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Sustainable High-Performance Particleboard from Corn Husk Fibers and Chitosan Adhesive Materials

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Keywords : Alkaline pretreatment; Biodegradable particleboard; Chitosan adhesive; Corn husk fibers; Sustainable composites

ABSTRACT

Biodegradable particleboards made from agricultural waste are emerging as sustainable alternatives to conventional wood-based materials. This study developed high-performance particleboards using alkaline-treated corn husk fibers and chitosan adhesive, a natural alternative to formaldehyde-based resins. Alkaline pretreatment improved fiber wettability by removing lignin, hemicellulose, and impurities, enhancing fiber-adhesive interaction. Chemical modifications were analyzed using FTIR and XRD, while contact angle measurements confirmed increased hydrophilicity. Mechanical testing showed significant improvements, with tensile and flexural strengths reaching 49.9 MPa and 56.8 MPa, respectively. SEM analysis revealed a well-bonded fiber-matrix interface, indicating strong adhesion. This approach demonstrates a scalable, eco-friendly method for producing biodegradable composites with superior mechanical performance. Future work will explore enhancing water resistance and assessing industrial-scale production feasibility.

INTRODUCTION

The demand for engineered wood products, such as plywood, particleboard, and fiberboard, has steadily increased in the construction industry (Nurdin et al., 2023; Setyayunita et al., 2025). This growth raises concerns about sustainability and resource availability. Researchers have explored alternative raw materials and environmentally friendly adhesives to address these challenges (Gasni et al., 2024; Shi & Huang, 2018; Shi, Ouyang, et al., 2024; Shi et al., 2025). Deforestation due to excessive logging has significantly impacted the availability of raw materials for particleboard production. Studies have shown that wood chip prices increased by 30% from 2006 to 2011, emphasizing the need for forest conservation and resource diversification (Eastin et al., 2012; Rahmadiawan, Abral, et al., 2024). As a result, utilizing agricultural byproducts has become a viable solution to reduce reliance on virgin timber.

Petroleum-based adhesives, particularly formaldehyde-based resins, have raised health and environmental concerns (Nurdin et al., 2025). These adhesives are derived from non-renewable petroleum sources and release toxic emissions. Therefore, developing bio-based adhesives has gained attention as a sustainable alternative (Rahmadiawan et al., 2021). Lignocellulosic biomass offers a renewable and sustainable resource for particleboard production. This type of biomass includes plant-derived materials such as bagasse (Iswanto et al., 2017; Oliveira et al., 2016), bamboo (Biswas et al., 2011; Papadopoulos et al., 2004), leaves (Aghakhani et al., 2014; Batiancela et al., 2014), stems (Oh & Yoo, 2011; Taha et al., 2018), and rice straw (Grigoriou, 2000).

Researchers use these materials to create eco-friendly composite boards without compromising mechanical performance. Effective pretreatment is essential for improving the adhesion and processability of lignocellulosic fibers (Chou et al., 2021; Shi et al., 2020). Among various methods—physical, chemical, physicochemical, and biological—alkaline pretreatment has been widely adopted due to its ability to remove lignin and modify fiber structure (Capolupo & Faraco, 2016; Hassan et al., 2018; Mankar et al., 2021; Rahmadiawan, Shi, et al., 2024; Shi, Cheng, et al., 2024). This treatment enhances fiber reactivity, promoting better adhesive bonding (Vitrone et al., 2021).

Chitosan, a bio-based polysaccharide derived from chitin, has gained recognition for its biodegradability, biocompatibility, and antibacterial properties (Shi, Lu, et al., 2024). The deacetylation

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process converts chitin into chitosan, typically with a degree of deacetylation ranging from 70% to 90%, which improves solubility and adhesion properties (Mati-Baouche et al., 2014; Patel, 2015). As a result, chitosan has been explored as an alternative adhesive for composite materials.

