Current Applied Science and Technology e-ISSN: 2586-9396

Curr. Appl. Sci. Technol. ….., Vol... (No...), e0267770

Research article

Effect of Pretreatment Methods on Cellulose Extraction from Corncobs and Its Application as a Fruit Coating

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Received: 28 May 2025, Revised: 5 January 2026, Accepted: 6 February 2026, Published: 15 May 2026

Abstract

This study examined pretreatment strategies to enrich cellulose from corncob biomass and evaluated the resulting cellulose as a natural fruit coating. Corncobs were pretreated by (i) steam at 100 or 120°C for 2 h or (ii) steam–NaOH using 2, 6, or 10 M NaOH at 80, 100, or 120°C for 2 h. The optimum condition (10 M NaOH, 120°C) produced 51.93±0.12% cellulose (30.90% higher than untreated), with hemicellulose at 25.45±0.18% and lignin 16.56±0.43%. Delignification with 1.3 M $NaClO_2$ at 75°C increased cellulose purity to 55.93±0.23%; however, additional delignification cycles did not significantly change cellulose content (p>0.05). The purified cellulose was slightly less bright than commercial carboxymethyl cellulose (CMC). In application, a 3% (w/v) aqueous extracted-cellulose coating was applied to Nam Dok Mai mangoes of similar maturity and compared with CMC-coated mangoes and an uncoated control. After 7 days, weight loss was 9.09% for cellulose-coated fruit and 8.73% for CMC-coated fruit, versus 13.60% for uncoated fruit. Moreover, both coatings delayed visible decay (no visible spoilage up to day 7; control showed spoilage by day 4). These results indicate that corncob-derived cellulose is a promising biodegradable coating for fruit preservation.

Keywords: carboxymethyl cellulose; corncobs; NaOH pretreatment; steam pretreatment; agricultural waste valorization; coating agent

1. Introduction

Cellulose is the most abundant renewable biopolymer on Earth. It is synthesized by plants through photosynthesis and deposited in the plant cell walls. Global annual production from terrestrial biomass exceeds 10^{11}-10^{12} tons, making cellulose a highly promising resource for sustainable material development (Shaghaleh et al., 2018; Madhushree et al., 2024). Because of this abundance, numerous agricultural residues have been explored as

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https://doi.org/10.55003/cast.2026.267770

alternative sources for cellulose extraction and bio-based materials. In Thailand, field corn is a major economic crop, producing over 5.033 million tons in 2024 (Ministry of Commerce, 2024). Approximately 25% of this output becomes residues such as corncobs and husks, much of which is openly burned, contributing significantly to seasonal haze. Corncobs contain roughly 45% cellulose, 35% hemicellulose, and 15% lignin (Howard et al., 2003; Maduang et al., 2018), making them a valuable yet underutilized lignocellulosic resource. These figures highlight both feedstock availability and national relevance, as corncob residues are a major contributor to open burning and seasonal haze in Northern Thailand. Valorizing corncobs into functional coatings therefore addresses a local waste-management problem while supporting Thailand's fresh-produce value chain.

Extracting cellulose from corncobs provides a valorization route for converting agricultural waste into value-added products. The resulting cellulose can be applied in bioplastics, surface coatings, and biomedical materials owing to its mechanical strength, biodegradability, and low toxicity. This approach aligns with circular-economy principles and supports sustainable development (Ganguly et al., 2020; Paudel & Janaswamy, 2024). In the food sector, cellulose and its derivatives such as CMC and HPMC are increasingly used as edible coatings to extend fruit shelf life by minimizing moisture loss, slowing respiration, and limiting microbial growth. For example, strawberries or Shine Muscat grapes coated with cellulose-based films exhibited lower weight loss and better freshness than uncoated fruits (Nadim et al., 2015; Ganguly et al., 2020; Bahmid et al., 2024; Paudel & Janaswamy, 2024).

Raw corncob cellulose offers several advantages over commercial CMC. As a low-cost agricultural residue, corncobs provide a renewable cellulose source without the environmental burdens associated with virgin cellulose materials such as cotton linter or wood pulp. Using crude cellulose also avoids the additional chemical derivatization steps required for CMC production. Although Ruengdechawiwat et al. (2023) successfully produced CMC from corncobs for fruit coating, their method involved multiple chemical-modification and purification steps. Here, we target a coating-grade crude cellulose fraction and avoid carboxymethylation and the associated solvent-washing steps required for CMC production. Because concentrated alkali and chlorite bleaching were used, we do not claim environmental or cost superiority; dedicated life-cycle and techno-economic assessments are required.

Corncobs exhibit a rigid lignocellulosic structure in which cellulose is tightly bound to hemicellulose and lignin. Pretreatment is therefore essential to disrupt this matrix, increase surface area, and enhance cellulose accessibility (Amin et al., 2017; Mankar et al., 2021). Several pretreatment routes were reported, including physical, chemical, thermal, and biological methods. Among these, steam exposure and alkaline treatment have been widely used because they effectively loosen fiber structures: steam under pressure disrupts hydrogen bonding and softens biomass, whereas alkaline conditions promote lignin solubilization and cellulose swelling. Moreover, together these actions facilitate the removal of lignin and hemicellulose (Mosier et al., 2005; Hendriks & Zeeman, 2009; Singh et al., 2014).

Steam-only pretreatment is widely applied as a mild, reagent-free method for reducing biomass rigidity, particularly in food-related applications where minimizing chemical residues is important. Although steam alone provides limited delignification, it increases fiber openness and serves as a useful baseline for evaluating how much alkaline assistance is required for efficient cellulose extraction. Previous studies have shown that aqueous NaOH combined with thermal treatment (commonly 100-121°C) can significantly enhance delignification and improve cellulose accessibility in various lignocellulosic substrates (Pandech & Chairattanamanokorn, 2010; Wang et al., 2010; Chansuk et al., 2019; Maneewong et al., 2023; Ruengdechawiwat et al., 2023). Building on this evidence, we investigated a wider NaOH concentration range (2-10 M) under controlled temperatures to examine how alkali strength influences corncob delignification and cellulose enrichment. This parameter study aimed to identify effective conditions; it does not imply environmental or economic superiority. For corncobs specifically, steam-assisted alkaline processing has been reported to further improve cellulose accessibility through enhanced depolymerization (Ouyang et al., 2018).

Despite these advances, previous studies have not systematically evaluated the combined influence of steam temperature and NaOH concentration on corncob pretreatment. To address this gap, the present work investigates two pretreatment approaches, namely steam treatment alone and steam treatment combined with sodium hydroxide, under controlled temperature and alkaline conditions. The extracted cellulose is then assessed for its suitability as a coating material for Nam Dok Mai mangoes, a fruit of high commercial value in Thailand.

