Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP07.20260338
Published: March 25, 2026

Application of Cellulose Nanocrystals from Sugarcane Bagasse in Eco-Friendly Detergent Formulations

Nattaya Kamwilaisak, Hathaichanok Promboot and Kantaphat Russamee
English Program of Khon Kaen Wittayayon School
Khon Kaen, Thailand
nattayaim9339@gmail.com, parewa0049@gmail.com, kantaphattutor@gmail.com

Khanita Kamwilaisak
Department of Chemical Engineering, Khon Kaen University
Khon Kaen, Thailand
khanita@kku.ac.th

Abstract

This research evaluated the potential of cellulose nanocrystals (CNCs) derived from sugarcane bagasse as an eco-friendly alternative to conventional surfactants in detergent formulations. Sugarcane bagasse was selected for its abundance as agricultural waste in northeastern Thailand and its potential for value-added utilization. The chemical structure and morphology of the CNCs were characterized using Fourier-transform infrared spectroscopy (FTIR). CNCs were incorporated into laundry and dishwashing detergents by partially replacing 50% of conventional surfactants. Cleaning performance was evaluated using cotton fabrics and dishware stained with chili oil, tomato ketchup, soy sauce, and lipstick. Fabric color changes were analyzed using CIELAB (Lab*) measurements from a colorimeter to determine stain removal efficiency. Results showed that CNC-based detergents effectively removed stains, particularly polar food stains, with higher ΔE values for tomato ketchup (21.97) and soy sauce (18.73) than detergents without CNC. In contrast, for chili oil, ΔE decreased from 35.90 to 31.84 (11.3% reduction), indicating lower efficiency for oil-based stains. Similar trends were observed for lipstick (8.29% reduction). For dishwashing, the CNC-containing detergent removed over 99% of oil on all surfaces, with highest efficiency on glass (99.38%). Environmental safety was evaluated using pumpkin seedlings, where CNC-based detergents showed no negative effects. The cleaning mechanism is attributed to amphiphilic behavior, where hydrophobic interactions remove oily stains and hydrophilic interactions improve rinsing. Overall, these findings highlight CNCs as a sustainable, eco-friendly detergent ingredient. Further studies could optimize formulations, improve hydrophobic stain removal, and assess long-term environmental impacts.

Keywords
Amphiphilic behavior, Cellulose Nanocrystals, Detergent, Sugarcane bagasse, Surfactant replacement

1. Introduction
1.1 Background and Significance of the Study
Detergents are widely used in households and industries because they effectively remove oils, dirt, and stains. Their cleaning ability mainly depends on surfactants, which reduce surface and interfacial tension between water and oil-based contaminants. However, the increasing consumption of detergents has raised environmental concerns (Sindhu et al. 2016). Many commercial detergents rely on synthetic surfactants such as linear alkylbenzene sulfonate (LAS), which are petroleum-derived and associated with high life-cycle carbon footprints of about 5-10 kg CO_2-eq kg^{-1} due to crude oil extraction, energy-intensive sulfonation, and incomplete biodegradation (Ventura et al.). Conventional

detergents also contain builders and phosphate-based compounds such as sodium carbonate and sodium tripolyphosphate to enhance cleaning efficiency. When released into water systems, these phosphate components can cause nutrient enrichment, leading to eutrophication, excessive algal growth, oxygen depletion, and damage to aquatic ecosystems. In addition, some surfactants may not be fully removed during wastewater treatment and can remain biologically active in aquatic environments. Therefore, researchers and regulatory agencies are promoting the development of biodegradable surfactants and phosphate-free detergent formulations (Sindhu et al. 2016).

At the same time, many regions produce large amounts of agricultural waste that have limited value-added applications. In Thailand, sugarcane bagasse, the fibrous residue left after sugar extraction, is produced in large quantities and is often burned or discarded, contributing to air pollution and resource loss, especially in northeastern provinces where sugarcane cultivation is concentrated (Punyanunt et al. 2018). Sugarcane bagasse is rich in cellulose, a biodegradable and renewable polysaccharide composed of β-1,4-linked glucose units, making it a promising raw material for sustainable materials.

Cellulose nanocrystals (CNCs), derived from cellulose-rich biomass, have nanoscale dimensions, high surface area, and abundant hydroxyl groups that allow interactions with both hydrophilic and hydrophobic substances. These properties enable CNCs to exhibit amphiphilic behavior and stabilize colloidal systems, potentially reducing the need for conventional surfactants while maintaining cleaning performance. Previous studies have explored CNCs and other cellulose-based materials in eco-friendly cleaning products, demonstrating cleaning efficiencies comparable to commercial detergents while lowering environmental impacts (Liu et al. 2025). Therefore, converting sugarcane bagasse into CNCs presents a promising strategy to utilize agricultural waste and develop more sustainable detergent formulations.

1.2 Principles and Scientific Rationale

Cellulose nanocrystals (CNCs) derived from biomass have a crystalline structure and abundant hydroxyl groups that give them hydrophilic properties. Their crystalline surfaces can also interact with hydrophobic substances, resulting in amphiphilic behavior. In detergents, CNCs can adsorb onto oily stains, disperse them in water, and aid their removal during rinsing. CNCs can also act as solid stabilizers in Pickering emulsions, improving oil-water stability while reducing the need for conventional surfactants (Liu et al. 2025). Therefore, partially replacing synthetic surfactants with CNCs may maintain cleaning performance while lowering environmental impact.