This study hypothesizes that using corn husk sheets as a lignocellulosic substrate will enhance chitosan adhesive bonding compared to shorter fibers. The larger fiber volume is expected to reduce adhesive consumption, improving cost efficiency. This research aims to develop a biodegradable and sustainable alternative to conventional particleboard by optimizing the bonding process.

Furthermore, the amino groups (NH_3^+) in chitosan are anticipated to form hydrogen bonds with hydroxyl groups on the corn husk surface. This interaction is expected to strengthen adhesion and improve particleboard performance. Understanding these bonding mechanisms can contribute to the advancement of bio-based adhesive technologies. Applied pressure facilitates uniform chitosan distribution during hot pressing, while elevated temperatures promote adhesive curing. These conditions increase board density and mechanical properties. Therefore, this study seeks to demonstrate the feasibility of chitosan-based adhesives in sustainable particleboard manufacturing.

MATERIALS AND METHODS

Raw Materials and Pretreatment

Corn husks were selected as the primary lignocellulosic material and pretreated to enhance fiber reactivity. The husks were sourced from a local market in Taiwan and rinsed with tap water before undergoing alkaline treatment. They were soaked in a 1M sodium hydroxide solution (1 g NaOH in 25 ml deionized water) at 450 rpm and 65°C for 30 minutes, then rinsed to pH 7, frozen for one day, and dried using a vacuum freeze dryer. This process improved fiber structure, preparing the material for composite fabrication.

Adhesive Preparation and Composite Fabrication

Chitosan adhesive was prepared to bond the fiber layers and form bio-based composites. Food-grade chitosan powder (100% purity) was purchased from Anxing Instrument Co., Ltd., Tainan, Taiwan. Chitosan powder was dissolved in a 2% (wt %) acetic acid solution and stirred at 75°C for 2 hours to achieve uniform dissolution, resulting in adhesive solutions of varying concentrations (5–8 wt %). The alkaline-treated husks were cut into uniform pieces, coated with chitosan adhesive, and layered perpendicularly before undergoing hot pressing at 145°C with a 5-minute pre-pressing at 250 kg, followed by 24-hour curing at 3000 kg. This process ensured strong adhesion and structural integrity in the bio-based composites.

Structural and Mechanical Analysis

The physical, chemical, and mechanical properties were analyzed to evaluate the composite performance. Contact angle measurements assessed surface wettability by placing a 2 μL water droplet on treated and untreated husks and recording images at 0 and 30 seconds. Fourier Transform Infrared Spectroscopy (FTIR, MRI1532S, ProTrusTech, Taiwan) collected spectra from 4500 to 500 cm^{-1}, while X-ray diffraction (XRD, Ultima IV-9407F701, RIGAKU, Japan) analyzed structural differences over a 2θ range of 10°–50°. Scanning electron microscopy (SEM, SU-5000, HITACHI) examined cross-sectional and surface morphology after metal coating. Mechanical properties were tested using a universal tensile tester (AGS-X, SHIMADZU, Japan), following ASTM D638 (Type V) for tensile strength and ASTM D3330 for the peeling test. Each mechanical test, including tensile, flexural, and peeling strength, was conducted with three replicates ($n = 3$).

RESULTS AND DISCUSSION

Corn Husk Alkaline Pretreatment

The surface morphology of corn husk composites was analyzed to assess their structural characteristics. As shown in Fig. 1a), the cross-sectional SEM image reveals a highly porous and layered structure, indicating the fibrous nature of the composite. The chemical composition of the corn husk composites was analyzed using FTIR spectroscopy to evaluate the effects of alkaline treatment. The spectral results (Fig. 1b) reveal a reduction in the intensities of characteristic absorption peaks at 1736 cm^{-1}, 1640 cm^{-1}, and 1247 cm^{-1}, corresponding to carbonyl (C=O) stretching in hemicellulose, conjugated C=C stretching in lignin, and C–O stretching in lignin and ester bonds, respectively.