This study contributes by: (i) systematically quantifying the combined effects of steam temperature and NaOH concentration on corncob composition using a factorial design; (ii) identifying a practical pretreatment/bleaching endpoint that yields a coating-grade cellulose fraction without chemical derivatization; and (iii) benchmarking coating performance on mangoes against commercial CMC using viscosity, weight loss, and spoilage endpoints.

2. Materials and Methods

2.1 Preparation of ground corncobs

The corncobs used in this study were obtained from a maize farming group in Mae Chan District, Chiang Rai Province, Thailand. The corncobs were first cut into slices with a thickness not exceeding 2 mm, then dried in a hot air oven at 105°C for 24 h until a constant weight was achieved. After drying, the corncobs were finely ground using an electric blender and sieved through a 200-mesh screen to ensure uniform particle size. The resulting ground corncobs were subjected to an additional drying process at 60°C for 3 h to reduce residual moisture content. The dried samples were then stored in a desiccator at room temperature prior to use in the experiments. The physical and chemical characteristics of the prepared ground corncobs are shown in Table 1.

Table 1. Physical and chemical characteristics of ground corncobs

Parameters	Ground Corncobs
Moisture, %	3.30±0.06
Cellulose, %	35.88±0.18
Hemicellulose, %	39.60±0.17
Lignin, %	18.13±0.06
Ash, %	2.35±0.05
Other, %	4.04±0.05
L*	34.71±0.42
a*	8.19±0.19
b*	34.67±0.26

Note: All chemical composition values are expressed on a dry basis.

2.2 Cellulose extraction from corncobs

2.2.1 Steam pretreatment

A 40-gram sample of ground corncobs was placed in a 1000 mL flask containing 600 mL of distilled water. The mixture was then subjected to steam pretreatment in a pressure steam sterilizer (DWS-280B, DRAWELL, China) operating at a working pressure of 0.142 MPa. Two steam temperature conditions, 100°C and 120°C, were applied for a duration of 2 h. After pretreatment, the liquid fraction was removed by filtration, and the solid residue was washed with distilled water. The washed solid was subsequently dried at 60°C for 6 h. This procedure was adapted from Mosier et al. (2005) and Hendriks and Zeeman (2009).

2.2.2 Steam and NaOH pretreatment

Another set of 40-gram ground corncob samples was treated with 600 mL of sodium hydroxide (NaOH) solution at three different concentrations: 2 M, 6 M, and 10 M. The mixtures were placed in 1000 mL flasks and subjected to steam treatment using the same sterilizer as above. The treatment was conducted at three temperatures: 80°C, 100°C, and 120°C for 2 h. After treatment, the solution was filtered, and the solid fraction was washed repeatedly with distilled water until a neutral pH was reached. The samples were then dried at 60°C for 6 h. This procedure was adapted from Hendriks and Zeeman (2009) and Singh et al. (2014).

2.2.3 Lignin removal

From the pretreatment condition yielding the highest cellulose content, a 12 g sample was selected for lignin removal. The sample was immersed in 1.3 M sodium chlorite ($NaClO_2$) solution and the pH was adjusted to between 3.5 and 4 using acetic acid. The mixture was maintained at 75°C for 2 h. Whatman No. 4 filter paper, pre-dried at 80°C for 1 h to a constant weight, was used to filter the solids. The residue was then washed with distilled water until a neutral pH was achieved and subsequently dried at 60°C for 6 h. The dried sample was ground and sieved through a 200-mesh screen (Browning, 1967). This process was repeated 1-3 times depending on visual whiteness of the product.

The overall process used for cellulose extraction from corncobs is summarized in Figure 1. This flow diagram outlines the main steps from raw material preparation to final cellulose purification, including optional lignin removal.

2.3 Evaluation of coating application for fruit preservation

Fresh Nam Dok Mai mangoes were obtained from a local wholesale market in Chiang Mai. The vendor confirmed that no postharvest coating or chemical preservatives had been applied. Each fruit was visually inspected to ensure the absence of waxy or unusually glossy residues on the peel. Mangoes were rinsed with distilled water to remove adhering dust and air-dried at room temperature. To ensure sample uniformity, only fruits of similar size and maturity were selected. Maturity was defined as the commercial mature-green stage based on peel color and firmness assessed by gentle hand palpation. The initial fruit weight was 360.33±9.50 g (n = 3).

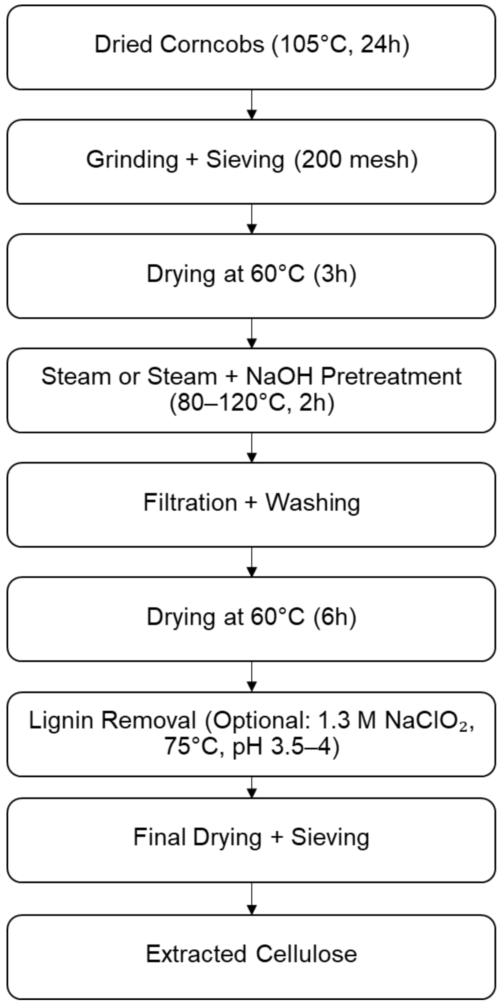


Figure 1. Cellulose extraction process flow

The preservation performance of the extracted corncob cellulose coating was compared with a commercial carboxymethyl cellulose (CMC) coating and an uncoated control. A concentration of 3% (w/v) was selected based on preliminary handling tests and was within the range reported for CMC-based coatings/films applied to mangoes (Ali et al., 2022; Carvalho et al., 2023; Ruengdechawiwat et al., 2023).

