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Edible Ideas/Recipes

Reformulation of Portuguese seafood rice: a plant-based approach using synergy between gelling polysaccharides and seaweeds

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Abstract

This reformulation of Portuguese seafood rice (*arroz de marisco*), through a plant-based formulation, integrates gelling polysaccharides / seaweeds synergies to reproduce the sensory properties of the traditional dish. This work aimed to develop vegan analogues of shrimp and fish, using combinations of xanthan and gellan gums, agar-agar and iota carrageenans to mimic seafood consistency. Infusions of kombu, sea lettuce and nori seaweeds provide an umami taste and marine flavour, enhancing the key sensory characteristics of the dish. Textural, visual, and odorant attributes were improved to mimic the organoleptic characteristics of the traditional dish, while ensuring a nutritious composition adapted to allergen-related conditions. The results demonstrated that the gelling polysaccharides effectively replicate the jelly-like and elastic texture of marine proteins. This

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approach represents a sustainable gastronomic innovation, aligning culinary tradition with contemporary demands for environmental responsibility and inclusivity.

Keywords
Recipe, seafood rice, gelling polysaccharides, seaweeds, plant-based, allergen-free

1. Introduction

The rising consumer demand for plant-based foods is driven by multiple factors, including health considerations, environmental sustainability, and the inclusion of vegan and allergen-sensitive consumers (Villiers *et al*., 2024). In particular, the seafood sector faces increasing scrutiny due to overfishing, habitat degradation, and biodiversity loss, exacerbated by climate change and ineffective resource management (Pham *et al*., 2023).

In this context, the development of suitable plant-based alternatives to seafood products can contribute to alleviating some of the pressures on aquatic ecosystems (Abotsi *et al*., 2024). Plant-based seafood analogues represent a promising approach to satisfy traditional gastronomic expectations, while reducing dependence on fish resources. However, reformulating seafood dishes into plant-based versions or commercial products presents specific technological and sensory challenges (consistency and flavour qualities).

Most seafood muscles exhibit a fibrous-gel structure, high water content, and a distinctive umami-rich taste profile derived from non-volatile compounds such as free glutamic acid salts and 5′-nucleotides (Chang *et al*., 2022; Abotsi *et al*., 2023).

Replicating these properties requires specialized structuring and flavouring strategies involving functional ingredients such as gelling polysaccharides as texturizing agents and seaweeds to mimic the sea related flavours. Seaweed species are currently being used to mimic the distinct flavours of various fish and shellfish species, owing to their inherent oceanic flavour (Kazir and Livney, 2021). Gelling and thickening agents such potato starch, methylcellulose, gum arabic, xanthan gum and maltodextrin have demonstrated significant potential for improving textural attributes in plant-based seafood analogues available in the marketplace (Future Farm Co., 2022; Current Foods, 2023; Good Catch, 2023).

Portugal is the European country with the highest per capita consumption of rice (Castanho *et al*., 2023). Rice cultivation was introduced to Portugal during the Muslim period, starting in the 8th century, with the Asian species known as *Oryza sativa* L. (Câmara, 2024). Data from The EU Fish Market report indicate that Portugal is also the country with the highest fish consumption in the European Union (European Commission, 2024). In this context, adapting a culturally significant dish such as Portuguese *arroz de marisco*, dating back to 1715 (Cândido, 2020), offers potential for both technological and gastronomic innovation. This traditional dish, which typically contains various seafood and rice cooked in an intense marine flavoured broth, embodies a strong regional identity of the Portuguese coastline.

Reformulating the dish as a fully plant-based version may help reduce exposure to common seafood allergens, while helps preserve culinary heritage and making it more accessible for vegan consumers and those with seafood allergies. Although seaweed allergy appears to be uncommon, allergic reactions to edible seaweeds (e.g., fresh nori (*Pyropia* sp.)) and seaweed-derived compounds such as carrageenan have been reported (Thomas *et al*., 2019; James *et al*., 2023). Therefore, a plant-based reformulation using seaweed may reduce exposure to common fish and shellfish allergens, it cannot be regarded as allergen-free.

Thus, the objectives of this study are: (1) to design and improve a gelling polysaccharides and seaweed system that replicates the

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Figure 1. Plant-based version of the traditional Portuguese seafood rice.

consistency, and chewing profile of the seafood components in *arroz de marisco* (Figure 1); (2) to integrate seaweed-derived flavour systems to mimic the marine aroma and visual cues; and (3) to demonstrate the potential of this approach in the development of a gastronomic innovation, based on a traditional dish, that is sustainable and inclusive.

2. Materials and methods

Equipment required for making the plant-based sea flavoured rice used: pot, blender, silicone spatula, round cutter, kitchen shears, water container, and shallow rectangular mould.

2.1. Component no. 1: Seaweed stock

The seaweed stock is a crucial component for adding a marine flavour to the dish.

Ingredients:
- 2 L water
- 20 g dried kombu seaweed (*Saccharina japonica*)
- 5-8 g dried “sea lettuce” (*Ulva* sp.)
- 100 g diced onion
- 100 g sliced leek
- 100 g sliced celery stalks

Preparation method:
1. Combine all ingredients in a pot and bring to a boil.

