

Original Article

Sea Moss (*Eucheuma cottonii*) Extract as a Natural X-ray Contrast Candidate: Experimental Evaluation of Image Quality, Physicochemical Behavior, and Sensory Acceptability

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Abstract

Synthetic radiographic contrast agents remain standard in diagnostic imaging but pose safety, cost, and acceptability concerns, which has renewed interest in bio-based alternatives. Seaweeds such as *Eucheuma cottonii* supply carrageenan and iodine and may offer a natural platform for contrast formulations. This experimental study evaluated three sea moss extract formulations and a commercial barium sulfate suspension as a reference. Prepared suspensions underwent in-vitro X-ray imaging under fixed exposure factors. Five radiologic technologists rated density, contrast, detail, and overall quality. Miscibility in water and alcohol and relative viscosity by gravitational flow were assessed. The most concentrated extract produced high image quality, whereas lower concentrations were rated low to moderate; barium sulfate achieved very high scores. The optimized extract showed complete miscibility in water, partial miscibility in alcohol, and the highest viscosity, consistent with a carrageenan-rich hydrocolloid. Results support *E. cottonii* extract as a promising candidate matrix for natural contrast development, subject to further optimization and safety testing.

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1. Introduction

Radiographic contrast agents increase X-ray attenuation within specific organs or lumina and are essential for many gastrointestinal and vascular examinations. Suspensions of barium sulfate remain the mainstay for fluoroscopic assessment of the esophagus, stomach, and bowel because they are highly radiopaque, chemically inert within the gut, and minimally absorbed (Najjar et al., 2024; Périard et al., 2003). Iodinated contrast media dominate intravascular and computed tomography applications, where their high atomic number and K-edge near diagnostic energies provide strong contrast enhancement (Andreucci et al., 2014; Wang et al., 2025).

Despite their value, conventional agents are not without risk. Iodinated media are associated with immediate hypersensitivity reactions, thyroid dysfunction, and contrast-associated acute kidney injury, especially in high-risk patients (Andreucci et al., 2014; Wang et al., 2025). Barium sulfate suspensions are generally safe when confined to the gastrointestinal lumen but can cause serious complications when leakage, obstruction, or aspiration occurs (Périard et al., 2003; Vega et al., 2024). These safety considerations, combined with cost and taste concerns, have prompted investigation of alternative contrast platforms, including nanoparticle-based agents and bio-derived matrices that seek to improve targeting, biocompatibility, and sustainability (Hsu et al., 2023; Wang et al., 2024).

Red seaweeds of the genera *Eucheuma* and *Kappaphycus* are central to the global carrageenan industry. *Eucheuma cottonii* is widely cultivated in Southeast Asia and is rich in κ -carrageenan, minerals, and iodine, which has made it attractive for food fortification and functional ingredients (Hurtado et al., 2017; Rasyid et al., 2017; Yulianto et al., 2023). Carrageenan forms hydrophilic gels and viscous solutions and has established use in pharmaceutical and biomedical formulations as a thickener, stabiliser, and matrix for drug delivery and tissue engineering (Li et al., 2014; Jabeen et al., 2025; Saleh et al., 2025). These characteristics suggest that *Eucheuma*-derived extracts could serve as a structural base for radiographic contrast preparations, combining inherent iodine content with a gel-forming polymer network that holds attenuating components in suspension.

There is growing interest in seaweed-based hydrogels and films for biomedical use, yet very few studies have examined their potential as X-ray contrast candidates (Wang et al., 2024; Chevenier et al., 2023). Most work on *Eucheuma cottonii* focuses on food products, packaging, or plant biostimulants rather than diagnostic imaging (Ha et al., 2022; Wang et al., 2024). To date, no published study has characterised *Eucheuma*-based preparations in comparison with barium sulfate for radiographic image formation in a controlled in-vitro setting.