Coating solutions were prepared by adding 15 g of either extracted cellulose (from the optimum pretreatment condition) or commercial CMC to 500 mL of distilled water in a 1000 mL beaker. The mixture was stirred using a magnetic stirrer and heated to 80°C for 5 min, then cooled to room temperature. The mangoes were immersed in the coating solution for 5 s, twice consecutively. After coating, the mangoes were placed on a wire rack and air-dried for 30 min before storage. All samples were stored under ambient laboratory conditions throughout the experiment. Laboratory conditions were monitored intermittently, with temperature typically 28±3°C and relative humidity 60-75%. Coated and uncoated mangoes were stored under identical conditions for comparison.

2.4 Analytical methods

The chemical properties of ground corncobs and extracted cellulose were analyzed for moisture and ash according to AOAC methods (AOAC, 2000). Fiber composition—including holocellulose, cellulose, and lignin—was determined based on standards of the Technical Association of the Pulp and Paper Industry (TAPPI). Hemicellulose content was calculated as the difference between holocellulose and cellulose. Lignin content was measured by digesting the samples with sulfuric acid at concentrations of 72% and 3% w/w (TAPPI, 1992). Holocellulose was analyzed using the acid chlorite method with sodium chlorite and acetic acid (Browning, 1967), resulting in a white fibrous product. Cellulose content was determined by treating holocellulose samples with 17.5% w/v sodium hydroxide solution (TAPPI, 1998). Color characteristics were evaluated using the CIE Lab* system (ColorFlex EZ, HunterLab, USA).

Coating viscosity was measured using a rotational viscometer (RVDV-I-PRIME, Brookfield, Canada) with spindle No. 5 at 4, 5, 10, and 20 rpm at ~25°C (Abbas et al., 2010). Coating performance was assessed by recording fruit weight daily for 7 days or until visible spoilage occurred. Weight loss (%) was calculated as $(W_1 - W_t) / W_1 \times 100$, where W_1 is the fruit weight after coating and air-drying for 30 min (Day 1; post-coating baseline) and W_t is the weight at storage day t. Day 0 refers to the pre-coating condition (reference only); therefore, weight loss was calculated from Day 1 onward to avoid apparent negative values due to coating uptake. During storage, fruit quality was evaluated once daily by visual inspection of peel wrinkling, discoloration, and the first appearance of black spots or visible decay. The storage-time endpoint was defined as the first day when visible spoilage was observed.

2.5 Statistical analysis

Statistical analysis was performed using one-way analysis of variance (ANOVA). Significant differences among treatment means were determined using Tukey's post hoc test at a 95% confidence level ($p<0.05$). A factorial DOE (3 × 3) was employed to evaluate the main and interaction effects of NaOH concentration (2, 6, and 10 M) and temperature (80°C, 100°C, and 120°C) within the steam + NaOH pretreatment set, while the steam-only pretreatment (100°C and 120°C) served as a reference treatment for overall comparisons. All statistical analyses were carried out using Minitab v.21 software (Minitab Inc., USA). Each experimental condition was performed in triplicate (n = 3), and results were expressed as mean±standard deviation.

3. Results and Discussion

3.1 Pretreatment of corncobs

From the experiments on the pretreatment of ground corncobs, Table 2 shows that all pretreatment methods were effective in removing non-cellulosic components and increasing the cellulose content. Hemicellulose, in particular, was significantly reduced, with removal efficiencies ranging from 2.19% to 35.73%. There was an inverse relationship between hemicellulose content and cellulose content—the more the hemicellulose was removed, the higher the cellulose proportion became. This was because hemicellulose, having a relatively simple polymer structure, is easier to break down, even under mild alkaline or low-temperature conditions (He et al., 2020; Xia et al., 2022). The most effective pretreatment was with 10 M NaOH combined with heating at 120°C.

In contrast, lignin removal was less efficient, with removal rates between 3.47% and 9.71%. Lignin is a complex aromatic polymer that is water-insoluble and structurally resilient, requiring strong alkaline conditions to disrupt its bonds (Wang et al., 2019; Kaur & Goyal, 2024). Pretreatments with 10 M NaOH and steam at either 100°C or 120°C showed similar effectiveness in lignin removal.

In the steam pretreatment experiments, increasing the temperature was found to enhance hemicellulose degradation. Specifically, hemicellulose removal efficiencies were 15.80% at 100°C and 18.08% at 120°C. Lignin removal, however, remained relatively unchanged between these two conditions, with efficiencies of 3.64% and 4.02%, respectively. As a result of hemicellulose breakdown, the cellulose content increased with temperature—reaching 43.76±0.24% at 100°C (an 18.00% increase) and 44.92±0.24% at 120°C (a 20.12% increase). These results were consistent with the findings of Yuan et al (2019), who reported that higher hydrothermal pretreatment temperatures significantly promoted hemicellulose degradation in corn stover. At higher pretreatment temperatures, partial cellulose depolymerization can occur, particularly under alkaline conditions (e.g., alkaline peeling), which may reduce the degree of polymerization even if the measured cellulose fraction increases. In the present work, cellulose content increased with temperature (100-120°C), suggesting preferential removal of hemicellulose rather than obvious cellulose loss within the tested window; however, molecular-weight/DP changes were not quantified. From a sustainability perspective, increasing temperature also raises energy demand, so the choice of 120°C should be viewed as a maximum-enrichment condition rather than an optimized energy-minimized setting.

When combining NaOH with steam pretreatment, a similar trend was observed: cellulose content increased at both higher NaOH concentration and elevated temperature (Figure 2b). The highest cellulose content—51.93 ± 0.2%—was obtained using 10 M NaOH and heating at 120°C, representing a 30.90% improvement over untreated corncobs. This condition also achieved the highest hemicellulose removal (35.73%) and lignin removal of 8.60%. Notably, milder conditions were included (2–6 M NaOH and/or lower temperature) to assess trade-offs between extraction intensity and compositional enrichment (Table 2). These conditions improved cellulose content relative to untreated biomass but did not achieve the same hemicellulose reduction as 10 M NaOH at 120°C, indicating that stronger alkali/temperature is required for substantial matrix disruption in corncobs under the fixed 2 h treatment time. While 10 M NaOH at 120°C maximized cellulose enrichment (51.93%), several less intensive conditions still provided meaningful improvements and may be preferable when prioritizing lower energy input and process practicality. For example, 10 M NaOH at 100°C yielded 45.32% cellulose with lignin levels similar to those of 120°C condition (Table 2). We, therefore, used 10 M at 120°C as a maximum-enrichment reference for subsequent bleaching and coating tests, while recognizing that defining a true application-ready optimum for food-related processing requires additional constraints (e.g., residue assessment and chemical/energy accounting).

From a coating perspective, cellulose enrichment and hemicellulose reduction are expected to influence dispersion and film cohesion. Higher cellulose fraction can promote interchain interactions and network formation during drying, supporting a cohesive film, whereas higher hemicellulose content may increase water sensitivity. Residual lignin and chromophoric compounds can affect brightness/yellowness and reduce visual acceptability in coatings (Paulsson & Parkås, 2012; Lucenius et al., 2019; Wohlert et al., 2022; Etale et al., 2023).

