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Development and Characterization of Fermented Seaweed-Based Meat Analogs Using Two Different Seaweed Types

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INTRODUCTION & AIM

The rising global demand for sustainable and health-focused diets has accelerated interest in developing meat alternatives from novel plant-based sources. Seaweeds, particularly *Kappaphycus alvarezii* and *Gracilaria sp*., are abundant marine resources rich in fibre, bioactive compounds, and functional nutrients, making them promising candidates for alternative protein development.

Fermentation offers a natural approach to improve the flavour, texture, and nutritional quality of seaweed-based ingredients while reducing undesirable marine odours. In this study, fermented *Kappaphycus alvarezii* and *Gracilaria sp*. were incorporated as protein substitutes in meatball analogs, with the aim of developing a functional, sustainable, and protein-rich meat alternative.

This study aims to evaluate the effects of fermentation on the physicochemical, textural, microbiological, and sensory properties of seaweed-based meat analogues, with the goal of developing clean-label, minimally processed foods aligned with sustainable nutrition trends.

METHOD

Figure 1. Overview of the fermented seaweed composite production process.

Table 1. Formulation of meatball analogs from fermented seaweed

Ingredients	Meatball analogue *Kappaphycus*	Meatball analogue *Gracilaria*
Fermented *Kappa* (block)	35.97	-
Fermented *Gracilaria* (block)	-	35.97
Wheat gluten	14.39	14.39
Tapioca starch	9.59	9.59
Fermented *Kappa* powder	4.80	-
Fermented *Gracilaria* powder	-	4.80
Fresh roselle calyx	6.00	6.00
Bread crumbs	9.59	9.59
Water	2.40	2.40
Bbq sauce	3.60	3.60
Salt	0.96	0.96
Oil	3.60	3.60
Red onion	2.40	2.40
Garlic	1.44	1.44
Sugar	1.20	1.20
Seasoning powder	0.96	0.96
Mix herbs	0.48	0.48
Black pepper	1.68	1.68
Paprika	0.96	0.96

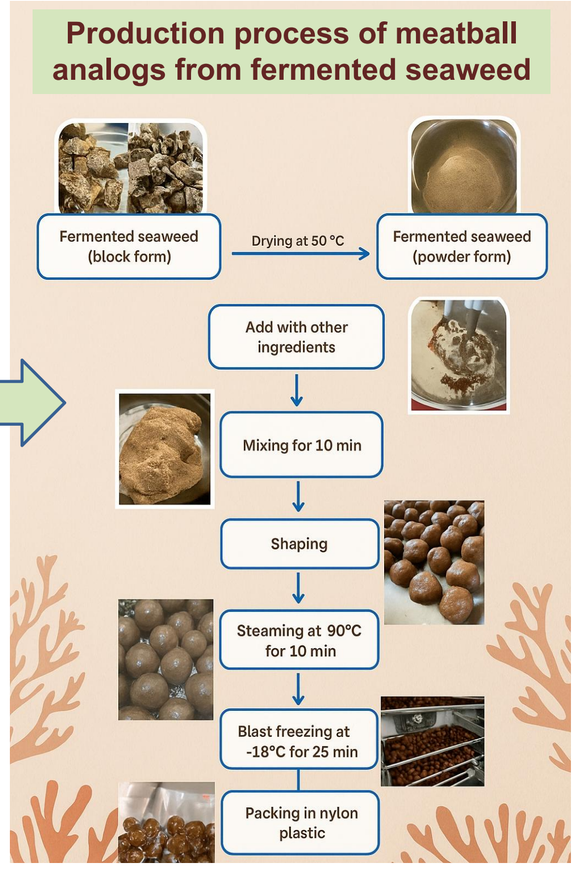

Figure 2. Processing flow of meatball analogs from fermented seaweed

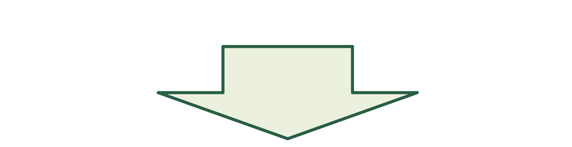

Figure 3. Meatball analogs from Kappaphycus (left), and Gracilaria (right) fermented seaweed

chemical composition
texture profile
microbiological analysis
sensory evaluation

RESULTS & DISCUSSION

Table 2. Proximate composition of meatball analogues using different types of fermented seaweed

Parameters	*Kappaphycus* Meatball analog	*Gracilaria* Meatball analog
Moisture (%)	49.10 ± 0.71[a]	48.25 ± 0.21[a]
Protein (%)	17.95 ± 0.07[a]	17.15 ± 0.49[a]
Fat (%)	3.25 ± 0.07[a]	3.25 ± 0.21[a]
Ash (%)	3.40 ± 0.14[b]	2.60 ± 0.00[a]
Carbohydrate (%)	22.15 ± 0.49[b]	24.65 ± 0.35[a]
Energy (%)	198.00 ± 2.83[a]	203.00 ± 2.12[a]
Total dietary fibre (%)	4.15 ± 0.07[a]	4.10 ± 0.14[a]
pH	5.05 ± 0.01[a]	4.93 ± 0.01[b]
Water activity (a_w)	0.95 ± 0.00[a]	0.95 ± 0.00[a]
Cooking yield (%)	94.68 ± 0.10[a]	97.18 ± 1.82[a]

Values are mean ± SD (% wet basis). Different lowercase letters indicate significant differences ($p \leq 0.05$).