This study addressed that gap by evaluating sea moss (*Eucheuma cottonii*) extract as a potential natural contrast candidate. The objectives were to compare the radiographic image quality of three extract formulations with a commercial barium sulfate suspension, to describe the sensory acceptability of the optimized extract, and to characterise its miscibility and viscosity relative to water and barium. The working

hypothesis proposed that a sufficiently concentrated *E. cottonii* extract would produce diagnostically acceptable radiographic images, though still inferior to those of commercial barium sulfate.

2. Methodology

2.1 Design

The study followed a quantitative experimental design using in-vitro X-ray imaging of prepared suspensions. Three *E. cottonii* extract formulations and a commercial barium sulfate suspension served as test and reference preparations respectively. Radiographic image quality was the primary outcome, while organoleptic acceptability and basic physicochemical behaviour were secondary outcomes.

2.2 Preparation of Sea Moss Extract and Reference Suspension

Commercially available dried *E. cottonii* was purchased from local markets in Iligan City. The seaweed was washed to remove debris, air-dried, and milled to powder. The powder was boiled in water and filtered to obtain a concentrated aqueous extract. This extract was blended with a base containing milk, honey, and flavouring in fixed proportions, and sea moss content varied to produce three formulations: T1 (10 percent sea moss extract by volume), T2 (20 percent), and T3 (30 percent).

Each formulation was placed in a 250-mL polyethylene terephthalate container. The reference suspension (TC) consisted of a commercially available barium sulfate powder prepared according to manufacturer instructions at 125 g powder in 125 mL water, placed in the same container type. All preparations were mixed until visually homogeneous.

2.3 Imaging Protocol and Image Quality Assessment

Each container was positioned on the image receptor of a fixed X-ray unit and imaged using 40 kVp, 2.5 mAs, and a source-to-image distance of 100 cm. Each sample received three exposures, and the clearest image for each was selected for evaluation.

Five licensed radiologic technologists with at least three years of experience independently rated each image. A five-point rating scale captured four domains: density, contrast, detail, and overall image quality, where 1 represented very low quality and 5 represented very high quality. Scores followed predetermined descriptive ranges for very low, low, moderate, high, and very high quality. Raters were blinded to formulation identity and viewed all images on the same display under controlled ambient lighting.

2.4 Organoleptic Evaluation

The optimized formulation T3 underwent organoleptic testing. Five student volunteers with no known allergy to seaweed, milk, or honey and with self-reported normal taste and smell participated. Each received a coded sample of T3 at room temperature and rated colour, aroma, taste, and texture on a five-point hedonic scale (1 = dislike very much, 5 = like very much). Plain water rinses were provided between tastings.

2.5 Miscibility and Viscosity

To characterise behaviour in mixed solvents, T3, water, and the barium suspension were tested with 70 percent alcohol. For each sample, 15 mL, 20 mL, and 25 mL of alcohol were added to a fixed volume of liquid and gently inverted. Visual inspection classified mixing as completely miscible, partially miscible, or practically immiscible.

Relative viscosity was estimated using a simple gravitational flow method. Identical pipettes were filled with water, barium suspension, or T3. After sealing the upper ends, the pipettes were opened simultaneously and the vertical distance travelled by the liquid column over a fixed time interval was measured in centimetres. Higher distance corresponded to lower viscosity.

2.6 Data Analysis

Descriptive statistics (means and qualitative descriptors) summarised image quality ratings, sensory scores, and physical test outcomes. One-way analysis of variance compared overall image quality across the three sea moss formulations and the barium reference. Where relevant, post hoc comparisons identified significant pairwise differences at $p < .05$.

2.7 Ethical Considerations

The institutional ethics review committee approved the protocol. Radiologic technologists and student evaluators received written information about the study and provided informed consent. The work involved only in-vitro imaging and tasting of food-grade materials and used no patient data.

3. Results

3.1 Radiographic Image Quality

Sea moss formulations showed concentration-dependent differences in radiographic performance. Table 1 presents mean ratings for density, contrast, detail, and overall quality. Radiographic images produced from the samples are shown in Figure 1.