1.3 Objectives of the Study

Specifically, this study aims to :

1. evaluate the potential of cellulose nanocrystals derived from sugarcane bagasse as a partial substitute for conventional surfactants in detergent formulations
2. assess the cleaning performance of CNC-containing detergent formulations in comparison with commercial detergents.
3. evaluate the preliminary environmental safety of CNC-based detergents through plant growth tests.

1.4 Expected Benefits

Authors are expected to promote value-added utilization of sugarcane bagasse as a sustainable agricultural resource and contribute to the development of eco-friendly detergent formulations with reduced chemical impact.

2. Theories and Related research

This chapter reviews theories and research related to the extraction of cellulose nanocrystals (CNCs) from agricultural waste and their application in detergent formulations.

2.1 Sugarcane Bagasse Pulp

Sugarcane bagasse is the fibrous residue remaining after sugarcane juice extraction in the sugar industry. It is often underutilized or discarded despite being a valuable lignocellulosic biomass. Bagasse mainly consists of cellulose, hemicellulose, and lignin, which form a structural matrix in plant fibers. Because of its high cellulose content and wide availability in sugar-producing regions, sugarcane bagasse has attracted attention as a renewable raw material for producing cellulose-based materials. Through appropriate chemical or mechanical treatments, the cellulose component of bagasse can be isolated and further processed into high-value products such as cellulose nanocrystals (CNCs) (Teh et al. 2016).

2.2 Cellulose

Cellulose is the most abundant natural polymer on Earth and serves as the primary structural component of plant cell walls. It is a biodegradable and renewable polymer composed of β-1,4-linked glucose units that form long, linear molecular chains. These chains interact through strong hydrogen bonding, creating both crystalline and amorphous regions within the cellulose structure. This hierarchical arrangement provides cellulose with high mechanical strength, chemical stability, and resistance to degradation. Due to its natural abundance and environmentally friendly properties, cellulose is widely studied as a sustainable alternative to petroleum-based polymers (Klemm et al. 2005).

2.3 Cellulose Nanocrystals

Cellulose nanocrystals (CNCs) are nanoscale rod-like particles produced by removing the amorphous regions of cellulose through acid hydrolysis. The remaining crystalline regions form highly ordered nanoparticles with high mechanical strength, large surface area, and excellent stability. CNCs also possess abundant surface hydroxyl groups that allow interactions with various chemical substances. These properties make CNCs attractive for applications in advanced materials, nanocomposites, coatings, and environmentally friendly products such as biodegradable packaging and detergent formulations (Teh et al. 2016).

2.4 Acid Hydrolysis

Acid hydrolysis is one of the most common methods used to extract CNCs from cellulose. In this process, strong acids selectively break down the amorphous regions of cellulose while preserving the crystalline domains. Sulfuric acid and hydrochloric acid are widely used because they effectively isolate cellulose nanocrystals and influence their surface properties. Sulfuric acid can introduce sulfate groups that improve the dispersion and stability of CNCs in aqueous suspensions, while hydrochloric acid helps preserve the native structure of cellulose. Pretreatment processes are often applied to remove lignin and hemicellulose to improve hydrolysis efficiency (Klemm et al. 2005; Sindhu et al. 2016).

2.5 Pickering Emulsions

Pickering emulsions are emulsions stabilized by solid particles rather than conventional surfactant molecules. In these systems, solid particles adsorb at the oil–water interface and form a protective layer around droplets, preventing them from coalescing. This mechanism improves emulsion stability and reduces the need for large amounts of surfactants. Pickering emulsions have gained significant interest in fields such as pharmaceuticals, cosmetics, food science, and environmentally friendly formulations (Kalashnikova et al. 2012).

2.6 Properties of Detergents According to Industrial Standards

Detergent products must meet certain quality standards to ensure safety and effective cleaning performance. These standards typically include uniform dispersion, absence of undesirable odors, and appropriate pH levels. In addition, detergents should demonstrate good biodegradability to minimize environmental impact and maintain sufficient cleaning efficiency compared with standard detergent formulations. Such requirements are important for ensuring product quality, consumer safety, and environmental sustainability (Liu et al. 2025).

2.7 Literature Review

2.7.1 Literature related to the nanocellulose extraction from starch

Sawanya Punyanunt et al. (2018) investigated the extraction and characterization of cellulose from cassava pulp, a byproduct of cassava starch production that contains approximately 55% residual starch on a dry weight basis. The process began with enzymatic destarching using α-amylase (Termamyl®) at 95-100 °C and pH 5.5-6 for 2 hours, which effectively reduced the starch content from 55.07 ± 0.82% to 0.39 ± 0.10% and increased crude fiber to 39.21 ± 0.14%. After starch removal, the destarched cassava pulp was treated with 2% NaOH in an autoclave at 120 °C for 1 hour to remove hemicellulose, followed by bleaching with 0.40% $NaClO_2$ at pH 5 and 80 °C for 4 hours to eliminate lignin and obtain purified cellulose. The final product contained 81.17 ± 0.95% α-cellulose, while lignin content decreased to 8.41 ± 1.80%, and the whiteness value reached L* = 81.85, indicating successful purification. Microstructural analysis showed that raw cassava pulp contained numerous starch granules embedded within the fiber matrix, while the destarched pulp displayed a clearer and more defined fibrous network after starch removal. FT-IR analysis further confirmed the removal of lignin and hemicellulose, as characteristic absorption peaks associated with acetyl and aryl lignin groups disappeared, while the cellulose β-glycosidic linkage signal became more prominent. Rheological testing of a 0.5 wt% cellulose suspension revealed gel-like behavior with shear-thinning properties, meaning viscosity decreased as shear rate increased. The suspension exhibited the highest viscosity at pH 3 due to reduced surface charge and stronger fiber interactions, while maintaining good stability at pH 3, 7, and 11. Overall, the study demonstrated that cassava pulp waste can be effectively converted into high-purity cellulose gel with desirable structural and rheological properties, highlighting its potential as a sustainable raw material for cellulose-based materials and nanocellulose production (Punyanunt et al., 2018).

