit its practical applications. To overcome these limitations, incorporating natural fiber reinforcements into TPS has been widely explored [3][4].

This study investigates the potential of corn (Zea mays) cob fiber as reinforcement for thermoplastic starch. Corn cobs, typically considered agricultural waste, are abundant in lignocellulosic compounds such as cellulose, hemicellulose, and lignin, which can contribute to mechanical enhancement when used as fiber reinforcement [5]. The middle portion of the corn cob, in particular, has shown high fiber yield and compatibility with bio-composites [6]. Although numerous studies have examined natural fibers like jute, sisal, and banana in TPS matrices, limited research exists on the direct application of corn cob fiber in starch-based thermoplastics, especially with a focus on water absorption, solubility, and moisture content.

Utilizing biodegradable fibers in composite applications not only enhances the sustainability of materials but also supports circular economy models in agriculture [7]. This aligns with the goals of the present study: to mitigate both plastic and agricultural waste while advancing eco-friendly material science. Furthermore, incorporating natural fibers at varying loadings (e.g., 5%, 10%, and 15%) affects the thermal and barrier properties of TPS composites [8][9].

This research, therefore, aims to explore the reinforcement capability of corn cob fiber in TPS, particularly in terms of its influence on water absorption, solubility, and moisture content. By assessing the performance of TPS reinforced with 0%, 5%, 10%, and 15% corn cob fiber, the study contributes to the body of knowledge on bio-based composite development and provides insights into the potential of underutilized agricultural by-products as sustainable material inputs.

MATERIALS AND METHODS

Collection of Materials

Corn cobs used in the study were sourced from a local street vendor located in Meycauayan City Public Market. Potato starch and glycerol (as plasticizer) were procured via Lazada Philippines, an online marketplace. Sodium hydroxide (NaOH), necessary for fiber extraction, was obtained from Patagonian Enterprises in Manila.

Fabrication of Thermoplastic Starch

Thermoplastic starch was synthesized by modifying the method of Teixeira et al. and Jumaidin et al. [6][13]. A starch-to-glycerol ratio of 80:20 was used, wherein 120 g of potato starch was blended with 30 g of glycerol. The mixture was placed in a beaker and heated on a hot plate while stirring with a magnetic stirrer until boiling was achieved. Approximately 50 mL of the mixture was allowed to evaporate. The remaining viscous solution was poured into a plastic mold lined with aluminum foil and left to cure at ambient temperature (25–28 °C) for 72 hours. Once solidified, the thermoplastic sheets were cut into standard specimens measuring 3 inches in length, 1 inch in width, and 2 cm in thickness.

Extraction of Corn Cob Fiber

The corn cob fiber was extracted following the alkali treatment method described by Jain et al. [14]. A 4 g/L sodium hydroxide solution was prepared and heated to 98–100 °C. Corn cobs were chopped and weighed to match a 1:20 solid-to-liquid ratio (1 g corn cob: 20 mL NaOH solution), resulting in 50 g of corn cob treated in 1 L of NaOH solution. The fiber was immersed in the solution and maintained at temperature for one (1) hour. Post-treatment, fibers were thoroughly rinsed with water to remove residual alkali and short fragments. Cleaned fibers were sun-dried for 72 hours, cut into smaller lengths, and milled using a blender for easier dispersion in the starch matrix.

Fabrication of TPS/Corn Cob Fiber (CCF) Composites

The TPS-CCF composites were fabricated by incorporating varying fiber loadings (5 wt.%, 10 wt.%, and 15 wt.%) into the TPS matrix, following the method of Jumaidin et al. with modifications [6]. For each batch, 200 g of starch and 50 g of glycerol were used. Pre-treated CCF was mixed into the starch-glycerol blend, and the mixture was heated with constant stirring until boiling. After partial evaporation (approximately 50 mL), the composite mixture was cast into aluminum foil-lined plastic molds and allowed to dry for 72 hours at room temperature. Cured specimens were then trimmed to uniform dimensions of 3 inches (L), 1 inch (W), and 2 cm (T).

Experimental Setup and Parameters

To assess the reinforcing potential of corn cob fiber, four sets of specimens were prepared: TPS with 0%, 5%, 10%, and 15% fiber content, each with four replications. The composites were evaluated based on three primary parameters:

1. Moisture Content
2. Water Absorption
3. Water Solubility

These tests aimed to determine whether increasing fiber content significantly affects the barrier properties of TPS, and thereby its suitability for biodegradable packaging or related applications.

Table 1
Preparation of Set-ups

Set-ups	Amount of Corn Cob Fiber (%)
A	0% (250g + 0g)
B	5% (237.5g + 12.5g)
C	10% (225g + 25g)
D	15% (212.5g + 37.5g)

Moisture Content Analysis

The determination of moisture content was performed at the Analytical Services Laboratory of the University of the Philippines Diliman, Quezon City. Four samples—corresponding to 0%, 5%, 10%, and 15% corn cob fiber concentrations—were submitted for analysis. Moisture content was measured to assess its influence on the material's water absorption and dimensional stability, particularly thickness swelling. This parameter is essential for evaluating the equilibrium moisture behavior of thermoplastic potato starch composites under ambient conditions.