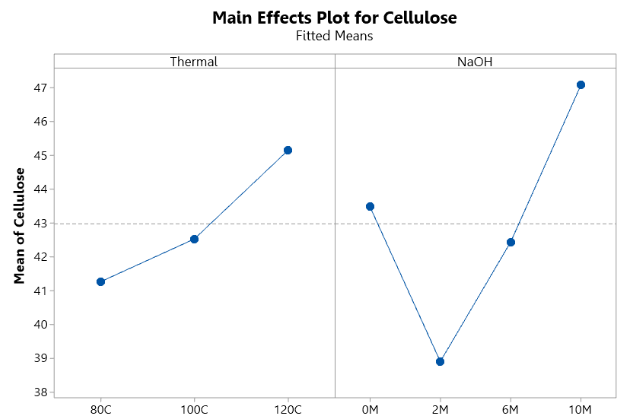
Table 2. Chemical composition of ground corncob after different pretreatment conditions

Condition	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Other (%)
untreated	35.88±0.18^{h}	39.60±0.17^{a}	18.13±0.06^{a}	2.35±0.05^{a}	4.04±0.05^{abcd}
steam at 100°C	43.76±0.14^{de}	33.34±0.18^{d}	17.47±0.06^{b}	2.20±0.00^{b}	3.22±0.02^{ef}
steam at 120°C	44.92±0.24^{bc}	32.44±0.25^{e}	17.40±0.00^{b}	2.20±0.00^{b}	3.03±0.32^{f}
2 M NaOH at 80°C	37.58±0.44^{g}	38.73±0.36^{ab}	17.03±0.00^{cd}	2.20±0.00^{b}	3.49±0.08^{def}
6 M NaOH at 80°C	41.33±0.42^{f}	34.93±0.50^{c}	16.83±0.06^{ef}	2.23±0.06^{b}	4.05±0.17^{abcd}
10 M NaOH at 80°C	44.01±0.20^{cd}	33.18±0.19^{de}	16.73±0.06^{f}	2.27±0.06^{b}	3.80±0.15^{cde}
2 M NaOH and steam at 100°C	38.20±0.12^{g}	38.61±0.13^{b}	17.50±0.06^{b}	2.20±0.00^{b}	4.45±0.10^{abc}
6 M NaOH and steam at 100°C	42.84±0.41^{e}	33.93±0.48^{d}	16.93±0.06^{de}	2.23±0.00^{b}	4.70±0.15^{a}
10 M NaOH and steam at 100°C	45.32±0.79^{b}	33.18±0.19^{de}	16.37±0.06^{h}	2.20±0.00^{b}	2.94±0.63^{f}
2 M NaOH and steam at 120°C	40.79±0.32^{f}	35.34±0.44^{c}	17.13±0.06^{c}	2.20±0.00^{b}	4.53±0.17^{ab}
6 M NaOH and steam at 120°C	42.93±0.38^{e}	33.67±0.29^{d}	16.87±0.06^{ef}	2.20±0.00^{b}	4.33±0.32^{abc}
10 M NaOH and steam at 120°C	51.93±0.12^{a}	25.45±0.05^{f}	16.57±0.06^{g}	2.20±0.00^{b}	3.85±0.16^{bcde}

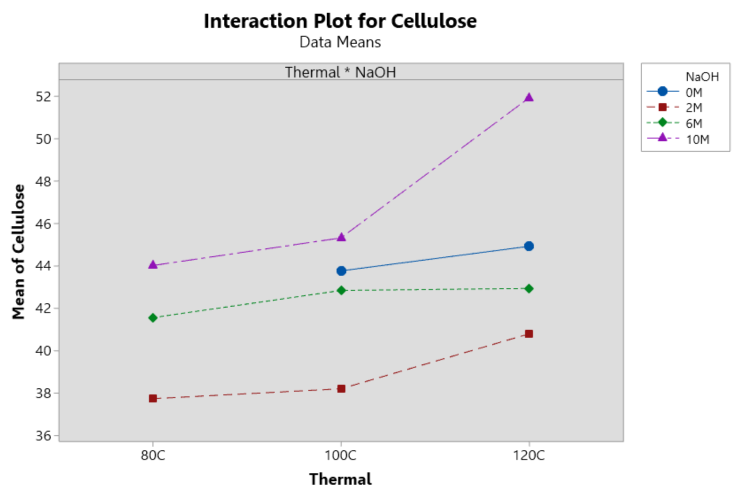
Note: Different superscript letters within the same column indicate a significant difference ($p<0.05$).

Compared with the multi-step carboxymethylation route reported by Ruengdechawiwat et al. (2023), the objective here was different: we aimed to obtain a coating-grade crude cellulose fraction rather than a chemically derivatized product. Although the selected condition uses concentrated NaOH (10 M) at elevated temperature (120°C), the workflow omits carboxymethylation and the associated neutralization and solvent-washing steps that are intrinsic to CMC synthesis. Accordingly, we frame the advantage as reduced process complexity (fewer unit operations), rather than environmental or cost superiority.

In addition, chlorite bleaching was performed only to the extent required for delignification: two cycles improved cellulose composition and visual appearance, whereas a third cycle provided no further benefit. These results indicate that extensive chemical derivatization is not necessary to obtain a corncob-derived cellulose fraction suitable for fruit-coating applications.



(a)



(b)

Figure 2. (a) Main and (b) interaction effects of pretreatment methods on cellulose content

To support these findings, Figure 2 summarizes the individual and combined effects of pretreatment variables on cellulose enrichment. Steam pretreatment increased cellulose content compared with untreated corncobs and produced higher cellulose contents than the NaOH treatments at 2 M and 6 M. At 10 M NaOH, cellulose content increased at all tested temperatures, confirming that alkali strength and temperature jointly influence corncob compositional changes. This trend was consistent with Modenbach and Nokes (2014), who reported that increasing NaOH pretreatment temperature from 100°C to 140°C enhanced hemicellulose and lignin solubilization in corncobs, increasing cellulose content from 32% to 70%. Similarly, Melesse et al. (2022) reported on combined NaOH and steam pretreatment of sugarcane bagasse at 120°C for 45 min. An increase in NaOH from 2.75% to 4%, resulted in an increase in cellulose content of 17.87% while reducing lignin by 70.78%.

