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Development and physicochemical characterization of a κ-carrageenan-based micro/nanostructured system loaded with *Melaleuca alternifolia* essential oil for controlled release applications.

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Introduction

Nanoparticles containing *Melaleuca alternifolia* essential oil represent a promising dermatological treatment for acne. Aiming to serve as an alternative to conventional active ingredients in formulations, current research has advanced the encapsulation of essential oils; however, significant gaps remain, particularly regarding the influence of synthesis parameters (Borotová et al. 2022; Homer et al. 2017). The present study develops and characterizes microparticles composed of κ-carrageenan — a natural, biocompatible, and biodegradable biopolymer with low toxicity — incorporating *Melaleuca alternifolia* essential oil.

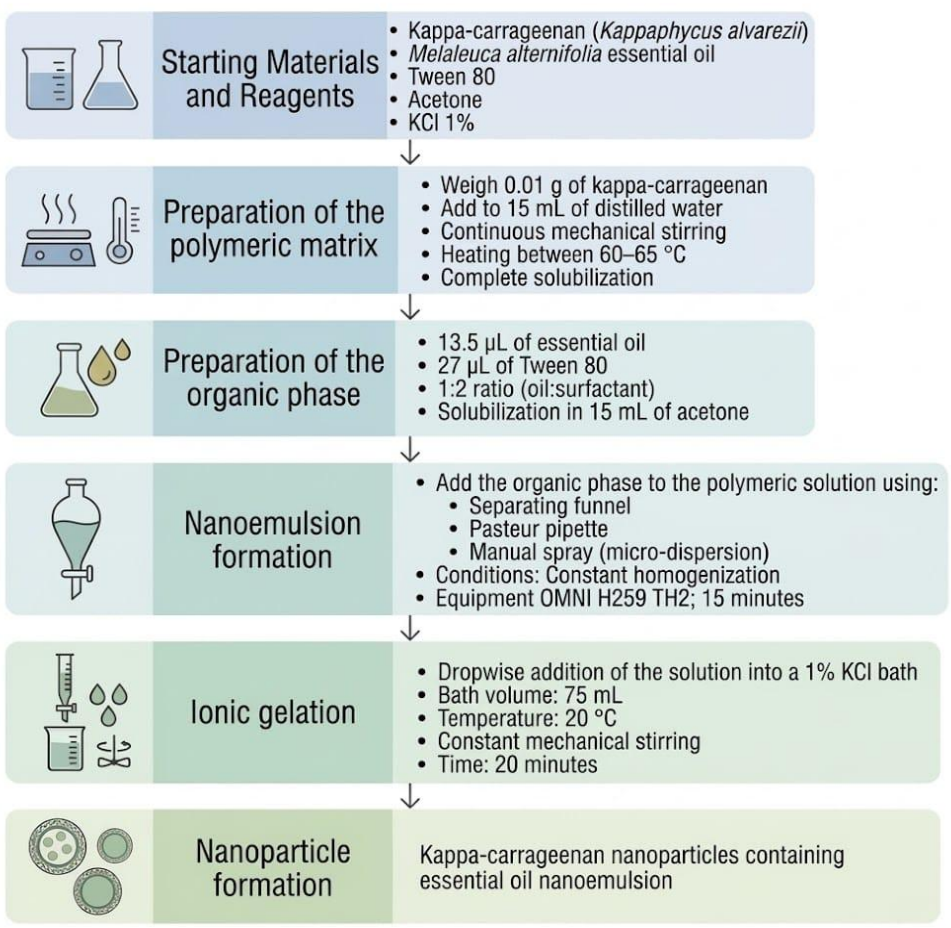
Objectives

Main Objective: To develop k-carrageenan nanocapsules with Melaleuca alternifolia essential oil

Specific Objectives:

- Characterization of the nanocapsules
- Measure the nanoparticles by Dynamic Light Scattering
- Determine the encapsulation efficiency
- Investigate the release of nanoparticles in vitro and mathematical modeling of the kinetics and release mechanisms
- Characterize nanoparticles using scanning electron microscopy (SEM), infrared spectroscopy (FTIR) and Raman spectroscopy

Methodology



Results and Discussion

Dynamic light scattering and zeta potential analysis were used to investigate the influence of incorporating *Melaleuca* essential oil on particle size distribution and colloidal stability. Table 1 presents the results for the blank formulations (BFC KCl, BSC KCl, and BMC KCl) and the compositions containing *Melaleuca* (MFC KCl, MSC KCl, and MMC KCl). The blank formulations exhibited hydrodynamic diameters ranging from 331.0 ± 90.4 to 489.7 ± 142.9 nm.

In contrast, the formulations containing *Melaleuca* oil showed larger particle sizes, ranging from 499.0 ± 44.9 to 696.8 ± 39.6 nm. The increase in hydrodynamic diameter following oil incorporation suggests the successful encapsulation of the essential oil within the polymer matrix, likely promoting the expansion and reorganization of the nanoparticle structure.

Table 1. Physicochemical characterization of the nanoparticles by dynamic light scattering (DLS) and zeta potential analysis. Results are expressed as mean ± standard deviation of triplicate measurements (n = 3).

Sample	Hydrodynamic Diameter (d.nm)	Polydispersity Index (PdI)	Zeta Potential (mV)
BFC KCl	331.0 ± 90.4	0.393 ± 0.02	−16.1 ± 5.5
MFC KCl	554.8 ± 46.2	0.475 ± 0.15	−41.8 ± 7.1
BSC KCl	351.4 ± 158.0	0.501 ± 0.03	−7.0 ± 4.4
MSC KCl	696.8 ± 39.6	0.590 ± 0.04	−43.0 ± 0.9
BMC KCl	489.7 ± 142.9	0.549 ± 0.06	−10.8 ± 10.4
MMC KCl	499.0 ± 44.9	0.633 ± 0.05	−41.6 ± 5.4

Conclusion

The results demonstrate the successful preparation of κ-carrageenan nanocapsules containing essential oil. κ-carrageenan is a sulfated polysaccharide extracted from red seaweed; it is highly significant in this context, particularly due to its ability to form stable three-dimensional networks via ionic gelation in the presence of cations such as K^+. This characteristic makes it widely applicable in systems for the encapsulation and controlled release of bioactive compounds (Liu et al., 2021; Ganesan et al., 2022).

K-carrageenan proved to be a highly viable and efficient polymeric matrix for the encapsulation and stabilization of *Melaleuca alternifolia* essential oil (OEM); the physicochemical performance of the system was strongly influenced by the mechanical processing method and by ionic cross-linking induced by K^+ ions.

References and Acknowledgments

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