Pertanika Proceedings 1 (7): 97 - 101 (2025)

PERTANIKA PROCEEDINGS

Journal homepage: http://www.pertanika.upm.edu.my/

Effects of Homogenised Coffee Extract Concentration on the Structural Properties and Solution Stability of Cellulose Nanocrystal (CNC)

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ABSTRACT

This study investigates the possibility of using spent ground coffee extract (SGCE) as a natural stabiliser for cellulose nanocrystals (CNC). SGCE, rich in polyphenols and polysaccharides, was extracted before being mixed with microcrystalline cellulose (MCC) at concentrations of 1%, 5%, and 10 % (w/v). Dynamic Light Scattering (DLS) and FTIR spectroscopy were conducted to investigate the formulations. Results showed that 5% SGCE created the most stable CNC solution, with lower hydrodynamic diameters (~229 nm), and shorter particle lengths than control samples. FTIR spectra revealed intermolecular interactions between SGCE and MCC, indicating a successful integration. These findings highlight SGCE as a sustainable alternative to synthetic stabilizers with potential applications in food packaging and biopolymer systems.

Keywords: Biopolymer stabilisation, food packaging, hydrogen bonding, nano whiskers, spent coffee grounds

INTRODUCTION

Cellulose nanocrystals (CNC) are renewable and biodegradable nanomaterials with high strength, large surface area, and biocompatibility. They are commonly synthesised from microcrystalline cellulose (MCC) using acid hydrolysis or related methods, producing rod-like particles with tuneable size and surface chemistry (Huang et al., 2020). Cellulose nanocrystals (CNC) have promising applications in food

ARTICLE INFO

Article history:
Received: 27 October 2025
Published: 10 December 2025

DOI: https://doi.org/10.47836/pp.1.7.017

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e-ISSN: 3083-9475

packaging, biomedical materials, and nanocomposites. However, the stability of CNC suspensions remains a key challenge. Conventional stabilizers such as polyvinyl alcohol (PVA) provide dispersion but are synthetic, non-biodegradable, and mostly unsuitable for food applications (Cheng et al., 2024).

Spent coffee grounds are an abundant agro-industrial by-product that often ends up in landfills. Extracts from these residues are rich in polyphenols and polysaccharides with antioxidant and emulsifying properties (Campos-Vega et al., 2015; Mohammadi et al., 2021). Previous studies have shown that plant-derived polysaccharides such as guar gum, alginate, and arabinogalactans had improved the CNC dispersion, while polyphenols enhance colloidal stability through hydrogen bonding interaction (Li et al., 2021). Despite these advances, limited research has evaluated the effect of spent ground coffee extract (SGCE) concentration on CNC stability and structure. This study addresses this gap by investigating SGCE as a natural dispersant for CNC suspensions, with potential applications in sustainable food packaging and biopolymer composites.

Problem Statement

Conventional stabilisers for CNC suspensions are predominantly synthetic surfactants, which are often non-biodegradable and environmentally hazardous. SGCE contains abundant in polyphenols and polysaccharides, presents a viable option for CNC stabilization while reducing agro-industrial waste.

Research Questions

How does SGCE concentration affect the structural features and particle size distribution of CNC? Can SGCE replace synthetic stabilizers while maintaining CNC suspension stability?

MATERIALS AND METHODS

Materials

Spent ground coffee, mixture of Arabica from Brazil and Papua New Guinea and Robusta from Java, Indonesiawas supplied by QAWA Coffee, Kuala Terengganu, Terengganu, Malaysia. Food grade microcrystalline cellulose (MCC) particle size of ~50 µm was purchased from Sigma-Aldrich, USA.

Spent Ground Coffee Extract (SGCE) Preparation and CNC Synthesis

Spent coffee grounds were oven dried overnight at 60ºC to standardise the moisture content of the spent coffee grounds. Next, the sample was homogenized with distilled water, and extracted at 1%, 5%, and 10 % (w/v). Extracts were centrifuged to obtain liquid spent coffee grounds extract (SGCE).

SCGE was mixed with 0.4 g MCC at constant time for 15 min and speed at 10,000-29,000 min-1 using handheld homogeniser (WiggenHauser D-500, Germany). The bottom layer of the solutions was removed after being centrifuged at room temperature for 10 min at 5,000 rpm. To increase the concentration of CNC, the top clear layer of the solution was removed, and the solution was reduced to 30 mL. Remaining solution was designated as CNC solution and further analysed.