3.2 Lignin removal effects

Cellulose extracted from ground corncobs, pretreated with 10 M NaOH and steam at 120°C, was further purified by bleaching with a $NaClO_2$ solution to remove residual lignin. This process aimed at obtaining higher-purity cellulose with a brighter, whiter appearance. The bleaching was performed in three cycles, as shown in Table 3. The results indicated that the second and third bleaching steps yielded no significant difference in the remaining lignin content. Similarly, the cellulose content did not significantly change between the second and third bleaching steps, suggesting diminishing returns beyond two treatments. Although cellulose and lignin contents did not differ significantly between the 2nd and 3rd bleaching cycles (Table 3), the 3rd cycle provided a small but statistically significant increase in brightness (L*) (Table 4), while b* showed no further improvement. From an economic standpoint, reducing the number of bleaching steps can improve process efficiency. After two rounds of bleaching, the cellulose content reached 55.93±0.23%, representing a 7.15% increase in purity compared to the initial pretreatment stage. Hemicellulose decreased further with each bleaching step. Ash was slightly higher after bleaching, likely because some organic matter was removed while the inorganic residue remained. The other fractions changed only slightly, which was consistent with the removal of minor constituents during purification.

Table 4 presents the color characteristics of ground corncobs in four stages: untreated, pretreated with 10 M NaOH and steam at 120°C, bleached cellulose after three cycles, and commercial CMC; the untreated corncob and commercial CMC are included for visual reference only. After lignin removal, the extracted cellulose showed a significant increase in L* value, which indicates brightness (0 = black, 100 = white). The L* values increased progressively across the bleaching steps; although the 3rd cycle produced only a marginal increase in L* relative to the 2nd cycle, the difference was statistically significant. Visually, the cellulose became noticeably brighter and whiter, approaching the appearance of commercial CMC. In practical applications, higher brightness and lower yellowness can reduce visible residue on coated produce and improve consumer acceptance. For cellulose-based materials used in films or coatings, improved color can also broaden the range of products where transparency or a neutral appearance is desired. The a* value, which indicates color hue along the green-red axis (−a* = green, +a* = red), decreased following pretreatment and remained relatively stable throughout the bleaching steps. These values also closely matched that of commercial CMC. The b* value, representing the blue-yellow axis (−b* = blue, +b* = yellow), was initially high in the untreated corncobs due to their yellowish hue. However, b* values significantly decreased after pretreatment and lignin removal, with no significant difference among the three bleaching cycles. These changes in color metrics are attributed to the removal of chromophoric compounds associated with lignin, which reduced the red and yellow tones in the samples (Chen et al., 2014).

3.3 Viscosity properties and application as a fruit coating agent

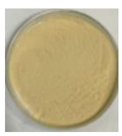
Viscosity is a key property influencing solution pickup during dipping and subsequent film formation and affects coating performance for fruit shelf life extension. In this study, a coating solution prepared from corncob-derived cellulose (bleached twice for lignin removal) was compared with commercial carboxymethyl cellulose (CMC). Both coatings were prepared at the same concentration and volume to ensure comparability.

Table 3. Percentage of chemical composition of cellulose extracted from ground corncobs

Condition	Cellulose	Hemicellulose	Lignin	Ash	Other
pretreated	51.93±0.12^{c}	25.45±0.05^{a}	16.57±0.06^{a}	2.20±0.00^{b}	3.85±0.16^{b}
1st bleaching	55.05±0.23^{b}	23.49±0.11^{b}	15.33±0.06^{b}	2.30±0.00^{a}	3.82±0.24^{b}
2nd bleaching	55.93±0.23^{a}	23.19±0.16^{c}	13.87±0.06^{c}	2.30±0.00^{a}	4.71±0.21^{a}
3rd bleaching	56.35±0.07^{a}	22.89±0.09^{d}	13.90±0.01^{c}	2.30±0.00^{a}	4.57±0.15^{a}

Note: Different superscript letters within the same column indicate a significant difference ($p<0.05$).

Table 4. Appearance and color value of cellulose extracted from ground corncobs

Untreated	Pretreated	1st Bleaching	2nd Bleaching	3rd Bleaching	Commercial CMC
					
L*	L*	L*	L*	L*	L*
34.71±0.42	36.62±0.04^{d}	58.73±0.24^{c}	69.44±0.32^{b}	70.69±0.19^{a}	92.69±1.16
a*	a*	a*	a*	a*	a*
8.19±0.19	3.65±0.51^{a}	3.77±0.01^{a}	3.72±0.24^{a}	3.31±0.05^{a}	0.92±0.14
b*	b*	b*	b*	b*	b*
34.67±0.26	10.32±0.31^{a}	7.47±0.11^{b}	7.38±0.35^{b}	7.62±0.07^{b}	0.95±0.09

Note: Different superscript letters within the same row indicate a significant difference ($p<0.05$).

Dynamic viscosity was measured at four spindle rotation speeds (Figure 3). The extracted cellulose coating exhibited viscosities of 4,287–6,100 cP, whereas commercial CMC showed substantially higher viscosities of 35,060–83,000 cP. For both coatings, viscosity decreased as spindle speed increased, consistent with shear-thinning (non-Newtonian) behavior (O'Banion & Es-haghi, 2023). The lower viscosity of the extracted cellulose likely produced a thinner, less uniform coating layer, which may explain the slightly higher weight loss relative to CMC, although both coatings demonstrated delayed visible spoilage compared with the uncoated control.

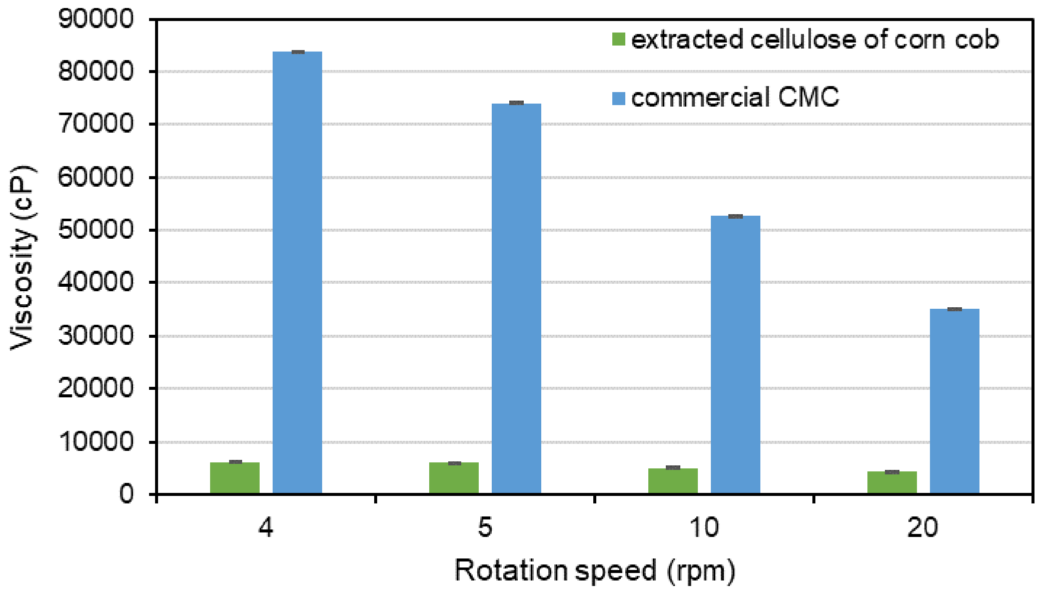


Figure 3. Comparison of viscosity of coating agent from CMC and extracted cellulose

