Development of a Bio-Soft Splint from Corn Husk Cellulose Fibers for Orthopedic Applications

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Abstract

In this study, we develop composite materials for orthopedic soft splint applications and investigate their tensile strength, thermal ventilation, water resistance and biodegradability. Cellulose fibers were extracted from corn husks using sodium hydroxide and hydrogen peroxide treatments and incorporated into a composite matrix of corn starch, glycerol and acetic acid. Four cellulose fiber loadings 0.25, 0.50, 0.75 and 1.00 g were investigated. Cellulose fiber content significantly affected the properties of the bio-soft splints. The specimen reinforced with 0.75 g of cellulose fiber exhibited the highest tensile strength of 44.93 ± 3.96 N, highest water contact angle of 81.62° ± 7.49° and highest weight loss after biodegradation of 33.33%. Thermal ventilation tests indicated all formulations exhibited similar temperature values ranging from 39 to 41°C, suggesting comparable heat dissipation properties. Furthermore, FTIR analysis confirmed formation of hydrogen bonding interactions within the composite structure, contributing to improved mechanical performance. In conclusion, incorporation of 0.75 g of cellulose fiber provided the most suitable formulation for biodegradable soft splints due to superior mechanical strength, water resistance and biodegradability. This study demonstrates the potential of utilizing corn husk agricultural waste as a value-added biomaterial, reducing use of synthetic materials and promoting environmentally friendly medical biomaterials for future orthopedic applications.

Keywords: Orthopedic splint, Natural fiber, Corn husk cellulose

Introduction

Currently, splints and orthopedic supports are widely utilized for individuals suffering from injuries, such as those affecting the wrists and ankles, or muscle weakness particularly among the elderly and patients in rehabilitation. However, most contemporary splints are manufactured from synthetic materials, including plastics, foams or fibers. These materials possess several limitations, such as poor ventilation leading to moisture accumulation and microbial growth, as well as discomfort caused by skin irritation.

Furthermore, these synthetic materials are non-biodegradable, resulting in long-term environmental impacts (North & Halden, 2013).

Current solutions involve the development of natural biomaterials, such as plant fibers, as components for splints to improve breathability and biodegradability, thereby reducing medical plastic waste. Nevertheless, existing natural fibers like jute or cotton, while environmentally friendly, face challenges regarding high production costs and low durability. Consequently, they have yet to fully replace synthetic materials in the market.

Thailand is an agricultural nation with extensive maize cultivation, resulting in a massive amount of agricultural byproduct. Corn husks, in particular, are often discarded or disposed of through open burning, which causes environmental issues such as air pollution and greenhouse gas emissions. Therefore, developing corn husks into medical biomaterials not only mitigates the environmental problems associated with waste burning but also adds significant value to agricultural residues.

To address these challenges, the researchers propose the development of splints using cellulose fibers extracted from corn husks an abundant source of and low-cost agricultural waste. Studies have indicated that corn husk fibers possess a strong cellulose structure that is lightweight, flexible, and mechanically robust, making them highly suitable for the production of supportive orthopedic devices. Although several natural fibers have been investigated for orthopedic applications, studies utilizing cellulose fibers extracted from corn husks remain limited. Furthermore, the influence of cellulose loading on the mechanical performance, water resistance, thermal behavior and biodegradability of bio-soft splints has not been comprehensively investigated.

Accordingly, this project aims to develop bio-based splints from cellulose fibers extracted from corn husks as a novel alternative to synthetic splints. It is expected that the resulting material will possess optimal properties for medical use, including being lightweight, having high tensile strength, providing excellent ventilation, being non-irritating to the skin, and being biodegradable. Furthermore, this approach will reduce production costs and promote long-term sustainable resource utilization.

Methodology

1) Fabrication of Bio-based Splints to Determine the Optimal Control Group Ratio

Experiment 1.1: Determination of the Optimal Ratio for Splint Molding

The control group was prepared with 10 g of corn starch, 1 g of sodium bicarbonate and 100 mL of distilled water. Seven experimental sets varied glycerol concentration and 5% v/v acetic acid volume, from minimum to maximum, to compare tensile strength and molding efficiency and identify the formulation with the best structural integrity and usability. Ingredients for each set were mixed in a beaker and heated to 85–100°C until viscous, then poured into molds, leveled for uniform thickness, and oven-dried at 60°C for 6 hours until fully dry and peelable without breaking.

Experiment 1.2: Tensile Strength Testing of the Optimized Control Splint

Samples from Experiment 1.1 were cut into standardized specimens (0.5 × 2 cm) and tested with a Tensile Strength Tester under controlled, identical conditions, repeated at least three times per sample for accuracy. Maximum tensile stress values were recorded and compared to determine the most effective control formulation ratio.

