Thermal degradation kinetics and multifunctional properties of gelatin/carrageenan films incorporating eugenol-loaded Pickering emulsions for active packaging applications

Journal of Food Measurement and Characterization • Article • 2026 •
DOI: 10.1007/s11694-026-04547-9

Hamid, Khadijah Husna Abd [a]; Kumar, Theja Sree Pothula Ganesh [b]; Masngut, Nasratun [a]; Arzmi, Mohd Hafiz [c]; Azman, Nurul Aini Mohd [a]

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

Abstract

Pickering emulsions are an emerging encapsulation technology for volatile compounds such as essential oils, which have been incorporated into packaging films to maintain the quality, safety, and nutritional value of food products. This study developed and characterized a sustainable active packaging film made from gelatin/semi-refined carrageenan incorporated with eugenol-loaded Pickering emulsion (EPE) stabilized by chitosan nanoparticles. The Coats-Redfern method (CRM) was applied to thermogravimetric (TGA) data to evaluate thermal degradation kinetics using various kinetic models, providing fundamental insights into thermal stability for active packaging

applications. The results showed that EPE droplets exhibited a monodisperse distribution (PDI < 0.3) with particle diameters of 18–47 nm maintained over 60 days. Scanning electron microscopy (SEM) observations revealed that films with 3% EPE maintained a homogeneous morphology, while obvious particle agglomeration occurred at higher concentrations (5% and 7% EPE). Incorporation of 3% EPE increased elongation at break to 58% and improved antioxidant activity to 89%, while tensile strength did not decrease significantly (P > 0.05) compared to the control film. The CRM indicated that the film with 3% EPE followed a complex degradation pathway involving multiple-step network ruptures, which was associated with a higher activation energy of 112.83 kJ/mol. Films containing 3–7% EPE exhibited effective antimicrobial properties, with clear inhibition zones significantly wider than those of the control film against Escherichia coli and Staphylococcus aureus. Overall, EPE-integrated films enhance the functionality and thermal stability of gelatin/semi-refined carrageenan-based films, highlighting their potential for sustainable active packaging applications.

Author keywords

Active packaging; Antimicrobe; Antioxidant; Eugenol; Pickering emulsion; Thermal degradation kinetics

Indexed keywords

Engineering controlled terms

Activation energy; Degradation; Emulsions; Escherichia coli; Food products; Food safety; Kinetics; Packaging; Plastic films; Staphylococcus aureus; Thermodynamic stability

Engineering uncontrolled terms

Active packaging; Antimicrobes; Carrageenans; Coats-Redfern method; Eugenol; Packaging applications; Packaging films; Pickering emulsions; Thermal; Thermal degradation kinetics

Engineering main heading

Antioxidants; Emulsification

Funding details

Details about financial support for research, including funding sources and grant numbers as provided in academic publications.