To evaluate its practical application, the coatings were applied on to Nam Dok Mai mangoes. Day 0 refers to pre-coating condition, whereas day 1 represents the post-coating baseline used to calculate weight loss (%) to avoid apparent negative values caused by initial coating uptake. Compared with CMC, the extracted-cellulose coating produced a less glossy and slightly uneven, yellowish surface, consistent with the heterogeneous nature of the cellulose dispersion, while CMC formed a smoother, gel-like film.

Over a 7-day observation period, uncoated mangoes showed black spots and skin wrinkling by day 3, with visible spoilage by day 4. in contrast, mangoes coated with the extracted cellulose remained in acceptable condition until day 6, when slight discoloration and wrinkling appeared; no visible spoilage was observed through day 7. mangoes coated with CMC showed slight darkening on day 7 (Figure 4), and the first visible black spots are highlighted by red boxes.

Weight loss was expressed relative to the post-coating baseline (day 1). The initial average fruit weight was 360.33 ± 9.50 g. Under ambient conditions, the uncoated mangoes lost weight more rapidly, as indicated by the steeper WL slope (Figure 5). After 7 days, weight loss was 13.61% for uncoated fruit, compared with 9.09% for cellulose-coated fruit and 8.73% for CMC-coated fruit. Overall, the extracted cellulose reduced 7-day weight loss by ~33% relative to the uncoated control, whereas CMC achieved ~36% reduction under identical conditions. The slightly higher weight loss with the extracted-cellulose coating may reflect its lower viscosity and thinner film formation, resulting in a weaker barrier to moisture and gas transfer. Barrier properties (e.g., water vapor and oxygen permeability), microbial load, and gas exchange were not quantified in this study. Consistent with this interpretation, Wang et al. (2022) reported that coating viscosity strongly influenced film uniformity and extended apple shelf life when nanocellulose was used.

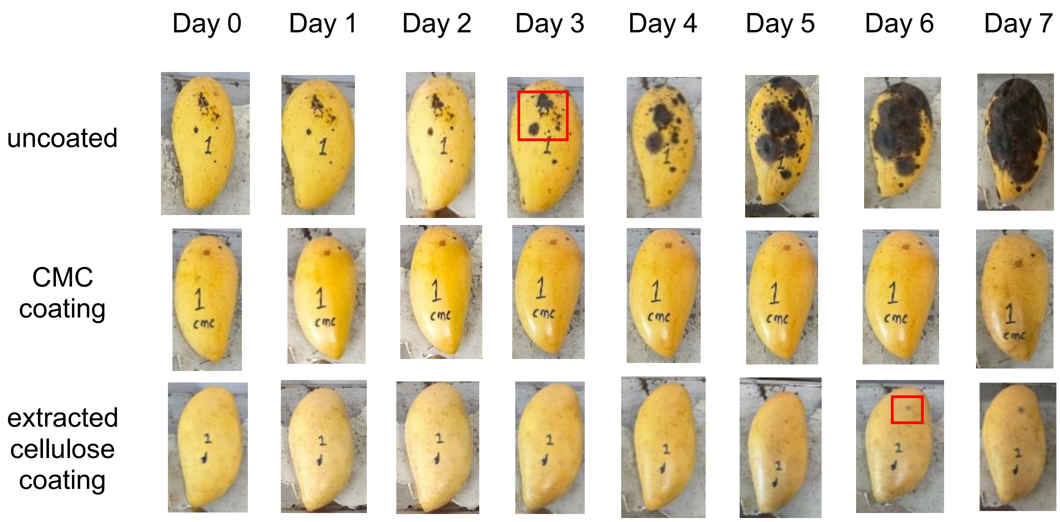


Figure 4. Appearance of mango fruit samples during one week of storage under different treatments

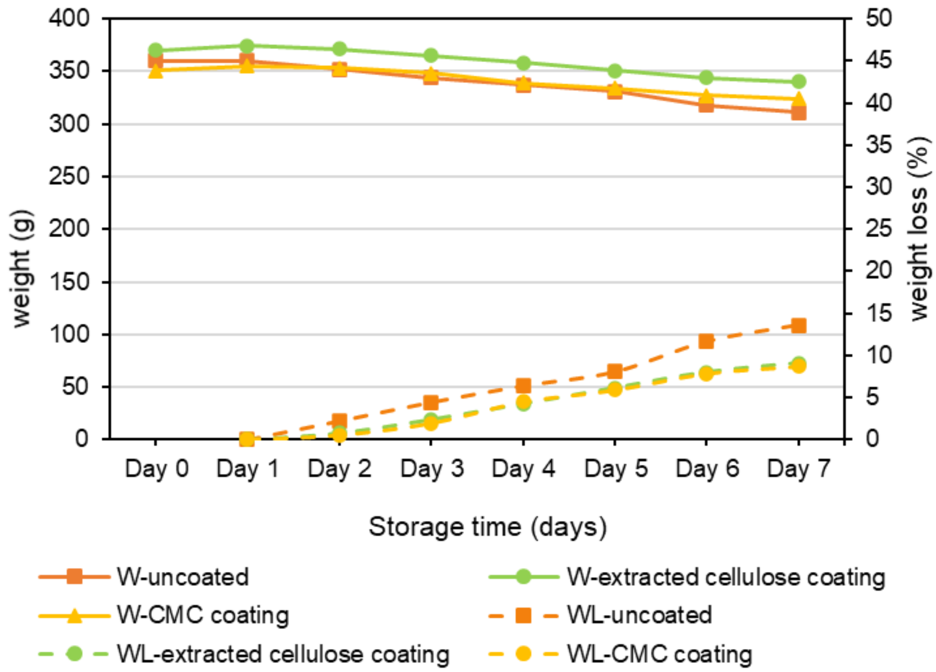


Figure 5. Changes in mango weight (g) and weight loss (%) during 7 days of storage under different coating treatments.