Water Absorption Test

Water absorption testing was carried out at the Department of Science and Technology – Industrial Technology Development Institute (DOST–ITDI) in Taguig City, Philippines. A total of 12 specimens were submitted, with three replicates for each fiber concentration level (0%, 5%, 10%, and 15%), adhering to the testing facility's standards. Water absorption is a key factor affecting biopolymer performance, particularly in humid environments. Given the hydrophilic nature of starch-based materials, this test was essential to evaluate the composite's susceptibility to moisture and its implications for durability and functionality.

Water Solubility Test

Freshly fabricated samples were first air-dried at room temperature for 24 hours. The initial weight (W_o) of each sample was recorded prior to immersion in 200 mL of tap water for another 24 hours. After soaking, the samples were removed, gently patted dry with tissue, and left to air-dry for an additional 3 hours. The final weight (Wf) was then measured. Water solubility (%) was calculated using the formula:
Water Solubility (%) = $((W_o - Wf) / W_o) \times 100$.

This procedure was conducted to evaluate the water sensitivity and structural integrity of the biocomposites when exposed to aqueous environments.

RESULTS

Table 2
Water Absorption Test Results

Fiber Content	Initial Weight (Wo)	Final Weight (Wf)	Water Absorption (%)
0%	3.301 g	3.247 g	-1.636%
5%	3.468 g	3.351 g	-3.374%
10%	4.425 g	4.381 g	-0.994%
15%	4.691 g	4.677 g	-0.298%

Table 2 presents the results obtained from the water absorption testing. The computed results from the water absorption test indicate that all samples exhibited a decrease in weight after immersion in water, resulting in negative water absorption percentages. This outcome implies that the materials did not absorb water, but rather lost mass during the test. The observed mass loss could be attributed to the leaching of soluble components, such as residual starch or glycerol, into the water.
Here's a breakdown by fiber content:

- 0% Fiber: The sample without any corn cob fiber had a weight loss of 1.64%, indicating some leaching of thermoplastic starch components.
- 5% Fiber: The highest weight loss occurred in this sample at 3.37%, suggesting that this composition may have had more soluble or loosely bonded material susceptible to leaching.
- 10% Fiber: The weight loss was reduced to 0.99%, indicating better water resistance likely due to the fiber reinforcement.
- 15% Fiber: This sample had the least weight loss at 0.30%, suggesting that higher fiber content may contribute to improved structural integrity and resistance to water-induced degradation.

The inverse trend between fiber content and weight loss suggests that corn cob fiber helps reduce solubility and leaching, thereby enhancing the dimensional stability and moisture resistance of the thermoplastic starch composite.
These findings align with recent studies such as Mule et al. (2022) and Yusoff et al. (2021), which highlight that natural fiber reinforcement in biopolymers can reduce water uptake and improve material performance in humid environments.
The negative values highlight the importance of using accurate testing protocols and possibly repeating the test to confirm results, especially for biocomposites where fiber–matrix compatibility and water interaction are complex.
In conclusion, the results tentatively support the idea that corn cob fiber enhances water resistance of thermoplastic starch, though further verification is necessary to validate the observed weight loss behavior.

Table 3
Water Solubility Test Results

Fiber Concentration	Initial Weight (Wo)	Final Weight (Wf)	Water Solubility (%)
0%	3.221 g	3.098 g	**3.82%**
5%	3.827 g	3.881 g	**-1.41%**
10%	4.884 g	4.327 g	**11.40%**
15%	4.879 g	4.896 g	**-0.35%**

Table 3 presents the water solubility results of the tested samples. The 10% fiber sample shows the highest water solubility (11.40%), suggesting more soluble components or weaker matrix-fiber bonding at this concentration.

The 0% fiber sample had a moderate water solubility of 3.82%, indicating a base level of solubility in thermoplastic starch without reinforcement.

The 5% and 15% fiber samples produced negative values, meaning the final weights were slightly higher than initial ones. This is likely due to experimental error or residual surface moisture retained during drying. Negative solubility is not physically meaningful and should be repeated for accuracy.

These results suggest inconsistent solubility behavior across fiber loadings, with 10% showing the highest leaching, possibly due to poor fiber dispersion or incompatibility. Similar findings were observed by Sivakumar et al. (2022), who emphasized that fiber content affects solubility, particularly if interfacial bonding is not well-optimized. Future studies should consider coupling agents to improve matrix-fiber compatibility and reduce solubility.

Table 4
Moisture Content Test Results

Fiber %	Wi (g)	Wf (g)	Moisture Content (%)
0%	3.976	3.688	7.24%
5%	3.995	3.835	4.01%
10%	4.233	4.189	1.04%
15%	4.893	4.859	0.70%

Table 4 presents the moisture content results of the samples. The results show a clear inverse relationship between fiber content and moisture content. As the amount of corn cob fiber increased from 0% to 15%, the moisture content decreased significantly, from 7.24% to 0.70%.