CNC Suspension in SGCE Solution Analysis

Particle size was measured by Dynamic Light Scattering (DLS) via Particle Size Analyser (PSA) (Anton Paar Litesizer DLS 500, Austria). Molecular interactions were assessed by FTIR spectrometer IRPrestige-21 (Shimadzu, Japan). Data were analysed using one-way ANOVA with Duncan's test at $P < 0.05$.

RESULTS AND DISCUSSION

Dynamic Light Scattering Analysis

Spent ground coffee extract (SGCE) greatly reduced particle aggregation, since non-homogenized suspensions had huge diameters (>15,000 nm), whereas SGCE-based systems had much smaller hydrodynamic sizes (229-291 nm) as shown in Figure 1. 5% SGCE sample had the smallest particle size, indicating excellent stabilization in comparison to other samples. This is consistent with recent observations in which polysaccharides and polyphenols improved CNC dispersion through steric hindrance and hydrogen bonding (Adam et al., 2021; Wang et al., 2024).

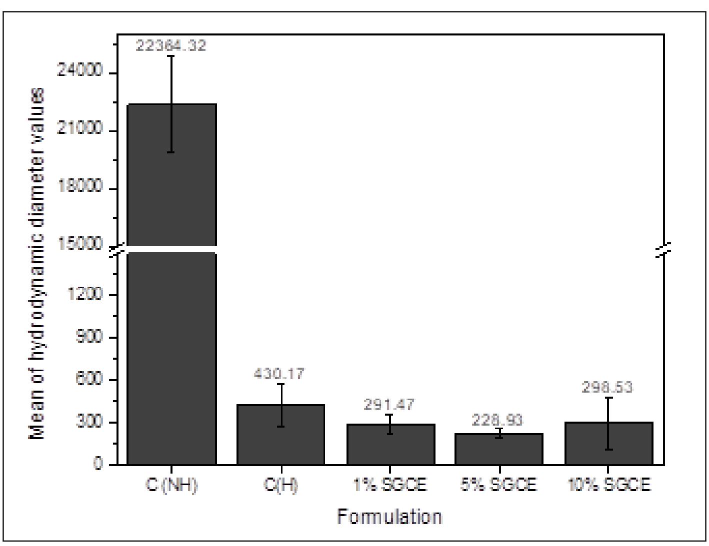

Figure 1. Mean of hydrodynamic diameter value of CNC suspension in SGCE solution

FTIR Spectroscopy Analysis

The FTIR peak analysis in Table 1 discovered changes in the hydroxyl and carbonyl peaks, demonstrating hydrogen bonding between SGCE chemicals and CNC surfaces. Due to limitation of cost, the FTIR analysis was conducted for three samples only - Control, 1% SGCE and 5% SGCE. Comparing between 1% SGCE and 5% SGCE, increasing amount of coffee extract shows absorbance increment of hydrogen bonded hydroxyl group (O-H), aliphatic (C-H) chains, carbonyl group (C=O) bending, and ether group (C-O) stretching. Such interactions improve dispersion by lowering interparticle attraction, which is consistent with previous studies on polyphenol-cellulose interactions in colloidal systems (Xu et al., 2013).

Table 1
Area under curve for selected functional groups

Formulation	Area under curve (cm^{-1})			
	O-H 3,600 cm^{-1}	**C-H 2,900 cm^{-1}**	**C=O 1,100 cm^{-1}**	**C-O 1,700 cm^{-1}**
Control (No SGCE)	594.40	N/D	221.65	191.11
1% SGCE	149.27	10.40	74.43	102.64
5% SGCE	213.06	29.23	101.10	115.84

* *N/D = not detected*

CONCLUSION

Spent ground coffee extract (SGCE) at 5% concentration was the most effective for stabilizing CNC suspensions, minimizing particle aggregation, and improving molecular interactions. Using used coffee grounds as a stabilizer promotes waste reutilization and circular economy concepts, providing a sustainable alternative to chemical stabilizers. Differences in coffee variety and composition may affect SGCE's stabilizing performance. Future study should investigate these aspects, as well as applications in food packaging systems.

ACKNOWLEDGEMENT

This research was funded by the Ministry of Higher Education Malaysia under the research scheme FRGS/1/2024/STG05/UNISZA/02/1; RF036.

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