Table 1. Radiographic image quality for sea moss formulations and barium sulfate.

| Sample | Density | Contrast | Detail | Overall | Description |
|--------|---------|----------|--------|---------|-------------|
| T1 | 2.60 | 2.60 | 2.33 | 2.51 | Low |
| T2 | 2.60 | 2.66 | 2.66 | 2.64 | Low |
| T3 | 3.53 | 3.46 | 3.46 | 3.48 | High |
| TC | 5.00 | 5.00 | 5.00 | 5.00 | Very high |

Legend: Very low 1.00–1.85; Low 1.86–2.65; Moderate 2.66–3.45; High 3.46–4.25; Very high 4.26–5.00.

T1 received low ratings across all domains. T2 showed marginal improvement, with moderate contrast and detail but an overall rating that remained low. T3 achieved high ratings for density, contrast, and detail, with an overall score in the high range. The barium reference achieved very high ratings for all variables.

Analysis of variance for overall quality indicated a significant difference among the four samples, $F(3, 16) = 92.4, p < .001$. Post hoc comparisons showed that TC scored significantly higher than all sea moss formulations and that T3 scored significantly higher than T1 and T2.

3.2 Organoleptic Characteristics of Optimized Extract

T3 demonstrated moderate sensory acceptability (Table 2). Mean scores for taste and texture (3.4) fell in the like slightly category. Aroma and colour scored 3.2, also within like slightly. No respondent rated any characteristic as dislike very much or like very much.

3.3 Miscibility Behaviour

Table 3 summarises miscibility findings for T3, water, and barium sulfate with 70 percent alcohol. Water blended uniformly with alcohol at all volumes. T3 showed partial miscibility with visually evident turbidity and incomplete homogenisation. Barium sulfate remained practically immiscible, forming a separate phase or sediment.

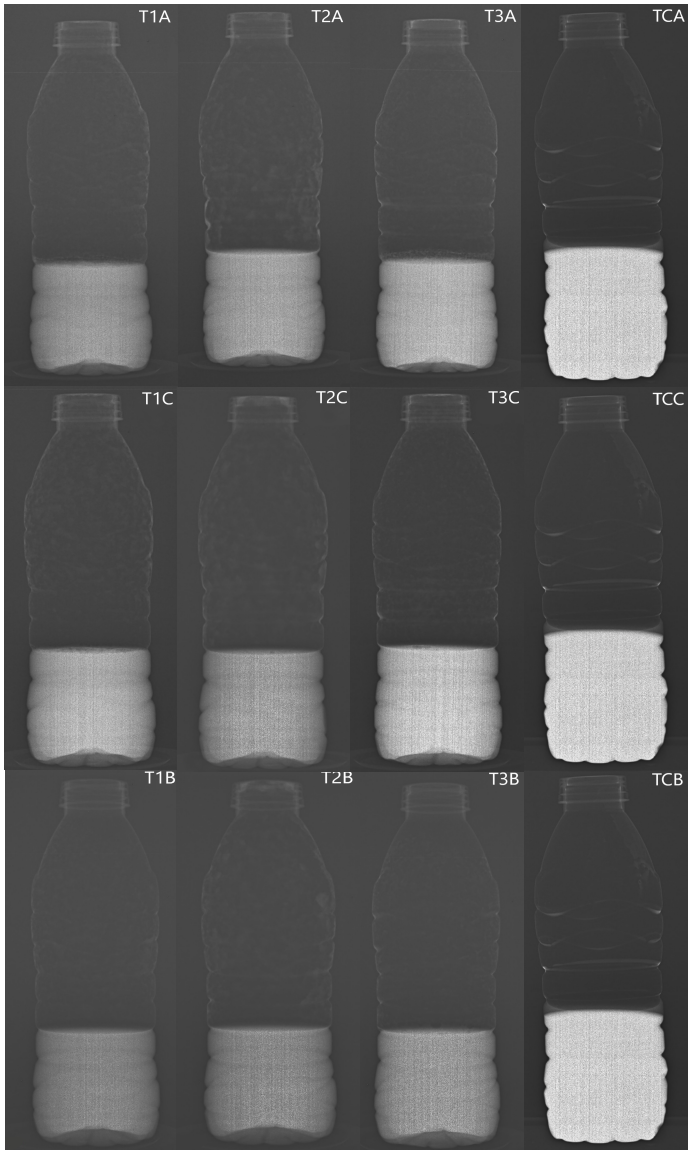


Figure 1. Radiographic images produced using experimental (T1, T2 and T3) and control (TC) samples.

