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Structurally Stable Aerogel from Marine Biopolymers for Functional Delivery of Virgin Fish Oil

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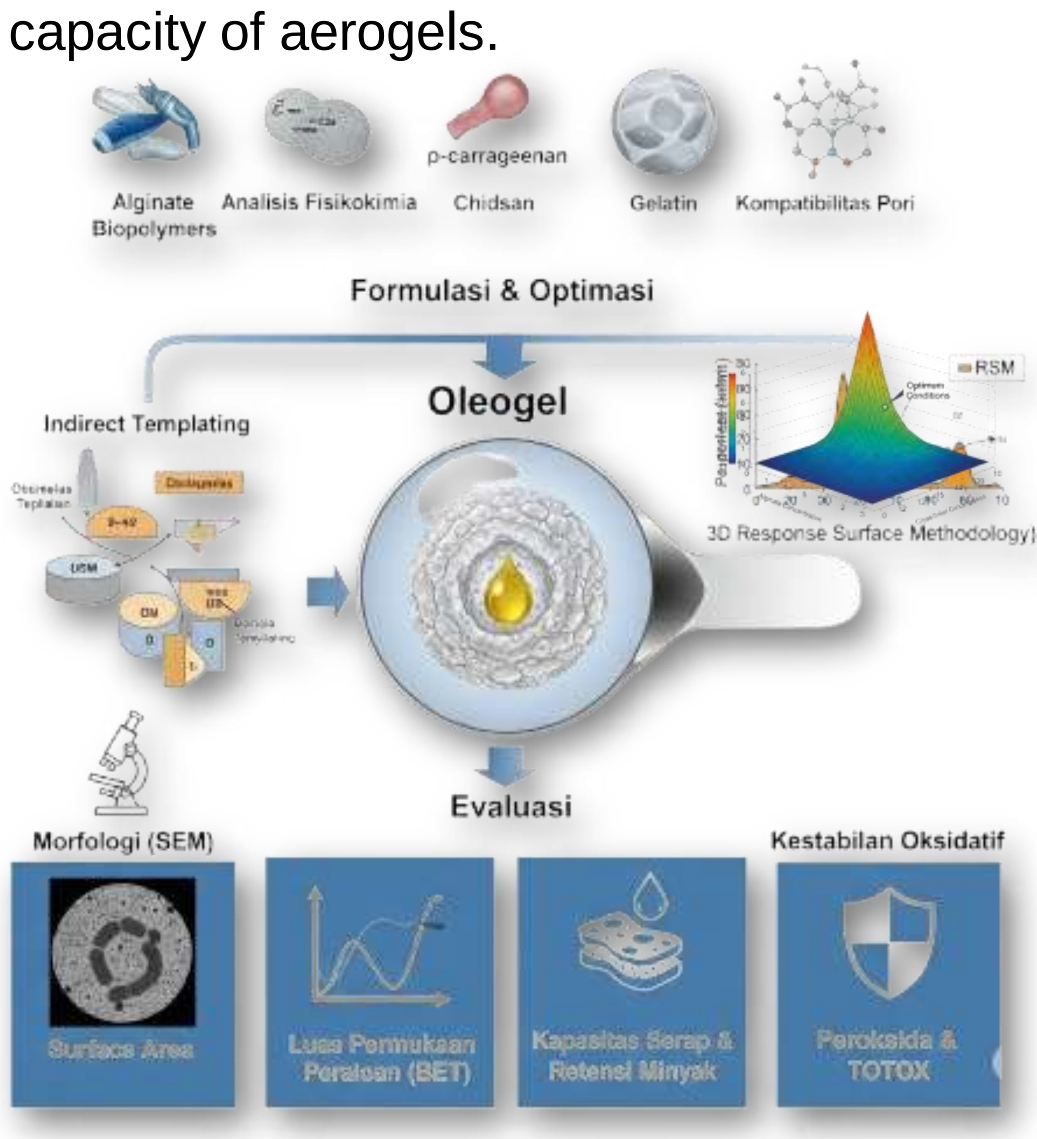
INTRODUCTION & AIM