4. Conclusions

This work demonstrated that steam–alkaline pretreatment can substantially enrich cellulose from corncobs and produce a coating-grade cellulose fraction without chemical derivatization. The best-performing condition (10 M NaOH, 120°C, 2 h) increased cellulose content from 35.88% in untreated corncobs to 51.93%, and two chlorite-bleaching cycles further improved cellulose purity to 55.93% with no meaningful benefit from a third cycle.

When applied as a 3% (w/v) aqueous coating on Nam Dok Mai mangoes, the extracted cellulose reduced 7-day weight loss to 9.09%, compared with 13.61% for uncoated fruit, while CMC coating resulted in 8.73% weight loss under the same conditions. The cellulose coating also delayed visible spoilage relative to the uncoated control.

Limitations of this study include the absence of permeability, gas-exchange, and microbial measurements, as well as the lack of concentration optimization and sustainability assessment. Future work should optimize coating formulation and concentration, quantify barrier properties and microbial effects, and evaluate greener pretreatment/reagent recovery to define an application-ready and more sustainable process window. Additional fruit-quality indices (e.g., firmness and total soluble solids, TSS) were not quantified; including these measures would strengthen control of initial maturity and interpretation of ripening-related changes.

5. Acknowledgements

The authors would like to express their sincere gratitude to the corn farmers group in Mae Chan District, Chiang Rai Province, Thailand, for providing corncobs for this research. The authors also thank the local wholesale market in Chiang Mai for supplying Nam Dok Mai mangoes.

6. Authors' Contributions

Janyawat T. Vuthijumnonk designed research; Ninlawan Chaitanoo, Panupong Kongta and Chainarong Tatongjai performed research; Autchara Junpong, Atchara Chaiya and Prud Netsawang contributed new reagents/analytic tools; Ninlawan Chaitanoo analyzed data; Ninlawan Chaitanoo coordinated research and wrote the paper.

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7. Conflicts of Interest

The authors declare no conflicts of interest.

8. AI Declaration

The preparation of this manuscript by ChatGPT and QuillBot in order to assist in language editing and improving clarity and readability has been reviewed and edited as needed by all authors. The authors take full responsibility for the content of the publication.

References

Abbas, K. A., Abdulkarim, S. M., Saleh, A. M., & Ebrahimian, M. (2010). Suitability of viscosity measurement methods for liquid food variety and applicability in food industry - A review. *Journal of Food Agriculture and Environment*, *8*(3-4), 100-107.

Ali, S., Anjum, M. A., Khan, A. S., Nawaz, A., Ejaz, S., Khaliq, G., Iqbal, S., Ullah, S., Rehman, R. N. U., Ali, M. M., & Saleem, M. S. (2022). Carboxymethyl cellulose coating delays ripening of harvested mango fruits by regulating softening enzymes activities. *Food Chemistry, 380*, Article 131804. https://doi.org/10.1016/j.foodchem.2021.131804

Amin, F. R., Khalid, H., Zhang, H., Rahman, S. U., Zhang, R., Liu, G., & Chen, C. (2017). Pretreatment methods of lignocellulosic biomass for anaerobic digestion. *AMB Express*, *7*(1), Article 72. https://doi.org/10.1186/s13568-017-0375-4

AOAC. (2000). *Official methods of analysis*. (17th ed.). Association of Official Analytical Chemists.

Bahmid, N. A., Siddiqui, S. A., Ariyanto, H. D., Sasmitaloka, K. S., Rathod, N. B., Wahono, S. K., Jaiswal, S., Goksen, G., & Indrianingsih, A. W. (2024). Cellulose-based coating for tropical fruits: Method, characteristic and functionality. *Food Reviews International*, *40*(4), 1069-1092. https://doi.org/10.1080/87559129.2023.2209800

Browning, B. L. (1967). *Methods of wood chemistry* (Vol. 2). Interscience Publishers.

Carvalho, A. S. e S., Santos, A. H., Assis, E. O., Freitas, G. S., Lima, L. A., & Plácido, G. R. (2023). The effect of carboxymethylcellulose coating on the temperature-controlled storage of mangoes. *Multi-Science Journal, 6*(1), 40-43. https://doi.org/10.33837/msj.v6i1.1615

Chansuk, T., Boonyasing, B., & Anuragudom, P. (2019). Carboxymethyl cellulose from corn peel. In *Proceedings of the 16th National Kasetsart University Conference, Kamphaeng Saen Campus* (pp. 3022-3027). Kasetsart University.

Chen, Y., Tshabalala, M. A., Gao, J., Stark, N. M., & Fan, Y. (2014). Color and surface chemistry changes of pine wood flour after extraction and delignification. *BioResources, 9*(2), 2937-2948. https://doi.org/10.15376/biores.9.2.2937-2948

Etale, A., Onyianta, A. J., Turner, S. R., & Eichhorn, S. J. (2023). Cellulose: A review of water interactions, applications in composites, and water treatment. *Chemical Reviews, 123*(5), 2016-2048. https://doi.org/10.1021/acs.chemrev.2c00477

Ganguly, P., Sengupta, S., Das, P., & Bhowal, A. (2020). Valorization of food waste: Extraction of cellulose, lignin and their application in energy use and water treatment. *Fuel*, *280*, Article 118581. https://doi.org/10.1016/j.fuel.2020.118581

He, L., Yang, S., Chen, D., Peng, L., Liu, Y., Guan, Q., & Li, J. (2020). Hemicellulose transportation from different tissues of corn stalk to alkaline hydrogen peroxide solution. *Cellulose, 27*, 4255–4269. https://doi.org/10.1007/s10570-020-03088-8

Hendriks, A. T. W. M., & Zeeman, G. (2009). Pretreatments to enhance the digestibility of lignocellulosic biomass. *Bioresource Technology*, *100*(1), 10-18. https://doi.org/10.1016/j.biortech.2008.05.027

Howard, R. L., Abotsi, E. L. J. R., Van Rensburg, E. J., & Howard, S. (2003). Lignocellulose biotechnology: Issues of bioconversion and enzyme production. *African Journal of Biotechnology*, *2*(12), 602-619. https://doi.org/10.5897/AJB2003.000-1115

Kaur, H., & Goyal, D. (2024). Lignin extraction from lignocellulosic biomass and its valorization to therapeutic phenolic compounds. *Journal of Environmental Management*, *372*, Article 123334. https://doi.org/10.1016/j.jenvman.2024.123334

Lucenius, J., Valle-Delgado, J. J., Parikka, K., & Österberg, M. (2019). Understanding hemicellulose–cellulose interactions in cellulose nanofibril-based composites. *Journal of Colloid and Interface Science, 555*, 104-114. https://doi.org/10.1016/j.jcis.2019.07.053

Madhushree, M., Kanchana, U., Mallaiah, G. P., & Nagabhushana, B. M. (2024). A comprehensive review of cellulose and cellulose-based materials: Extraction, modification, and sustainable applications. *Journal of Macromolecular Science, Part A, 61*(7), Article 2418357. https://doi.org/10.1080/15440478.2024.2418357

Maduang, T., Chunhachart, O., & Pawongrat, R. (2018). The effect on morphological change of cellulose fibers by sonochemical-assisted pretreatment of lignocellusic biomass. *Rajamangala University of Technology Suvarnabhumi Academic Journal*, *6*(1), 26-36.