This decline in peak intensity indicates a decrease in lignin and hemicellulose content, suggesting that the alkaline treatment effectively removes surface impurities such as lignin, waxes, and oils. Consequently, this purification process enhances the accessibility of hydroxyl (-OH) functional groups, which play a crucial role in improving fiber-matrix adhesion in composite applications. These findings are consistent with previous studies (Mir Md et al., 2021), which reported that alkaline pretreatment increases cellulose exposure, thereby enhancing interfacial bonding and the overall mechanical performance of lignocellulosic composites.

Crystallinity analysis was performed using XRD to assess the structural integrity of the corn husk composites. The XRD spectra (Fig. 1c) exhibited two dominant diffraction peaks at 2θ = 16.7° and 22.2°, characteristic of the semi-crystalline nature of cellulose fibers. The sharp peak at 22.2° corresponds to type Iβ cellulose, confirming the monoclinic crystalline structure of the fibers, while the broader peak at 16.7° indicates the presence of amorphous or non-cellulosic components. The relative intensity and sharpness of these peaks provide insight into the material's crystallinity. The broadening at 16.7° suggests contributions from hemicellulose, lignin, or residual extractives. Following alkaline treatment, the reduction of these non-cellulosic constituents led to an increase in the relative crystallinity of cellulose, reflecting enhanced structural organization. This finding is consistent with previous studies (Herlina Sari et al., 2018), which reported similar crystalline structure retention after alkaline pretreatment.

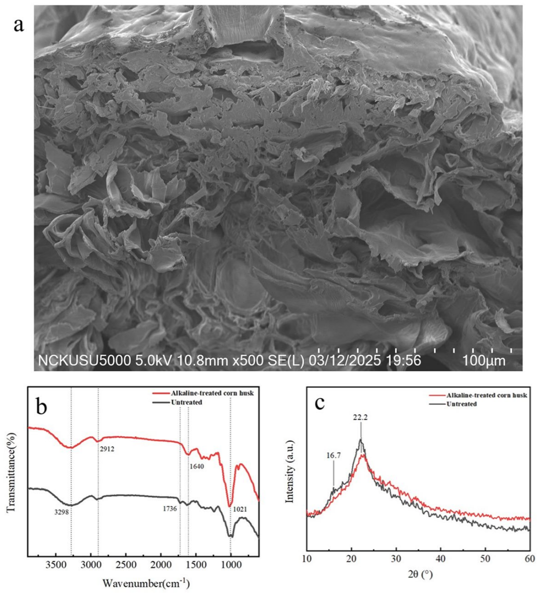


Fig. 1. Cross-sectional SEM images (a), FTIR spectra (b), and XRD patterns (c) of the corn husk composites.

Water Contact Angle Analysis

The hydrophilicity of untreated and alkaline-treated corn husks was evaluated using contact angle measurements. As shown in Fig. 2a, untreated husks exhibited hydrophobic properties due to their surface microstructure, which prevented water absorption. In contrast, after alkaline pretreatment, the microstructure was altered, and lignin and hemicellulose were removed, exposing the internal fibers. Eliminating these components allowed water droplets to penetrate the fibers more efficiently.

Water contact angle measurements were performed to quantify these changes in surface wettability. The initial contact angle was measured at approximately 112°, indicating strong hydrophobicity. After treatment, the contact angle decreased to below 20°, confirming a significant increase in hydrophilicity. This drastic reduction suggests alkaline pretreatment enhances surface energy, making the fibers more receptive to adhesives.

The results demonstrate the impact of surface modifications on wettability. The untreated corn husks maintained their hydrophobicity due to their intact microstructure, whereas alkaline treatment disrupted this structure, increasing water absorption. This change validates that pretreatment is an effective strategy for improving fiber wettability and adhesion performance, essential for bio-based composite applications.