2) Preparation of Cellulose Fibers from Corn Husks

Corn husks were washed, cut into small pieces, and sun-dried until fully dehydrated, then oven-dried at 50–60°C for 2–3 hours before being ground into a fine powder. To remove hemicellulose, fats and lignin, the powder was soaked in 7% v/v Sodium Hydroxide (NaOH) solution at 80–100°C for 1–2 hours, then rinsed repeatedly with distilled water until neutral pH was reached. For bleaching, the fibers were treated with 10% v/v Hydrogen Peroxide (H2O2) at 70–80°C for 1 hour to remove residual pigments and enhance whiteness. The fibers were then rinsed again until neutral and oven-dried at 60°C until completely dry (Jansuk et al., 2019).

3) Fabrication of Soft Splints from Corn Husk Cellulose Fibers

Using the previously determined optimal control formula, cellulose fibers were incorporated while keeping the amounts of corn starch, water, and other components constant to ensure consistent comparisons. Four experimental groups were created based on cellulose fiber content: 0.25 g, 0.50 g, 0.75 g, and 1.00 g. After measuring the ingredients for each group, the mixtures were heated with continuous stirring at 85–100°C until a homogeneous, viscous gel formed. The mixtures were then poured into molds, spread evenly, and cured in an oven at 60°C for 12 hours until fully dried. The resulting splints were then evaluated through various performance tests, including tensile strength, heat dissipation, water resistance and biodegradability.

Experiment 1: Tensile Strength Test

The splint sheets were cut into standard specimens measuring 0.5 × 2 cm. Four samples per group were prepared to ensure uniformity. Each specimen was tested using a Tensile Strength Tester under controlled conditions. The test was performed in triplicate (3 rounds) for each sample type to ensure data reliability.

Experiment 2: Heat Dissipation Test

100 mL of distilled water was heated on a hot plate at 100 °C until boiling. The splint samples were then submerged in the boiling water. After 1 minute of immersion, the initial temperature of the splint was recorded. Subsequent temperature measurements were taken every 30 seconds for a total duration of 3 minutes (Suddung & Ruangkrai, 2024).

Experiment 3: Water Resistance Test

1-2 drops of water were placed onto each of the four splint samples to observe the water's behavior on the surface. A Contact Angle Meter was used to record the water contact angle. A higher contact angle indicates hydrophobic properties, while a lower contact angle indicates hydrophilic properties.

Experiment 4: Biodegradability Study

The splint samples from all four experimental groups were cut into 2 × 2 cm pieces. The initial weight of each piece was recorded before being buried 10 mm deep in a container, covered with approximately 5 cm of soil. The samples remained buried for 7 days. After the burial period, the final weight was recorded and the biodegradability was calculated using the following equation:

$$Biodegradability = (\frac{W_i - W_f}{W_i}) \times 100$$

where W_i is the initial weight of the cast.

W_f is the final weight of the cast.

Result and Discussion

Results of the tensile strength test, heat dissipation test, water resistance test and biodegradability of cellulose-reinforced soft splint.

Table 1 shows a summary of the tensile strength test, heat dissipation test water resistance and biodegradability test of cellulose-reinforced soft splints.

Cellulose Fiber (grams)	Mean ± standard deviation			
	Tensile Strength Test (N)	Temperature (°C)	Water contact angle (°)	Biodegradability (%)
0.00	10.33±0.60	38.40±0.36	26.53±2.21	15.56
0.25	15.13±1.84	39.47±1.15	72.61±2.49	18.09
0.50	32.70±1.13	40.23±0.66	79.14±1.07	26.00
0.75	44.93±3.96	39.69±0.95	91.68±7.49	33.33
1.00	37.80±3.74	41.30±0.80	78.19±4.43	15.79

Tensile results showed 0.75 g cellulose produced the highest tensile strength (44.93±3.96 N), as well-distributed fibers within the starch–glycerin matrix enabled effective stress transfer; at 1.00 g, strength declined due to fiber agglomeration. Thermally, all formulations remained stable within 39–41°C. The 0.25 g sample showed the lowest temperature (39.47±1.15°C), suggesting slightly better heat dissipation, while 0.75 g (39.69±0.95°C) stayed functionally equivalent, as cellulose and starch share similar thermophysical properties. For water resistance, contact angles ranged from 26.53° to 91.68°, indicating mild hydrophobicity, with 0.75 g achieving the highest value. Moderate cellulose loading increases surface roughness and limits exposure of hydrophilic starch chains, enhancing water repellency, whereas excessive loading (1.00 g) causes uneven surfaces and micro-cracks, reducing hydrophobicity.