Khanita Kamwilaisak et al. (2022) studied the modification of rice starch nanoparticles (SNPs) to function as stabilizers in Pickering emulsions, particularly for encapsulating curcumin in sunflower oil. The SNPs were produced by acid hydrolysis of rice starch using hydrochloric acid (HCl) at concentrations ranging from 1 to 6 M, with a rice-to-acid ratio of 25:250 g/mL. The mixture was incubated at 40 °C and 180 rpm for 5-7 days, after which the particles were collected by centrifugation, washed to neutral pH, and freeze-dried. To improve their emulsifying ability, the SNPs were further modified through crosslinking with 30 wt% citric acid in ethanol, followed by drying and heating at 130 ± 5 °C for 2, 4, or 6 hours. After washing to remove unreacted citric acid, the modified particles were obtained and labeled according to crosslinking time. Structural analysis indicated that the optimal hydrolysis condition was 2.2 M HCl for 6 days, producing SNPs with a yield of 21.87 ± 0.69% and crystallinity of 45.56%. Surface characterization showed that particles crosslinked for 6 hours exhibited the highest hydrophobicity, with a water contact angle of 87.2°, making them suitable for stabilizing oil-water interfaces. Using these modified particles, a Pickering emulsion containing 3.0 wt% SNP-M-6h was able to stabilize 30 wt% curcumin-loaded sunflower oil, producing droplets with an average size of 47.16 ± 4.22 µm and maintaining stability for at least five weeks. The emulsion also displayed shear-thinning rheological behavior typical of pseudoplastic fluids. Furthermore, curcumin release from the system was pH-dependent, occurring more slowly at low pH and more rapidly at higher pH while retaining strong antioxidant activity. These results demonstrate that modified rice starch nanoparticles can effectively stabilize Pickering emulsions and serve as promising carriers for controlled delivery of bioactive compounds (Kamwilaisak et al., 2022).

2.7.2 Literature related to the application of organic waste in detergent production

Tan Van Hau (2024) reviewed methods for producing eco-friendly detergents and soaps from organic agricultural waste, particularly citrus by-products such as orange, grapefruit, lemon, and tangerine peels. The review highlights that large amounts of waste generated by the food processing industry can be converted into value-added cleaning products, helping reduce environmental pollution while creating economic benefits. One approach involves fermenting citrus peels with brown sugar, water, and sometimes soapberry for about 40–45 days to produce ecological enzyme solutions containing ethyl alcohol and acetic acid, which can be used as natural cleaning agents for dishwashing, glass cleaning, and household cleaning. Another method uses waste frying oil combined with orange peel extract to produce soap through saponification, with optimal conditions including an oil-to-coconut-oil ratio of 6:4, 30% NaOH, a saponification temperature of 70 °C, and the addition of about 15% orange peel extract. The review also discusses the extraction of bioactive compounds from citrus peels, such as essential oils, limonene, saponins, flavonoids, and alkaloids, which provide antimicrobial and surfactant-like properties. Overall, the article emphasizes sustainable waste management and green chemistry, highlighting citrus waste as a low-cost and renewable raw material for biodegradable detergent formulations (Hau, 2024).

Nisha Gupta et al. (2024) investigated the use of de-oiled rice bran (DORB), an inexpensive agro-industrial by-product, as a substrate for producing detergent-stable α-amylase using Bacillus tequilensis TB5 through submerged fermentation. This approach reduces enzyme production costs, which normally account for 30–40% of manufacturing expenses. Optimal enzyme production occurred at pH 8.0, 37 °C, and 96 hours with 1.5% maltose and 15 g DORB. The partially purified enzyme showed maximum activity at pH 9.0 and 60 °C, with Km = 0.31 mg/mL and Vmax = 222.22 mg/mL/min. Immobilization in 3% calcium alginate beads allowed the enzyme to retain 61.95% activity after five cycles, improving reusability. The enzyme effectively removed starch stains in laundry detergent formulations and also performed well in textile desizing, achieving 17.34% weight loss with an 8–9 TEGEWA rating. These results demonstrate that DORB can serve as a low-cost and sustainable substrate for producing industrial enzymes used in detergents and textile processing (Gupta et al., 2024).

K.H. Lee et al. (2023) studied the impact of household detergents on anaerobic methane fermentation of kitchen wastewater from food waste disposers (FWDs). Using synthetic wastewater with high organic content, anaerobic toxicity assays showed that methane production decreased significantly as detergent concentration increased. The results fitted well with the Gompertz model, revealing strong inhibition of methane yield and production rate. The IC50 value was 603 mg/L, indicating that this concentration reduced methane production rate by half. Analysis of microbial membrane lipids showed that detergents damaged anaerobic microbial cell membranes, as key fatty acids such as C16 and C18:2n6 decreased at higher detergent levels. The study concluded that although FWD wastewater has high potential for biogas production, the presence of household detergents can severely inhibit fermentation. Therefore, reducing detergent concentration is necessary to support effective anaerobic digestion and sustainable food waste management (Lee et al., 2023).