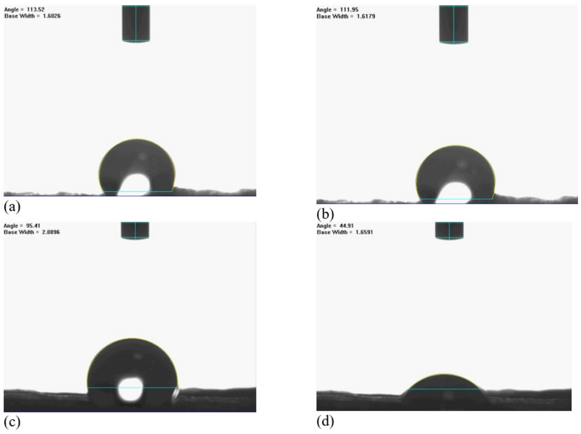


Fig. 2. Water contact angle measurements of untreated and alkaline-treated corn husk. (a, b) untreated corn husk: immediately after water droplet deposition and after 30 seconds; (c, d) alkaline treated corn husk: immediately after water droplet deposition and after 30 seconds.

Physical and Mechanical Properties

After The bonding mechanism between chitosan and corn husk fibers was examined to understand composite adhesion. Fig. 3a illustrates that NH_3^+ groups in chitosan formed ionic bonds with O^- groups on the alkaline-treated fiber surfaces (Jiang et al., 2023). These interactions promoted stronger adhesion, forming a stable composite structure. Hydroxyl and amino functional groups have been shown to facilitate hydrogen bonding, further strengthening the interface between the fibers and the chitosan adhesive.

The influence of adhesive resin content on particleboard performance was analyzed by examining density variations. Higher adhesive concentrations improved particle interaction and cohesion, resulting in greater density and mechanical strength (Azambuja et al., 2018). However, excessive resin use increased production costs, making medium-density formulations more favorable. As shown in Fig. 2, untreated samples exhibit a high contact angle, indicating low adhesive affinity. Therefore, density, tensile, and peeling tests were performed using treated samples. Alkaline treatment enhances fiber wettability by removing surface impurities such as waxes and lignin, thereby improving chitosan adhesion through stronger hydrogen bonding.

The density of corn husk-based composites, as shown in Fig. 3b, remains consistent with findings from prior research on biomass-based particleboards. Compared to waste tea leaf-based particleboard (650 kg/m³, 13 MPa flexural strength) (Batiancela et al., 2014), bagasse-based particleboard (672 kg/m³, 12.5 MPa) (Mendes et al., 2015), and bamboo-based particleboard (873 kg/m³, 17.7 MPa) (Biswas et al., 2011), the corn husk composite exhibited superior density and mechanical performance. This improvement is attributed to the structural characteristics of corn husk fibers, which form a compact, gap-free matrix requiring lower adhesive content for effective bonding.

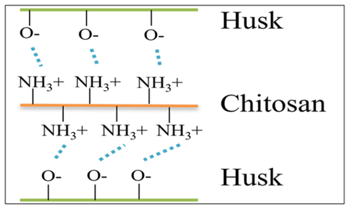
To evaluate the effect of chitosan concentration on the mechanical performance of the composite, tensile and flexural strength tests were conducted, as shown in Fig. 3c. Tensile strength increased with chitosan content, with values of 39.2 ± 2.63 MPa (5 wt%), 42.3 ± 2.14 MPa (6 wt%), 46.5 ± 1.99 MPa (7 wt%), and 49.9 ± 1.58 MPa (8 wt%). Flexural strength also improved, measured at 37.5 ± 3.00 MPa, 41.2 ± 2.14 MPa, 50.2 ± 1.99 MPa, and 56.8 ± 1.58 MPa, respectively. Peeling force values were 5.83 ± 2.16 N (5 wt%), 8.29 ± 0.98 N (6 wt%), 5.92 ± 0.77 N (7 wt%), and 10.60 ± 1.18 N (8 wt%). These results confirm that higher chitosan concentrations enhance both mechanical strength and interfacial adhesion.