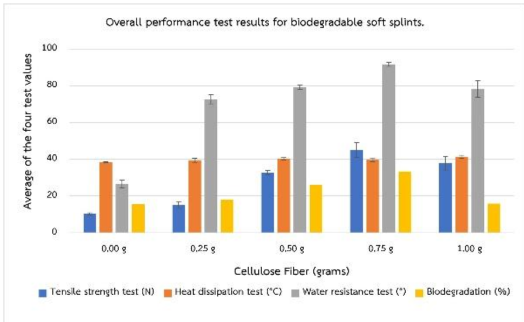

Fig. 1 Comparison chart of the four tests.

1. Tensile Strength Testing

The 0.75 g cellulose sample showed the highest tensile strength (44.93 N), roughly 3–4 times greater than samples with lower fiber content. This optimal reinforcement resulted from effective dispersion of cellulose fibers within the starch–glycerol matrix, enabling efficient stress transfer throughout the composite. However, increasing fiber content to 1.00 g caused tensile strength to decline, as fiber agglomeration disrupted interfacial bonding between the polymer and fibers and led to microvoid formation, ultimately reducing mechanical performance (Schutz, 2024).

2. Heat Dissipation Testing

The results of the study revealed that all formulations exhibited thermal stability within a narrow range of 39–41°C. The 0.25 g cellulose sample showed the lowest temperature (about 39.47°C), indicating slightly better heat dissipation, while the 0.75 g sample remained within a comparable, functionally equivalent range. Differences in thermal conductivity among formulations were minimal, since cellulose and starch share similar thermal properties. Therefore, selection of the optimal formulation should rely primarily on mechanical properties rather than on the relatively minor variations observed in thermal behavior.

3. Water Resistance Testing

The water contact angle values ranged from 72.61° to 81.62°, which classified the material as exhibiting moderate water-resistant properties. The 0.75 g formulation was found to exhibited the highest contact angle value. This improvement was attributed to the reinforcement of cellulose fibers at an appropriate level, which increased surface roughness and reduced the exposure of hydrophilic groups originating from the starch, thereby enhancing the water resistance of the material. However, when the fiber content was excessively increased (1.00 g).

4. Biodegradability Efficiency Testing

The experimental results demonstrated that increasing the cellulose fiber content enhanced the biodegradability efficiency of the bio-based soft cast up to an optimal level. The highest biodegradability value was observed at a cellulose content of 0.75 g, which was attributed to the ability of microorganisms to effectively decompose natural fibers. However, when the fiber content was further increased beyond this level, the biodegradation efficiency was found to decrease, owing to the increased structural density of the material.

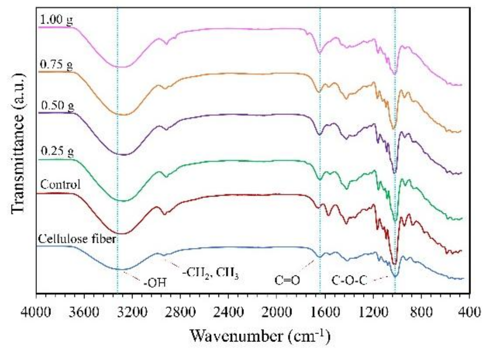

Fig. 2 FTIR Spectra of Cellulose from Corn Husks and the composite casts.

FTIR spectra of the cellulose fibers, control matrix, and composites confirmed successful incorporation of cellulose into the polymer network. The control cast displayed O–H stretching at ~3323 cm^{-1}, C–H stretching near 2934 cm^{-1}, C=O and C–O bands at 1637 and 1020–1150 cm^{-1}, attributed to glycerol starch interactions. With cellulose addition, O–H band intensity increased, reflecting enhanced hydrogen bonding among cellulose, starch, and glycerol, while a stronger peak near 1020–1050 cm^{-1} (C–O–C and C–O stretching) confirmed fiber incorporation. A slight shift in the carbonyl band (1700–1750 cm^{-1}) further indicated strengthened intermolecular interactions. Overall, increasing cellulose content produced more pronounced cellulose-related bands and a denser hydrogen-bonding network.

Conclusions

The development of a bio-soft splint from corn husk cellulose fibers for orthopedic applications showed that cellulose reinforcement played a critical role in enhancing performance. Among all samples, the cast containing 0.75 g of cellulose exhibited the most suitable properties, with a tensile strength of 44.93 N, appropriate heat dissipation, and improved water resistance, indicating that this ratio effectively strengthens the internal structure without compromising flexibility or usability. Therefore, the 0.75 g cellulose formulation is considered optimal for further development. This finding highlights the potential of corn husk cellulose as a value-added biomaterial for medical applications.

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