3. Operational Procedures

3.1 Chemicals and Raw Materials Used

3.1.1 Sugarcane Bagasse
3.1.2 Water Processed through Reverse Osmosis (RO water)
3.1.3 Sulfuric Acid 96 wt%
3.1.4 Ethanol
3.1.5 Chilli oil
3.1.6 Soy sauce
3.1.7 lipstick
3.1.8 Ketchup
3.1.9 Cotton fabric (1 × 1 inch)
3.1.10 Pumpkin Seeds

3.2 Equipment and Tools

3.2.1 Extraction of Nanocrystals from Waste Sugarcane Bagasse

1. Sieve size 40 mesh
2. Hot Air Oven
3. Refrigerator
4. Centrifuge used to separate water from cellulose
5. Freeze Dryer
6. Grinder

3.2.2 Study of the Properties of Nanocrystals Derived from sugarcane bagasse

1. Fourier Transform Infrared Spectroscopy (FTIR); used to analyze the functional groups present in nanocrystals derived from sugarcane bagasse.
2. Transmission electron microscopy (TEM); used to examined the characteristics and structures of the sugarcane bagasse derived nanocrystals

3.2.3 Evaluation of detergency performance with 50% CNC substitution for LAS

1. Colorimeter; used to analyze cleaning efficiency.

3.2.4 Evaluation of the environmental impact of 50% CNC substitution for LAS surfactants using plant growth

1. Measuring tape

3.3 Operational Procedures

3.3.1 Preparation of Cellulose Nanocrystals (CNCs) from Sugarcane Bagasse (Adapted from Original Research Method)

Preparation of Cellulose Nanocrystals (CNC) Cellulose nanocrystals (CNC) were isolated from sugarcane bagasse pulp through sulfuric acid hydrolysis, adapted from the procedure outlined by Pasakorn et al. (2020). In brief, the bagasse pulp was first pulverized and passed through a 40-mesh sieve. Hydrolysis was performed using a cellulose-to-H_2SO_4 ratio of 1:20 (g/mL) with a 40% (w/w) sulfuric acid solution at 60°C for 80 minutes. Upon completion of the reaction, the process was halted by adding a large volume of cold water. The mixture was then repeatedly centrifuged at 5000 rpm for 5 minutes to eliminate residual acid and collect the supernatant. The resulting solid residue was washed and neutralized with distilled water to yield the CNC suspension. Finally, the CNC product was freeze-dried after freezing.

3.3.2 Characterization of Properties of Nanocrystals Derived from Sugarcane Bagasse

The properties of the cellulose nanocrystals (CNCs) extracted from sugarcane bagasse were characterized using the following techniques:

1. The chemical structure of the CNCs that obtained from sugarcane bagasse was analyzed using Fourier-transform infrared spectroscopy (FTIR) operated in attenuated total reflectance (ATR) mode over the wavenumber range of 4,000-400 cm^{-1}.
2. The morphological characteristics and structure of the CNCs derived from sugarcane bagasse were examined using transmission electron microscopy (TEM).

3.3.3 Comparison of Cleaning Efficiency with Commercial Products

To evaluate the cleaning performance of the CNC's incorporated detergent in comparison with commercially available products, two types of cleaning agents were selected:

1. A concentrated laundry detergent, comprising the following ingredients:
    1. Shampoo base N8000 (sodium lauryl ether sulfate at 28% concentration) 5 g
    2. Stain remover F24 (linear alkylbenzene sulfonate at 24% concentration) 2.5 g
    3. Cleansing agent FS-1 (Carbopol SF-1) 2.5 g
    4. Fragrance 0.15 ml
    5. Preservative 0.0375 ml
    6. Purified water 15 ml
2. A dishwashing liquid, comprising the following ingredients:
    1. Shampoo base N70 (sodium lauryl ether sulfate, 70% concentration) 1.67 g
    2. Stain remover LA60 (linear alkyl benzene sulfonic acid, 60% concentration) 1.67 g
    3. Thickener (salt) 0.835 g
    4. Lemon fragrance 0.05 ml
    5. Foaming agent 0.165 g
    6. Purified water 21.665 ml

The experimental procedure was as follows:

1. Prepare the laundry detergent and dishwashing liquid by substituting the CNCs prepared in this study for the stain removers (i.e., F24 and LA60) at a 50:50 ratio.
2. Prepare solutions from the various products, including the formulated one, at a concentration of 5% w/w in 1 liter of water.
3. Prepare raw cotton fabric pieces (1 × 1 inch) stained with contaminants such as chili oil, tomato sauce, soy sauce, and lipstick (1 g each), as well as bowls stained with chili oil. Dry the stained items in an oven at 350°C for 12 hours.
4. Immerse the oven-dried stained fabrics in a beaker containing 200 mL of the prepared solution and agitate using a magnetic stir bar for 10 minutes.
5. Oven-dry the fabrics again at 50°C for 12 hours
6. Measure the Lab* color values using a colorimeter to compare the cleaning efficiency.

3.3.4 Analysis of the Impact of CNCs on Plant Growth

The biocompatibility of CNCs was evaluated through the growth of pumpkin seedlings under different treatment conditions.

1. Pumpkin seedlings were cultivated in aqueous solutions containing ACNCs and laundry detergent, with distilled water used as the control. The seedlings were maintained under controlled conditions for 11 days.
2. Growth was assessed by measuring shoot lengths, then compared across all treatments to evaluate the effects on plant growth.

4. Results and Discussion

This research investigates the potential of cellulose nanocrystals (CNCs) derived from sugarcane bagasse as a sustainable additive in detergent formulations. The objective of this study is to evaluate the effectiveness of CNC in enhancing cleaning performance for household applications while promoting environmentally friendly practices. Furthermore, this study explores the potential reuse of wastewater generated from the cleaning process for plant cultivation, supporting sustainable water management and reducing environmental impact.