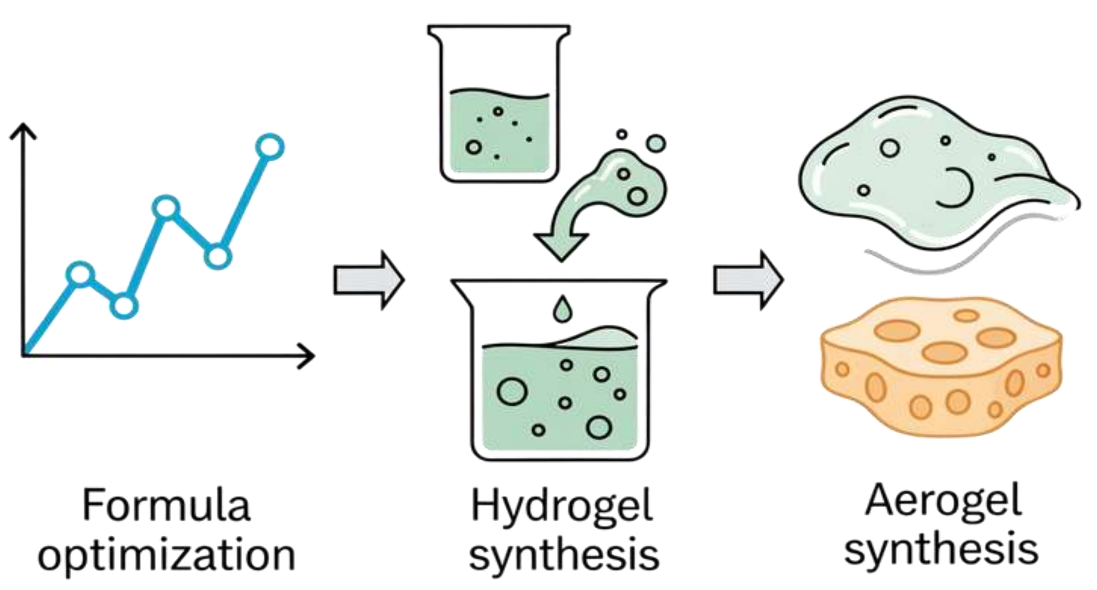
The growing demand for stable and natural omega-3 delivery systems has driven the development of innovative technologies such as **oleogelation** (Ramadhan *et al*. 2024). Virgin fish oil (VFO), rich in EPA and DHA, is highly susceptible to oxidation, requiring an effective protective matrix. **Marine biopolymer aerogels** offer a promising solution due to their highly porous structure capable of oil absorption and retention through capillary mechanisms. The combination of **κ-carrageenan, chitosan, and gelatin** enhances the structural strength and oil-holding capacity of aerogels.



This study applies the **Response Surface Methodology (RSM)** to optimize biopolymer composition for constructing aerogels with superior structural capacity as a stable and safe VFO delivery system.

METHOD

The study applied Response Surface Methodology (RSM) to optimize marine biopolymer-based hydrogels (κ-carrageenan, chitosan, and gelatin) (Thambiliyagodage *et al*. 2023). Hydrogels were gelled at 4°C for 24 h, then freeze-dried (-55°C, 0.2 mbar, 48 h) to obtain aerogels (Manzocco *et al*. 2017; Zhao *et al*. 2023; Li *et al*. 2023)



The aerogels were saturated with virgin fish oil and characterized for gel fraction, swelling ratio, morphology (SEM), surface area (BET), oil absorption and retention, rheology, and thermal stability (DSC).

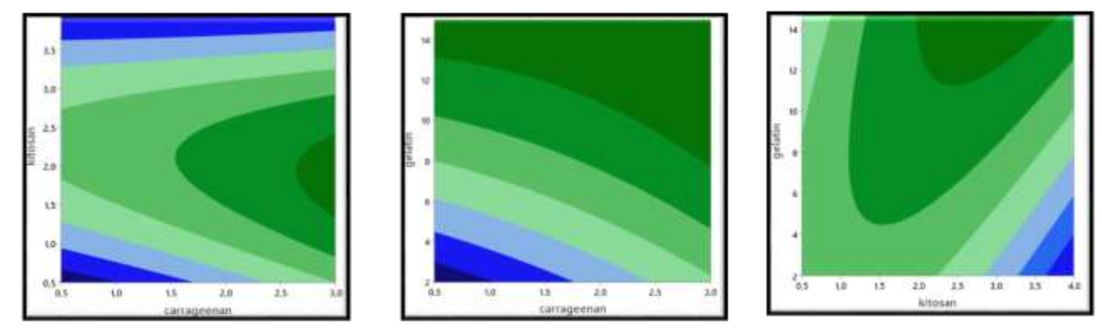
RESULTS & DISCUSSION

1. Hydrogel Optimization (RSM)

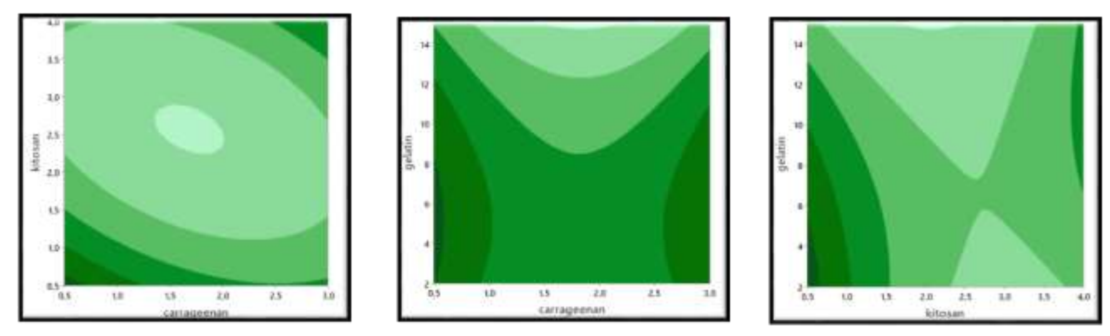
- Optimum formula: **0.9% κ-carrageenan, 0.5% chitosan, 2.02% gelatin**.
- Model validated with **Composite Desirability = 0.84**, confirming high predictive accuracy.