Maneewong, C., Changkhaochai, K., & Detchewa, P. (2023). Optimizing extraction of cellulose and preparing carboxymethyl cellulose from young longan fruit waste. *Siam University Journal of Food Technology, 18*(2), 59-67.

Mankar, A. R., Pandey, A., Modak, A., & Pant, K. K. (2021). Pretreatment of lignocellulosic biomass: A review on recent advances. *Bioresource Technology, 334*, Article 125235. https://doi.org/10.1016/j.biortech.2021.125235

Melesse, G. T., Hone, F. G., & Mekonnen, M. A. (2022). Extraction of cellulose from sugarcane bagasse optimization and characterization. *Advances in Materials Science and Engineering*, *2022*, Article 1712207. https://doi.org/10.1155/2022/1712207

Ministry of Commerce. (2024). *Foreign trade statistics of Thailand*. https://regional.moc.go.th/th/file/get/file/202404293963bcaa091ebea421d0a0189aec29a9094515.pdf

Modenbach, A. A., & Nokes, S. E. (2014). Effects of sodium hydroxide pretreatment on structural components of biomass. *Transactions of the ASABE*, *57*(4), 1187-1198. https://doi.org/10.13031/trans.57.10046

Mosier, N., Wyman, C., Dale, B., Elander, R., Lee, Y. Y., Holtzapple, M., & Ladisch, M. (2005). Features of promising technologies for pretreatment of lignocellulosic biomass. *Bioresource Technology*, *96*(6), 673-686. https://doi.org/10.1016/j.biortech.2004.06.025

Nadim, Z., Ahmadi, E., Sarikhani, H., & Amiri Chayjan, R. (2015). Effect of methylcellulose-based edible coating on strawberry fruit's quality maintenance during storage. *Journal of Food Processing and Preservation*, *39*(1), 80-90. https://doi.org/10.1111/jfpp.12227

O'Banion, E. E., & Es-haghi, S. S. (2023). Rheological behavior of cellulose nanofibril suspensions with varied levels of fines and solid content. *Polymer, 288*, Article 126445. https://doi.org/10.1016/j.polymer.2023.126445

Ouyang, X., Chen, L., Zhang, S., Yuan, Q., Wang, W., & Linhardt, R. J. (2018). Effect of simultaneous steam explosion and alkaline depolymerization on corncob lignin and cellulose structure. *Chemical and Biochemical Engineering Quarterly, 32*(2), 177-189. https://doi.org/10.15255/CABEQ.2017.1251

Pandech, J., & Chairattanamanokorn, P. (2010). Pretreatment of sawdust with alkaline and heat for hydrogen production. In *Proceedings of the 48th Kasetsart University Annual Conference: Natural Resources and Environment* (pp. 73-79). The Thailand Research Fund.

Paudel, S., & Janaswamy, S. (2024). Corncob-derived biodegradable packaging films: A sustainable solution for raspberry post-harvest preservation. *Food Chemistry, 454*, Article 139749. https://doi.org/10.1016/j.foodchem.2024.139749

Paulsson, M., & Parkås, J. (2012). Review: Light-induced yellowing of lignocellulosic pulps – Mechanisms and preventive methods. *BioResources, 7*(4), 5995-6040.

Ruengdechawiwat, S., Sanawong, P., & Boonmee, S. (2023). Extraction of CMC from corncob and its application as coating agent on mango fruit. *Life Sciences and Environment Journal, 24*(2), 327-337. https://doi.org/10.14456/lsej.2023.25

Shaghaleh, H., Xu, X., & Wang, S. (2018). Current progress in production of biopolymeric materials based on cellulose, cellulose nanofibers, and cellulose derivatives. *RSC Advances, 8*, 825-842. https://doi.org/10.1039/C7RA11157F

Singh, R., Shukla, A., Tiwari, S., & Srivastava, M. (2014). A review on delignification of lignocellulosic biomass for enhancement of ethanol production potential. *Renewable and Sustainable Energy Reviews, 32*, 713-728. https://doi.org/10.1016/j.rser.2014.01.051

TAPPI. (1992). *Alpha-, beta- and gama-cellulose in pulp and wood* (T-203 om-88). Technical Association of the Pulp and Paper Industry, Tappi Press.

TAPPI. (1998). *Acid insoluble lignin in pulp and wood* (T-222 om-98). Technical Association of the Pulp and Paper Industry, Tappi Press

Wang, H., Pu, Y., Ragauskas, A., & Yang, B. (2019). From lignin to valuable products–strategies, challenges, and prospects. *Bioresource Technology, 271*, 449-461. https://doi.org/10.1016/j.biortech.2018.09.072

Wang, Y., Zhang, J., Wang, X., Zhang, T., Zhang, F., Zhang, S., Li, Y., Gao, W., You, C., Wang, X., & Yu, K. (2022). Cellulose nanofibers extracted from natural wood improve the postharvest appearance quality of apples. *Frontiers in Nutrition, 9*, Article 881783. https://doi.org/10.3389/fnut.2022.881783

Wang, Z., Keshwani, D. R., Redding, A. P., & Cheng, J. J. (2010). Sodium hydroxide pretreatment and enzymatic hydrolysis of coastal Bermuda grass. *Bioresource Technology, 101*(10), 3583-3585. https://doi.org/10.1016/j.biortech.2009.12.097

Wohlert, M., Benselfelt, T., Wågberg, L., Furó, I., Berglund, L. A., & Wohlert, J. (2022). Cellulose and the role of hydrogen bonds: not in charge of everything. *Cellulose, 29*, 1-23. https://doi.org/10.1007/s10570-021-04325-4

Xia, Y., Liu, Q., Hu, X., Li, X., Huang, Y., Li, W., & Ma, L. (2022). Structural evolution during corn stalk acidic and alkaline hydrogen peroxide pretreatment. *Industrial Crops and Products, 176*, Article 114386. https://doi.org/10.1016/j.indcrop.2021.114386

Yuan, H., Song, X., Guan, R., Zhang, L., Li, X., & Zuo, X. (2019). Effect of low severity hydrothermal pretreatment on anaerobic digestion performance of corn stover. *Bioresource Technology, 294*, Article 122238. https://doi.org/10.1016/j.biortech.2019.122238