4.1 Numerical Results

4.1.1 Fabric Stain Removal Performance

The cleaning performance of detergent formulations was evaluated using the CIELAB color difference (ΔE) obtained from spectrophotometric measurements. Cotton fabric samples (1 × 1 inch) were stained with approximately 1 g of soy sauce, tomato ketchup, and lipstick, representing common polar and hydrophobic household stains. The stained fabrics were dried at 50 °C for 12 hours before cleaning. Cleaning was performed using a 5% (w/w) detergent solution with agitation for 10 minutes using a magnetic stirrer. After washing, samples were dried again under the same conditions, and color differences were measured at three points on each sample using a colorimeter. The color difference between stained and cleaned fabrics was calculated using Equation (4.1):

$$\Delta E * ab = \sqrt{[(\Delta L^*) + (\Delta a^*) + (\Delta b^*)]}$$

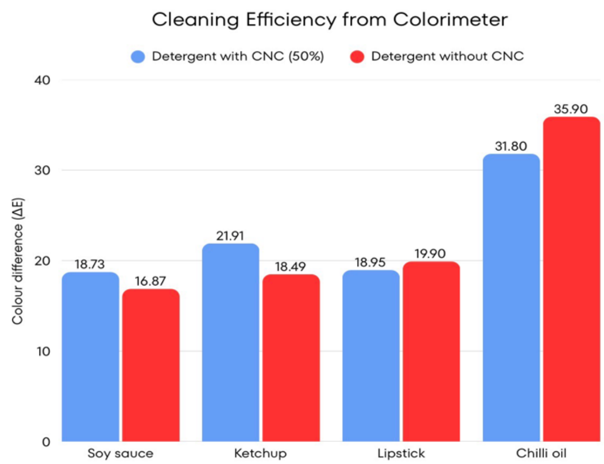


Figure 1. Comparison of Cleaning Efficiency Measured Using a Colorimeter

The results indicate that the incorporation of cellulose nanocrystals (CNC) influenced cleaning performance depending on the stain type, as shown in Figure 1. For food-based stains, detergents containing CNC (50% LAS substitution) showed improved cleaning efficiency. The ΔE value for tomato ketchup increased from 18.49 to 21.91 (18.5% improvement), while the value for soy sauce increased from 16.87 to 18.73 (11.03% improvement). Therefore, in chili oil, it decreases from 35.90 to 31.84 (11.3% reduction). In contrast, for hydrophobic stains such as lipstick, the detergent without CNC showed slightly better performance, with ΔE decreasing from 19.90 to 18.25 after CNC incorporation (8.29% reduction). These results suggest that CNC enhances the removal of polar, water-soluble stains but is less effective for oil-based contaminants.

4.1.2 Oil Removal Efficiency on Household Utensils

To further investigate the detergent's performance in removing oily residues from solid household surfaces, an additional experiment was conducted using common kitchen utensils made of glass and ceramic. These materials were selected because they represent typical household surfaces with different surface energies and textures.

Each utensil was weighed before contamination, and approximately 1 g of chili oil was applied to create a uniform oily stain. After staining, the utensils were immersed in a 5% (w/w) cleaning solution and subjected to ultrasonic agitation for 10 minutes to simulate an enhanced cleaning process. The utensils were then dried in an oven at 50 °C for 12 hours before weighing again to determine the remaining oil on the surface.
The oil removal efficiency was calculated using Equation 4.2:

$$\mathrm{Eff} = \frac{W2 - W1}{W0 - W1} \times 100$$

Where:

- W0 is the weight of the empty utensil (g),
- W1 is the weight of the utensil with oil before cleaning (g),
- W2 is the weight of the utensil with residual oil after cleaning (g),

- Eff represents the oil removal efficiency (%).

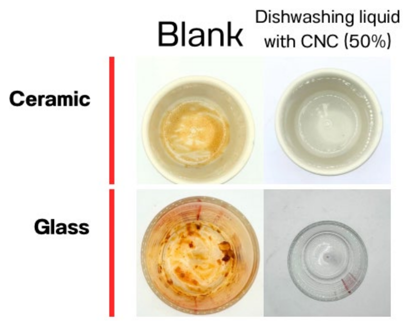


Figure 2. Comparison of dishwashing performance on ceramic and glass surfaces

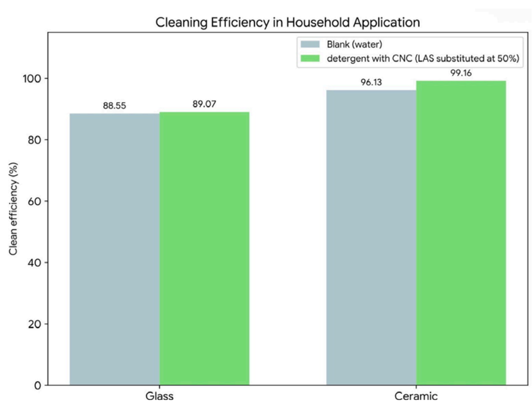


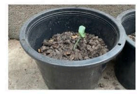
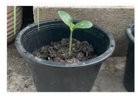
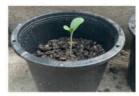
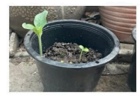
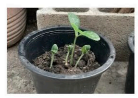
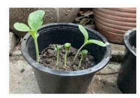
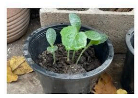
Figure 3. Comparative results of oil stain removal efficiency

The results in Figure 2 and Figure 3 show that the detergent containing CNC achieved high oil removal efficiency on both surfaces, reaching 99.38% on glass and 99.16% on ceramic, indicating effective cleaning of oil residues from common household materials.