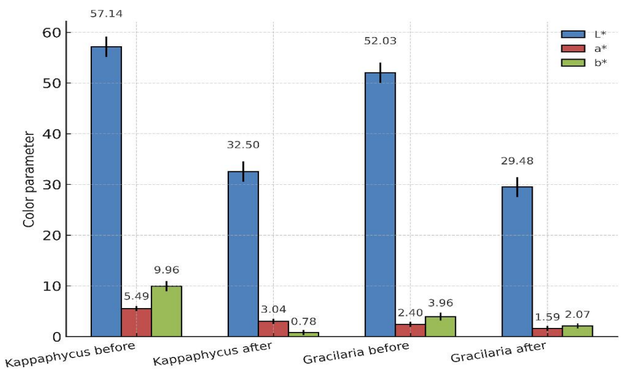

Figure 3. Colour parameter of meatball analogs from (i) Kappaphycus, and (ii) Gracilaria fermented seaweed

Table 3. Antioxidant content of meatball analogs from different types of fermented seaweed

Parameters	*Kappaphycus* Meatball analog	*Gracilaria* Meatball analog
TPC (mg GAE/g)	1.86 ± 0.03[a]	1.49 ± 0.01[b]
FRAP (mg FE/g)	2.19 ± 0.02[b]	2.49 ± 0.02[a]
TEAC (mg TE/g)	1.29 ± 0.02[a]	1.18 ± 0.02[b]
TFC (mg QE/g)	0.36 ± 0.01[b]	0.39 ± 0.01[a]
DPPH (% inhibition)	47.71 ± 0.51[a]	44.04 ± 2.72[a]

Data are expressed as mean ± standard deviation. Means in the same column with different superscripts were significantly different ($p<0.05$)

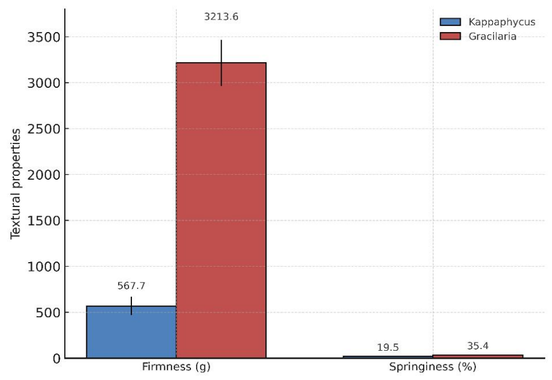

Figure 4. Textural properties of meatball analogs from (i) Kappaphycus, and (ii) Gracilaria fermented seaweed

Table 4. Microbiological parameters of meatball analogs using fermented *Kappaphycus* and *Gracilaria* seaweed as a protein substitute

Sample	Microbiological analysis (CFU/g)				
	Total Plate Count	Total yeast & mould count	Total coliform	*E. coli*	*S. aureus*
Meatball analog *Kappaphycus*	4.0 x 10^2	ND	ND	ND	ND
Meatball analog *Gracilaria*	4.0 x 10^2	ND	ND	ND	ND

Values are given as mean ± standard deviation
ND = Not Detected (below detection limit of 10 CFU/g)

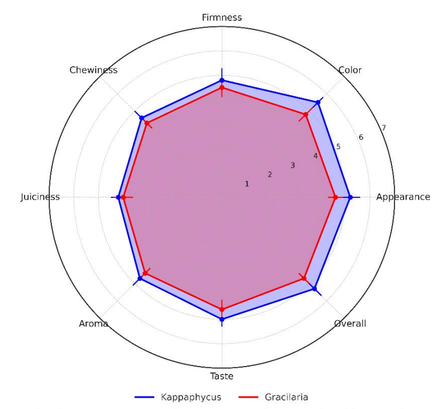

Figure 5. Sensory evaluation of meatball analogs from Kappaphycus and Gracilaria fermented seaweed

The fermented seaweed meatball is vacuum-packed in a Nylon/PE plastic (as primary packaging) and semi-rigid black polypropylene (PP) tray, sealed for freshness and durability (as secondary packaging). A printed paperboard sleeve provides product information and branding, offering an eco-friendly and attractive presentation suitable for chilled or frozen plant-based foods.

KEY ADVANTAGES OF SEAWEED-BASED MEATBALL ANALOGS

- **Plant-Based** — Suitable for vegans and vegetarians
- **High in Protein & Fibre** — Enhanced through fermentation
- **Environmentally Friendly** — Seaweed cultivation requires no fertilizer or soil
- **Nutrient-Rich** — A good source of iodine, calcium, vitamins, and antioxidants
- **Natural Umami Flavor** — Delicious taste without MSG
- **Probiotic Potential** — Supports gut health

CONCLUSION

- Fermented *Kappaphycus* and *Gracilaria* seaweeds produced nutritious, shelf-stable meatball analogs lasting up to 12 months.
- Both showed low cooking loss, indicating good moisture and nutrient retention.
- The *Kappaphycus* variant received higher sensory acceptance due to its lighter, meat-like colour.
- Visual similarity plays a key role in consumer preference for plant-based alternatives.

FUTURE WORK / REFERENCES

Future research should aim to optimise amino acid composition and enhance colour and texture without compromising nutritional quality.