3.4 Relative viscosity

The gravitational flow test revealed marked differences in apparent viscosity (Table 4). Higher descent corresponds to lower viscosity. Water descended fastest and had the lowest viscosity. The barium suspension descended more slowly, reflecting a dense particulate suspension. T3 descended slowest and exhibited the highest apparent viscosity, consistent with a carrageenan-rich hydrocolloid.

Table 2. Organoleptic ratings of optimized sea moss extract (T3).

| Respondent | Taste | Aroma | Color | Texture |
|------------|-------|-------|-------|---------|
| 1 | 3 | 3 | 3 | 3 |
| 2 | 3 | 4 | 4 | 3 |
| 3 | 4 | 3 | 3 | 3 |
| 4 | 3 | 3 | 3 | 4 |
| 5 | 4 | 3 | 3 | 4 |
| Overall | 3.4 | 3.2 | 3.2 | 3.4 |

Legend: Dislike very much 1.00–1.85; dislike moderately 1.86–2.65; like slightly 2.66–3.45; like moderately 3.46–4.25; like very much 4.26–5.00.

Table 3. Miscibility of optimized sea moss extract, water, and barium sulfate with 70 percent alcohol.

| Sample | A1 (15 mL alcohol) | A2 (20 mL alcohol) | A3 (25 mL alcohol) |
|----------------|------------------------|------------------------|------------------------|
| T3 | Partially miscible | Partially miscible | Partially miscible |
| Water | Completely miscible | Completely miscible | Completely miscible |
| Barium sulfate | Practically immiscible | Practically immiscible | Practically immiscible |

Table 4. Relative viscosity inferred from rate of descent in pipette flow.

| Sample | Trial 1 | Trial 2 | Trial 3 | Mean |
|------------------|---------|---------|---------|------|
| Water | 24.4 | 25.0 | 24.6 | 24.7 |
| Barium sulfate | 7.0 | 6.4 | 6.8 | 6.7 |
| Sea moss extract | 3.6 | 3.8 | 3.2 | 3.5 |

4. Discussion

This study provides initial experimental evidence that *E. cottonii* extract can produce diagnostically acceptable radiographic images in vitro when formulated at sufficient concentration, although image quality remains lower than that of commercial barium sulfate. The concentration-response pattern, where T3 outperformed T1 and T2, suggests that radiopacity and structural delineation depend

on the amount of sea moss extract, likely reflecting both iodine content and the density of the carrageenan network (Ha et al., 2022; Rasyid et al., 2017; Yulianto et al., 2023).

The superiority of barium sulfate in all image quality parameters aligns with its long-established role as the reference standard for gastrointestinal fluoroscopy. High atomic number, inert behaviour within the lumen, and excellent mucosal coating have made barium suspensions difficult to surpass (Najjar et al., 2024; Périard et al., 2003). The present results confirm that *Eucheuma*-based preparations do not replace barium sulfate in current practice. Instead, they point to a potential complementary role, especially in contexts where natural, locally sourced, or lower-cost options are desirable and where moderate image quality may suffice, such as preliminary screening or low-resource settings.

The high viscosity of the optimized extract is both an opportunity and a challenge. Carrageenan forms strong gels and viscous solutions that can stabilise dispersed phases and prolong residence time on mucosal surfaces (Li et al., 2014; Wang et al., 2024; Jabeen et al., 2025). In imaging, such properties could improve coating and reduce separation of attenuating components, which may support stable contrast over the duration of an examination (Jabeen et al., 2025; Saleh et al., 2025). At the same time, excessively viscous preparations may increase risk of aspiration in vulnerable patients or complicate administration through narrow catheters, echoing concerns about thick barium formulas in dysphagic populations (Vega et al., 2024). The intermediate sensory scores in this study indicate that T3 is palatable enough for ingestion but still relatively thick, suggesting that fine-tuning gel strength and flavour could enhance acceptance.

