Received: 17 July 2023 | Revised: 22 September 2023 | Accepted: 2 November 2023

DOI: 10.1002/app.54943

RESEARCH ARTICLE

Applied Polymer SCIENCE WILEY

Thermo-mechanical and antioxidant properties of eugenol-loaded carrageenan-cellulose nanofiber films for sustainable packaging applications

Wan Amnin Wan Yahaya[1] | **Nurul Aini Mohd Azman**[1] | **Prithinah M. Krishnnan**[1] | **Fatmawati Adam**[1] | **Maria Pilar Almajano**[2]

[1]Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Kuantan, Pahang, Malaysia

[2]Chemical Engineering Department (DEQ), Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (ETSEIB), Universitat Politècnica de Catalunya (UPC), Barcelona, Spain

Correspondence
Nurul Aini Mohd Azman, Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Kuantan, Pahang, Malaysia.
Email: ainiazman@umpsa.edu.my

Funding information
Ministry of Higher Education, Malaysia, Grant/Award Number: FRGS/1/2021/TK0/UMP/02/51 (University reference RDU210149); Universiti Malaysia Pahang, Grant/Award Number: PGRS 210368

Abstract

This study aimed to investigate the thermomechanical and antioxidant properties of an active film composed of carrageenan and cellulose nanofibers incorporating (0.1%v/v–0.5%v/v) eugenol (Eu), intended for active packaging applications. The mechanical, physical, morphology, and thermal properties of the active film were extensively characterized, and the antioxidant activity was monitored over a 34-day-storage period. Broido's model was employed to assess the thermomechanical properties and activation energy of the films towards the Eu structure in carrageenan and cellulose nanofiber film. The findings revealed that the addition of Eu had a negative impact on the activation energy of the film's decomposition while positively affecting the release of antioxidants during storage. The film containing 0.4% Eu demonstrated optimal physical and mechanical characteristics, including a tensile strength of 38.08 ± 2.06 MPa and elongation at break of 21.95% ± 9.02%. Furthermore, the SGC-0.4% (SGC stand for Semi refined carragenan + Glycerol + Cellulose nanofiber) Eu film exhibited a higher activation energy (365.82 kJ/mol), suggesting enhanced stability and durability compared with other films. The film with 0.4% Eu content showed the highest release rate of polyphenols (614.9290 mg gallic acid/L sample) up to 28 days of storage. Additionally, it exhibited a 58% efficiency of radical scavenging activity. Overall, these results highlight the potential of the SGC-0.4% Eu film as a biodegradable packaging solution that offers prolonged food shelf life.

KEYWORDS

activation energy, carrageenan, cellulose nanofiber, eugenol, thermal properties

1 | INTRODUCTION

Active packaging is designed to incorporate antioxidant substances into the packaging to delay food oxidation during food storage, postharvest transportation, and retail display.[1] Biodegradable active packaging made from polysaccharides such as carrageenan is becoming popular in the development of bio-based films because it is renewable, inexpensive, widely available, mechanically, and thermally stable, and serves as a carrier of active ingredients to inhibit the oxidation process in foods.[2,3] Carrageenan is a polysaccharide with a high-molecular