2. Hydrogel Characteristics

- **Gel fraction**: 43.44–86.23%, increased with gelatin and κ-carrageenan concentration.
- **Swelling ratio**: 0–23.21%, decreased due to over-crosslinking of chitosan and gelatin.



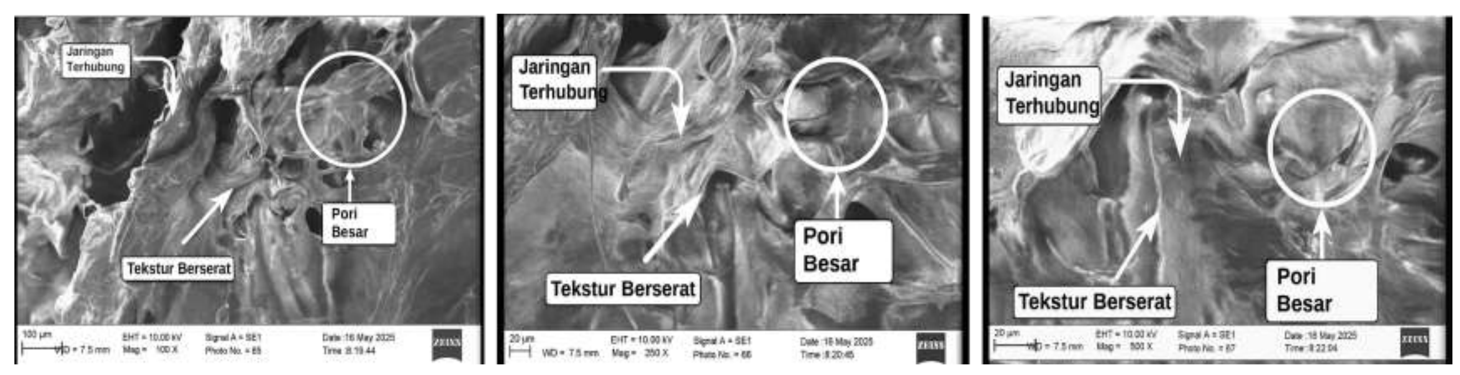
(a) κ-carrageenan vs kitosan (konsentrasi 2,0-2,5%) (b) κ-carrageenan vs gelatin (konsentrasi >2,0%) (c) Kitosan vs gelatin (2,0-3,0%) dan (5-10%)



(a) κ-carrageenan vs kitosan (2%) dan (2,5) (b) κ-carrageenan vs gelatin (konsentrasi (1,5-2,5%) (c) Kitosan vs gelatin (3-4%) dan (10-12%)

3. Aerogel Morphology and Structure

- Interconnected pores (10–30 µm), fibrous surface.
- **Surface area:** 21.87 m²/g; **Pore volume:** 0.023 cm³/g; **Mean pore size:** 4.12 nm (mesoporous).

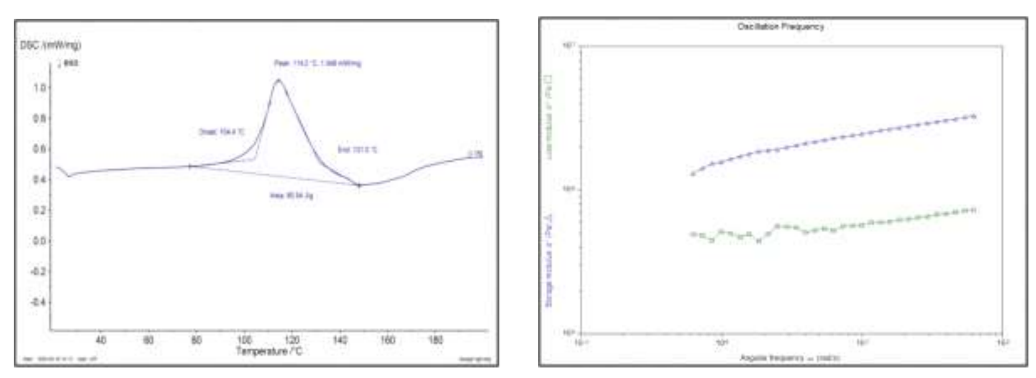


4. Oil Absorption and Retention Capacity

- Oil absorption: **17.2 g/g**, Oil retention: **50.55%**.
- Mesoporous (Type IV) structure enables strong capillary absorption and prevents oil leakage.

5. Thermal and Rheological Stability

- DSC: **Tpeak 114.2°C**, **ΔH 80.54 J/g** — high thermal resistance.
- **G' > G''** across all frequencies, confirming **elastic-dominant viscoelasticity** and stable gel network.



CONCLUSION

Marine biopolymer aerogel was successfully developed as a VFO carrier system **(0.9% κ-carrageenan, 0.5% chitosan, 2.02% gelatin).** It **shows mesoporous structure (21.87 m²/g), high oil uptake (17.2 g/g), 50.55% retention, and excellent thermal–elastic stability.**

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