The miscibility profile highlights the hydrophilic character of the extract. Partial miscibility with 70 percent alcohol and complete miscibility with water are consistent with the behaviour of sulfated polysaccharides, which form hydrophilic colloids but show limited solubility in hydro-alcoholic systems (Chevenier et al., 2023; Wang et al., 2024). This supports the use of *Eucheuma*-based preparations as water-borne oral contrast media and suggests that formulations relying on alcohol will require further adaptation. The immiscibility of barium sulfate in alcohol reflects its particulate nature and confirms that the flow test captured meaningful physicochemical differences.

Within the broader contrast-agent landscape, this seaweed-based approach sits alongside nanomaterial and hybrid systems that seek to improve safety and multifunctionality. Nanoparticle-based contrast agents can deliver high payloads of attenuating elements, enable targeting, and support multimodal imaging, but they also raise concerns about long-term biodistribution and environmental fate (Hsu et al., 2023). Seaweed-derived hydrogels and nanocomposites have attracted attention as sustainable carriers for therapeutic and imaging applications because they combine biocompatibility with tunable mechanical and release properties (De Jesus Raposo et al., 2015; Wang et al., 2024; Saleh et al., 2025). *E. cottonii* extract could act as a base matrix into which additional radiopaque components, including iodinated molecules

or nano-contrast particles, are incorporated, blending natural and engineered strategies.

Safety remains a central consideration before any *in vivo* use. Food-grade carrageenan and processed *Eucheuma* seaweed are authorised as food additives with defined acceptable daily intakes, and recent evaluations have reaffirmed their safety at typical dietary exposures when high-molecular-weight fractions are used (Azevedo et al., 2023). However, imaging contrast doses, routes, and patient populations differ from routine dietary intake. There is ongoing debate about inflammatory responses to degraded carrageenan in some experimental settings, which underscores the need for rigorous characterisation of molecular weight distribution and toxicity for any contrast application (EFSA Panel on Food Additives and Nutrient Sources Added to Food, 2018; Azevedo et al., 2023). Against this background, replacing barium sulfate, which is virtually inert, would require strong evidence that *Eucheuma*-based agents are at least as safe under clinical conditions.

Several limitations should be acknowledged. The study used a relatively small sample of radiologic technologists and sensory evaluators from a single city, which may limit generalisability. The *in-vitro* imaging set-up does not capture dynamic features of gastrointestinal transit, mixing with secretions, or peristalsis. The gravitational flow method provides only a crude estimate of viscosity and does not replace full rheological profiling. The study did not directly quantify iodine content, so inferences about radiopacity mechanisms remain indirect.

Future research should therefore include robust chemical characterisation of *Eucheuma* extracts, including iodine concentration, molecular weight distribution, and rheological properties under physiological conditions. Animal studies could evaluate mucosal coating, transit behaviour, and safety. Formulation optimisation might explore blending *Eucheuma* extract with other natural ingredients or small amounts of conventional agents to balance radiopacity, viscosity, and palatability. Comparative studies against other candidate natural contrast agents, such as milk or plant-based hydrogels, would clarify where *Eucheuma*-based preparations fit within an emerging portfolio of bio-derived imaging tools.

5. Conclusion

Eucheuma cottonii extract formulated as a concentrated suspension produced high-quality radiographic images *in vitro*, with clear improvement over lower concentrations, while remaining inferior to commercial barium sulfate. The optimized formulation showed complete miscibility in water, partial miscibility in alcohol, high apparent viscosity, and moderate sensory acceptability, consistent with a carrageenan-rich hydrocolloid. These results suggest that sea moss extract can serve as a promising natural matrix for future contrast-agent development.

Further work should refine viscosity and taste, quantify iodine content with advanced analytical methods, and conduct comprehensive toxicological and *in vivo* imaging studies. If safety and diagnostic performance are confirmed, *Eucheuma*-based

contrast agents could offer locally sourced, sustainable options that complement existing synthetic formulations, particularly in low-resource settings.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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