4.1.3 Plant Growth Response under Wastewater Irrigation

To evaluate the environmental compatibility of CNC-based detergent formulations, a plant growth experiment was conducted using pumpkin plants. The plants were irrigated for 11 days under three treatments: detergent wastewater containing CNC, detergent wastewater without CNC, and water as a control. Each treatment received 100 mL of irrigation per day. Environmental conditions were monitored throughout the experiment, with temperatures ranging from 17-31 °C and relative humidity between 40-80%.

Table 1. Growth of pumpkin plants irrigated with different post-washing solutions from Day 1 to Day 11

Pumpkin	Detergent with CNC (50%) 100 ml	Detergent without CNC 100 ml	Water 100 ml
Day 1 T : 17 °C , RH : 77%			
Day 3 T : 31 °C , RH : 40%			
Day 5 T : 29 °C , RH : 50%			
Day 7 T : 19 °C , RH : 75%			
Day 9 T : 19 °C , RH : 74%			
Day 11 T : 17 °C , RH : 80%			

Pumpkin plants showed continuous growth under all irrigation treatments. Plants irrigated with detergent wastewater containing CNC grew from 3 cm on Day 3 to 12 cm by Day 11. Plants treated with detergent wastewater without CNC showed slightly slower growth, increasing from 2 cm on Day 3 to 10 cm by Day 11. In contrast, plants irrigated with water alone had delayed initial growth (1 cm on Day 4) but later grew faster, reaching the highest height of 13 cm by Days 10-11, as shown in Table 1.

Overall, the results suggest that irrigation with detergent wastewater containing CNC does not negatively affect early plant growth under the tested conditions. The absence of growth inhibition indicates low phytotoxicity and good environmental compatibility of CNC-based detergents. Stable growth within the observed temperature and humidity ranges also suggests the potential reuse of such wastewater for irrigation, supporting sustainable water management and environmentally friendly household practices, as shown in Figure 4.

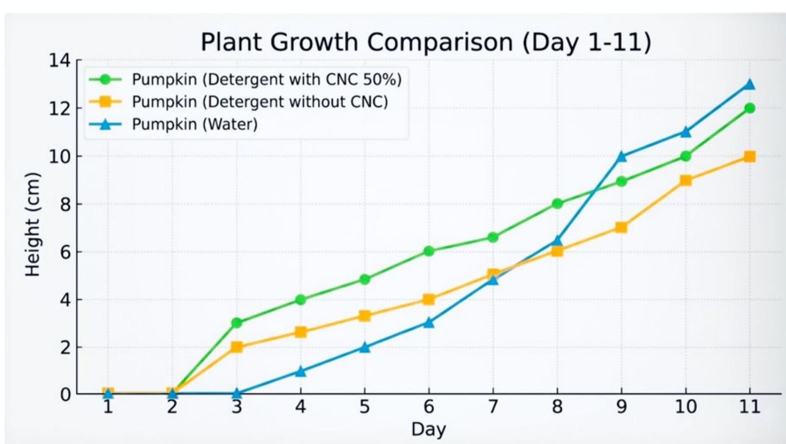


Figure 4. Growth of pumpkin plants under different treatments from Day 1 to Day 11

4.2 Graphical Results

4.2.1 Structural Characterization of CNC

The structural characteristics of cellulose nanocrystals derived from sugarcane bagasse were analyzed using Fourier-transform infrared spectroscopy (FT-IR), as illustrated in Figure 5. The FT-IR spectrum shows several characteristic absorption peaks corresponding to the functional groups present in cellulose.

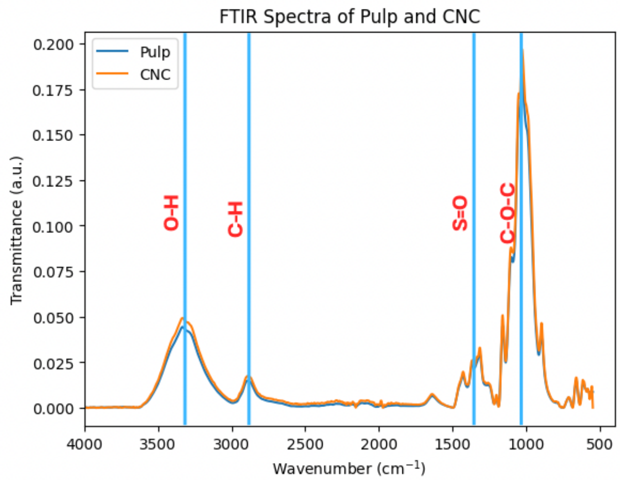


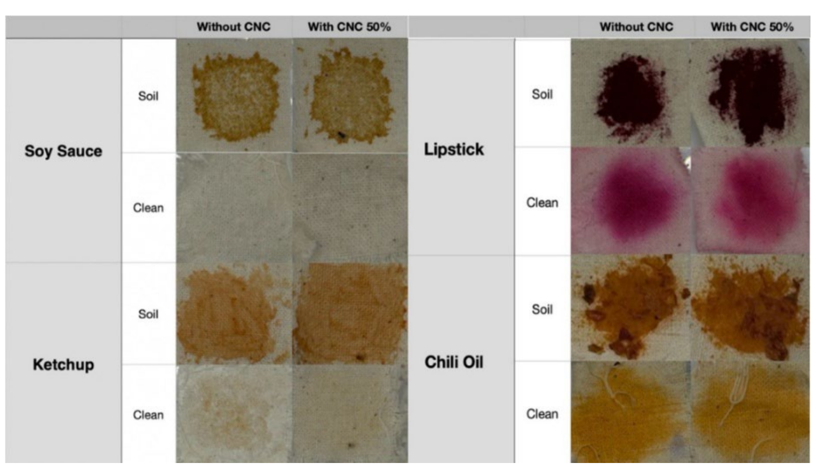
Figure 5. Functional group analysis of sugarcane bagasse nanocrystals in the wavenumber range of 500–4000 cm^{-1}