The results indicate that increasing chitosan glue concentration significantly enhances both tensile and flexural strength. At 5 wt% chitosan, the tensile strength is approximately 39 MPa, increasing steadily to over 49.9 MPa at 8 wt%. Similarly, flexural strength exhibits a comparable increasing trend, confirming the role of chitosan in improving the composite's load-bearing capability. The improvement is attributed to stronger fiber-matrix adhesion, as higher chitosan content enhances interfacial bonding through hydrogen bonding and electrostatic interactions with cellulose and hemicellulose (Jiang et al., 2023).

To further assess adhesion performance, a peeling test was conducted, as shown in Fig. 3d. The results reveal that increasing the chitosan concentration enhances peeling force, indicating stronger interfacial bonding between composite layers. This is consistent with the observed increase in tensile and flexural strength, suggesting that a well-distributed adhesive layer improves the load transfer efficiency and reduces delamination risk.

These findings confirm the feasibility of corn husk-based composites for sustainable particleboard applications, and align with previous studies on chitosan-modified biopolymer composites, where the controlled addition of biopolymeric adhesives improved both tensile and flexural strength while enhancing peeling resistance (Rofii et al., 2014; Zhao & Umemura, 2014).

a



b

Concentration (wt%)	5	6	7	8
Density (Kg/m³)	846.9	933.3	963.3	931.6

c d

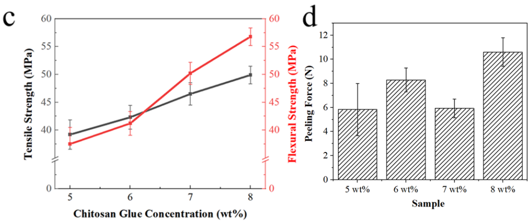


Fig. 3. Schematic illustration of electrostatic interactions between protonated amine groups (NH_3^+) of chitosan and negatively charged groups (O^-) in the husk (a), density values of composites prepared with varying chitosan glue concentrations (5–8 wt%) (b), variation in tensile strength (black line) and flexural strength (red line) with increasing chitosan concentration (c), and peeling force comparison of samples with different chitosan concentrations (d).

CONCLUSIONS

This study develops a high-performance biodegradable particleboard from corn husk fibers and chitosan, providing a sustainable alternative to conventional wood-based materials. These particleboards reduce reliance on timber by repurposing lignocellulosic biomass while lowering production costs. Corn husk performs superior as a filler due to its large structure and high fiber integrity, making it an ideal component for biodegradable composites.

Alkaline pretreatment is essential for enhancing fiber bonding properties. The results show that this process removes lignin, hemicellulose, and surface impurities, which improves hydrophilicity and chitosan adhesion. These modifications strengthen fiber-matrix interactions, leading to improved composite performance. Chitosan serves as an effective bio-based adhesive.

Its protonated $-NH_3^+$ groups form ionic bonds with negatively charged fiber surfaces, enhancing adhesion strength. After hot pressing, the adhesive penetrates the fiber structure, resulting in a composite with superior mechanical properties and sustainability. The fabricated particleboard achieves excellent mechanical strength. The tensile strength ranges from 39 to 49.9 MPa, and the flexural strength reaches 37 to 56 MPa. These findings confirm that corn husk fiber and chitosan-based composites can be a sustainable alternative for industrial applications.

This study successfully fabricates formaldehyde-free biodegradable particleboards suitable for plastic casings and furniture. However, further research is needed to enhance water resistance and durability. Future studies will focus on optimizing adhesive formulations and large-scale manufacturability. These results demonstrate that high-performance biodegradable particleboards from corn husk fibers and chitosan offer a viable solution for sustainable material development. With continued advancements, this technology will support the transition toward eco-friendly manufacturing.

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