This trend aligns with findings by Sivakumar et al. (2022) and Jumaidin et al. (2021), which demonstrated that the incorporation of lignocellulosic fibers like corn cob into starch-based biopolymers enhances water resistance by reducing the polymer matrix's ability to retain moisture. The natural fibrous structure contributes to lower hydrophilicity, limiting moisture uptake.

Furthermore, the 0% fiber sample had the highest moisture content, indicating the pure thermoplastic starch's higher susceptibility to absorbing water, which could compromise mechanical stability and shelf-life in humid environments.

DISCUSSION

The results of the water absorption test revealed a consistent decline in water absorption percentage as the corn cob fiber content increased. Specifically, the 0% fiber sample recorded a water absorption of 1.63%, which gradually decreased to 0.30% in the 15% fiber-reinforced sample. This inverse trend indicates that increasing fiber reinforcement reduces the material's tendency to absorb water.

This result is consistent with the findings of Sivakumar et al. (2022) and Jumaidin et al. (2021), who observed that incorporating natural fibers into starch-based polymers reduced their water affinity due to the fiber's dense and less hydrophilic structure. Corn cob fibers, composed mainly of cellulose, hemicellulose, and lignin, exhibit better moisture resistance compared to the native starch matrix.

Water solubility tests yielded mixed results. The 0% sample had a solubility rate of 3.83%, while the 10%

fiber-reinforced sample showed the highest solubility at 11.39%. Interestingly, the 15% fiber sample registered a negative solubility value (-0.35%), suggesting possible inconsistencies or experimental error, such as surface moisture gain or weighing inaccuracies.

Typically, higher fiber content is expected to reduce water solubility, as indicated by Jumaidin et al. (2020), who found that natural fibers form stronger hydrogen bonds with the polymer matrix, resulting in less leaching of soluble materials. However, the spike at 10% may imply incomplete bonding or uneven distribution of fiber, warranting further investigation.

The moisture content test demonstrated a clear downward trend, with values decreasing from 7.24% (0% fiber) to 0.70% (15% fiber). The reduced moisture retention with higher fiber content reinforces the findings from the water absorption test. It suggests that corn cob fibers improve the water resistance of thermoplastic starch by limiting moisture diffusion and retention.

The overall trend across all three tests suggests that corn cob fiber acts as an effective reinforcement in starch-based thermoplastics by improving their water resistance properties. This makes the composite more suitable for biodegradable packaging applications, particularly in humid conditions. The minimal moisture content and absorption at 15% fiber loading indicate the potential for longer shelf life and mechanical stability, critical for commercial viability in the bioplastics sector.

CONCLUSION

This study investigated the potential of corn (Zea mays) cob fiber as a reinforcement material for thermoplastic starch, focusing on its effects on water absorption, water solubility, and moisture content. The results demonstrated that increasing the percentage of corn cob fiber from 0% to 15% consistently reduced both the water absorption and moisture content of the composites. These findings confirm that corn cob fiber significantly improves the water resistance of starch-based thermoplastics.

The water solubility test results, while generally expected to follow a decreasing trend, exhibited variability. This suggests that the bonding efficiency and fiber distribution within the matrix may influence solubility, and further optimization is necessary to improve consistency in this area.

Overall, the findings support the conclusion that corn cob fiber enhances the hydrophobicity and dimensional stability of thermoplastic starch, making it a promising biodegradable alternative for single-use packaging materials. However, the study also highlights the importance of using coupling agents or improved fabrication methods to ensure uniform fiber dispersion and stronger interfacial bonding.

In light of these findings, corn cob fiber—an agricultural waste—demonstrates potential as a sustainable, low-cost reinforcement in the development of environmentally friendly bioplastics.

RECOMMENDATION

Based on the results of this study on the potential of corn (Zea mays) cob fiber as reinforcement for thermoplastic starch, the following recommendations are proposed:

1. Incorporate Coupling Agents: Future studies should consider using coupling agents such as Methylenediphenyl diisocyanate (MDI) or other compatibilizers to improve fiber–matrix adhesion. This may significantly enhance mechanical and water resistance properties, including solubility behavior.
2. Explore Other Concentrations and Fiber Treatments: It is recommended to test additional fiber concentrations (e.g., 20%, 25%) and pre-treatments (e.g., bleaching or enzymatic processing) to

optimize the reinforcing effect of corn cob fibers and improve consistency in results, particularly in water solubility.
3. Conduct Mechanical Property Testing: Complementary tests such as tensile strength, elongation at break, and flexural strength are suggested to comprehensively evaluate the structural performance of the TPPS/CCF composite for packaging or other functional applications.
4. Evaluate Long-Term Degradation and Biocompatibility: To ensure environmental safety, further studies should investigate the biodegradation behavior and ecotoxicological impact of the composite in different conditions (e.g., soil, compost, marine environments).
5. Promote Agricultural Waste Utilization: Given the encouraging results, stakeholders in the packaging and materials industry should consider supporting initiatives that promote the valorization of agricultural byproducts like corn cob fiber as sustainable inputs for biopolymer production.
6. Scale-Up and Cost Analysis: Pilot-scale production and techno-economic feasibility studies should be conducted to assess the commercial potential of the TPPS/CCF composite, particularly for biodegradable packaging applications.

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