The absorption peak at 1050-1100 cm^{-1} corresponds to C–O–C stretching vibrations associated with the cellulose polysaccharide backbone. A peak near 1380-1400 cm^{-1} is attributed to S=O stretching vibrations, suggesting the presence of sulfate ester groups introduced during acid hydrolysis. Additional peaks at 2800-2950 cm^{-1} correspond to C–H stretching, while the broad band at 3200-3500 cm^{-1} represents O–H stretching vibrations responsible for the hydrophilic properties of cellulose nanocrystals. These spectral characteristics are clearly illustrated in Figure 5 and are consistent with previous studies on CNC derived from sugarcane bagasse reported by Joseph et al. (2023), confirming the successful formation of cellulose nanocrystals.

4.2.2 Experimental Setup for Cleaning Evaluation

The experimental setup used to evaluate the cleaning performance of the detergent formulations is illustrated in Table 2. Cotton fabric samples were stained with different contaminants, including soy sauce, tomato ketchup, lipstick, and chili oil, and were treated with either a detergent containing CNC (LAS substituted at 50%) or a detergent without CNC. The cleaning performance was then analyzed using colorimeter to determine the color differences before and after washing (Table 2).

Table 2. Comparison of cleaning performance on fabric surfaces (1 × 1 inch)



4.3 Proposed Improvements

Although this study demonstrates the potential of cellulose nanocrystals derived from sugarcane bagasse in detergent formulations, further investigation is required to optimize the formulation. Evaluating a wider range of CNC concentrations could help identify the most effective ratio for improving cleaning performance. Future research should also examine a broader range of stain types, including grease, protein-based stains, and soil contaminants, to better represent real household conditions. In addition, testing the detergent in practical washing systems and evaluating the long-term stability of CNC-based formulations would provide deeper insight into their real-world applications.

4.4 Validation

To ensure reliability, all experiments were conducted under controlled and standardized conditions. Fabric samples of identical size (1 × 1 inch) were stained with equal quantities of contaminants, and stain removal efficiency was measured using spectrophotometric analysis at three different points on each sample, as illustrated in Table 2. Oil removal efficiency from utensils was determined using a mass-based method by comparing weights before contamination, after oil application, and after cleaning, as shown in Figures 2 and 3. In the plant growth experiment, irrigation treatments were applied consistently at 100 mL per day, while environmental conditions were monitored with temperatures ranging from 17-31 °C and relative humidity between 40-80%, as illustrated in Table 1. These standardized procedures and quantitative measurements enhance the reliability of the results and support the conclusion that CNC-based detergents demonstrate effective cleaning performance with good environmental compatibility.

5. Conclusion

This study investigated the potential application of cellulose nanocrystals (CNC) derived from sugarcane bagasse as a sustainable component in household detergent formulations. Structural characterization using Fourier-transform infrared spectroscopy (FT-IR) confirmed the presence of characteristic cellulose functional groups, indicating the successful production of CNC from agricultural waste. Cleaning performance was evaluated through fabric stain removal and utensil cleaning experiments. The results showed that detergents containing CNC improved the removal efficiency of polar stains. The CIELAB color difference (ΔE) increased from 18.49 to 21.91 for tomato ketchup (18.5% improvement) and from 16.87 to 18.73 for soy sauce (11.03% improvement). Therefore, in chili oil, it decreases from 35.90 to 31.84 (11.3% reduction). In contrast, slightly lower performance was observed for hydrophobic stains such as lipstick, where ΔE decreased from 19.90 to 18.25 (8.29% reduction) after CNC incorporation. The CNC-based detergent also demonstrated excellent oil removal efficiency on household utensils, achieving 99.38% removal on glass surfaces and 99.16% on ceramic surfaces. Environmental compatibility was further evaluated through plant irrigation experiments using detergent wastewater. Pumpkin plants grew from 3 cm to 12 cm under CNC-containing wastewater over an 11-day period, indicating no growth inhibition and suggesting low phytotoxicity and favorable environmental compatibility. Overall, these findings demonstrate that CNC derived from sugarcane bagasse can serve as a promising environmentally friendly additive in detergent formulations while supporting sustainable resource utilization and greener household cleaning technologies.

References

Arvidsson, R., Nguyen, D., Svanström, M., Escarré, J. and Sandin, G., Harmonized life-cycle inventories of nanocellulose and its applications: Comparison of environmental impacts, Environmental Science & Technology, vol. 57, no. 24, pp. 9305–9317, 2023.

Gupta, N., Paul, J. S. and Jadhav, S. K., Biovalorization of de-oiled rice bran for α-amylase production and its application in detergents, Bioresource Technology, vol. 375, 128912, 2024.

Hau, T. V., Production of eco-friendly detergents from citrus agricultural waste, Journal of Cleaner Production, vol. 434, 140289, 2024.

Joseph, S. R., Sandra, H. T. P., Nair, A., Chandran, S. A. and Ushamani, M., Cellulose nanocrystals from sugarcane bagasse: Isolation, characterization and application, Cellulose Chemistry and Technology, vol. 57, no. 1–2, pp. 37–47, 2023.

Kalashnikova, A., Bizot, H., Cathala, B. and Capron, I., Modulation of cellulose nanocrystals amphiphilic properties to stabilize oil/water interface, Biomacromolecules, vol. 13, no. 12, pp. 2671–2679, 2012.

Kamwilaisak, K. and Wright, P. C., Citric acid-crosslinked rice starch nanoparticles for Pickering emulsions, Food Hydrocolloids, vol. 124, 107312, 2022.

Klemm, D., Heublein, B., Fink, H. P. and Bohn, A., Cellulose: Fascinating biopolymer and sustainable raw material, Angewandte Chemie International Edition, vol. 44, no. 22, pp. 3358–3393, 2005.
Lee, K. H., Park, K. Y., Khanal, S. K. and Lee, J. W., Inhibitory effects of household detergents on anaerobic methane fermentation, Bioresource Technology, vol. 367, 128234, 2023.
Liu, W., Wang, W., Cui, Y., Liu, J. and Liu, P., Physical cross-linking of cellulose nanofibrils with zein particles as an eco-friendly detergent, Langmuir, vol. 41, no. 8, pp. 5147–5157, 2025.
OECD, Environmentally friendly detergents: Policies and practices, Organisation for Economic Co-operation and Development, Available: https://www.oecd.org/environment/waste/policy/detergents.htm, 2019.
Phuangngam, S. and Gheewala, S. H., Sugarcane bagasse management in Thailand, Journal of Cleaner Production, vol. 196, pp. 1456–1465, 2018.
Punyanunt, S., Thuwapanichayanan, R. and Jiraratsatit, J., Preparation and characterization of cellulose gel from cassava pulp, Journal of Food Science and Technology, vol. 55, no. 12, pp. 4895–4905, 2018.
Scott, M. J. and Jones, M. N., The biodegradation of surfactants in the environment, Biochimica et Biophysica Acta-Biomembranes, vol. 1508, no. 1–2, pp. 235–251, 2000.
Sindhu, R., Binod, P. and Pandey, A., Biological pretreatment of lignocellulosic biomass, Bioresource Technology, vol. 199, pp. 76–82, 2016.
Teh, Z. H., Ma, Z. and Tan, E. M., Extraction and characterization of cellulose nanocrystals from sugarcane bagasse, Carbohydrate Polymers, vol. 144, pp. 460–469, 2016.
Varjani, S., Rakmi, A. R., Gnansounou, E. et al., Life cycle assessment of biosurfactants: A critical analysis, Recent Advances in Environmental Science, vol. 5, no. 2, pp. 45–63, 2023.
Ventura, A., Saling, P., Roode-Gutzmer, Q., Thylmann, D. and Griesshammer, R., Life cycle carbon footprint of detergents: A comparative assessment of conventional and eco-innovative products, International Journal of Life Cycle Assessment, vol. 18, no. 3, pp. 498–510, 2013.

Biographies

Nattaya Kamwilaisak is a Grade 11 scholarship student in the English Program at Khon Kaen Wittayayon School, based in Khon Kaen, Thailand. She aspires to become a physician and researcher, with interests in medical innovation, disease treatment, and nanotechnology. Raised in a household of doctors and professors, she developed an early passion for science and research. She has participated in several academic competitions and won a national competition for a stroke-related innovation. Beyond academics, Nattaya is also a visual artist whose work explores themes of activism, social justice, and human rights. She hopes to combine scientific research and social awareness to contribute meaningful innovations that improve healthcare and society.

Hathaichanok Promboot is a Grade 11 student in the English Program at Khon Kaen Wittayayon School, Thailand, maintaining a perfect GPAX of 4.00. Growing up with a mother who is a nursing teacher and a father who is an architect, she developed a strong interest in both healthcare and innovation. She aspires to become a doctor, particularly in plastic surgery, and is passionate about medical research and creating practical healthcare solutions. Her interest in innovation has led her to participate in academic competitions, where she received a winning award for a stroke-related project. Beyond academics, she is also active in beauty pageants, earning both national and international titles. These experiences have strengthened her confidence, discipline, and public speaking skills. By combining her academic dedication, interest in medical innovation, and communication skills, Hathaichanok aims to contribute to meaningful advancements in healthcare while promoting awareness and positive change in society.

Kantaphat Russamee is a Grade 11 student at Khon Kaen Wittayayon School in Thailand with a strong interest in environmental science and medical science. He is particularly interested in scientific research that promotes environmental conservation and improves human well-being. Kantaphat believes that science plays an important role in addressing real-world problems and developing sustainable solutions for both society and the environment. Outside the classroom, he enjoys photography, playing football, and reading articles about environmental sustainability and eco-friendly innovations. His curiosity about nature and sustainability inspires him to explore how scientific research and technological development can help protect natural resources and improve environmental quality. In the future, he hopes to pursue higher education in environmental science or medical science and contribute to research that supports environmental conservation while improving the quality of life for people.

Assoc. Prof. Khanita Kamwilaisak was born on 24th of May 1971 at Bangkok, Thailand. She graduated B.Eng in chemical Engineering at Khon Kaen University, Thailand in 1993, M.Eng in Chemical Engineering at KMUTT, Thailand in 1999 and PhD. in Chemical and Process Engineering at The University of Sheffield, United Kingdom. She was a lecturer in chemical engineering at Mahanakorn University of Technology, Thailand from June 1995 to May 2005. Now She is working at chemical engineering at Khon Kaen University, Thailand since April 2009. She is interested in photocatalytic reaction, sustainable product, circular economy and waste management.