ISSN 2431-0859

2. Once boiling, reduce to low heat, put the lid on and simmer for 25 minutes.
3. Strain and reserve 1.6 L of stock.

2.2. Component no. 2: Plant-based shrimp analogue

This formulation creates a plant-based shrimp analogue, using seaweed for marine flavour and gelling polysaccharides for the gel structure. Tofu and miso contribute with vegetable proteins, as well as monosodium glutamate responsible for the umami taste, while calcium chloride enhances firmness.

Ingredients:
- 600 mL water (divided into 300 mL for the infusion + 300 mL for the gelling agents)
- 10 g dried kombu seaweed (*Saccharina japonica*)
- 5 g dried "sea lettuce" (*Ulva* sp.)
- 1.5 g xanthan gum, Sosa
- 6 g gellan gum LA (low acyl), Sosa
- 6 g agar-agar, Sosa
- 50 g cooked yam (in boiling water for 20 minutes)
- 70 g pressed extra firm tofu
- 20 g cassava starch
- 3 g salt
-10 g dark miso
- 1.2 g calcium chloride, Sosa
- 4 g iota carrageenan, Sosa
- 5 g smoked paprika

Preparation method:
1. Prepare the seaweed infusion: bring 300 mL of water with the kombu and sea lettuce to a boil. Once boiling, reduce to low heat, put the lid on and simmer for 20 minutes. Turn off the heat and let infuse for another 20 minutes.
2. Disperse xanthan gum, gellan gum and agar-agar in 300 mL water, and boil until fully hydrated (ca. 2-3 minutes).
3. Blend the yam until smooth. Add tofu, cassava starch, salt, miso, calcium chloride, the seaweed infusion (step 1), and the hydrated gelling agents (step 2). Blend until homogeneous.
4. Add iota carrageenan and blend for 5 more seconds.
5. Transfer the mixture to a saucepan over medium heat, stirring constantly. Once boiling, cook for about 5 minutes.
6. On a parchment-lined tray, sprinkle smoked paprika. Pour the mixture in a shallow rectangular mould (~ 20×30 cm) to a height of 1 cm, then sprinkle more paprika on top.
7. Refrigerate for ~ 20 minutes. Once set, cut with a round mould (max. 10 cm diameter), then cut in half. Use scissors to make ~ 3 small cuts along the edge to simulate shrimp shape.

2.3. Component no. 3: Plant-based fish analogue

This plant-based fish analogue was also created by using vegetable proteins, gelling polysaccharides and a seaweed infusion.

Ingredients:
- 420 mL water (divided into 210 mL for the infusion + 210 mL for the gelling agents)
- 7 g dried kombu seaweed (*Saccharina japonica*)
- 3.5 g dried "sea lettuce" (*Ulva* sp.)
- 2 g xanthan gum, Sosa
- 6 g gellan gum, Sosa
- 6 g agar-agar, Sosa
- 140 g pressed extra firm tofu
- 4 g salt
- 5 g miso
- 3 g calcium chloride, Sosa
- 4 g iota carrageenan, Sosa
- 5 g nori seaweed (*Pyropia* sp.)

Preparation method:
1. Prepare the seaweed infusion with 210 mL water, kombu and nori, as in the shrimp analogue recipe. Strain and set aside.
2. In a separate saucepan, disperse the xanthan gum, gellan gum and agar-agar in 210 mL water, and boil until hydrated.
3. Blend the tofu, salt, miso and calcium chloride

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with the seaweed infusion and the hydrated gelling agents from steps 1 and 2, until smooth.
4. On a parchment-lined tray, place a sheet of nori seaweed. Pour the mixture into a shallow rectangular mould (~ 20×30 cm) to a height of ~ 1.5 cm.
5. Refrigerate for approximately 20 minutes. Once set, cut into 2 x 4 cm pieces.

2.4. Component no. 4: Rice

Carolino rice (ssp. *japonica*), the most widely produced rice in Portugal and the one commonly used in traditional Portuguese cuisine (Marques *et al.*, 2022; INE, 2024), is used to prepare this dish. A seaweed stock allows to mimic the marine sensory attributes and the vegetable ingredients, typically used in this dish, are also added.

Ingredients:
- 90 mL olive oil (30 mL for sautéing + 60 mL for finishing)
- 10 g minced garlic
- 100 g diced red bell pepper
- 50 g chopped onion
- 400 g Carolino rice (ssp. *japonica*)
- 150 mL dry white wine
- 1.6 L seaweed stock
- 5 g chopped parsley
- 5 g chopped coriander
- grated zest of 1 lemon

Preparation method:
1. In a pot, heat 30 mL olive oil and sauté the garlic, red pepper, and onion.
2. Add the rice and stir for about 2 minutes.
3. Pour in the white wine and stir until fully evaporated.
4. Add the seaweed stock and stir regularly for about 25 minutes, until rice is cooked but still has some liquid (this is a soupy rice). Serve hot as soon as possible.

2.5. Plating instructions

The dish is assembled with a base of rice, topped with the plant-based shrimp and fish analogues, and finished with chopped parsley and coriander, a drizzle of olive oil and lemon zest before serving.

2.6. Focus Group

After obtaining the dish version whose production method was described above, a focus group was conducted, as proposed by Krueger and Casey (2015), with 6 untrained panellists, who tasted the dish, discussed it, and evaluated its attributes (appearance, odour, flavour, texture and overall assessment) using a 9-point hedonic scale, ranging from 1 (“disliked extremely”) to 9 (“liked extremely”).

3. Results and Discussion

Three distinct elements, i.e., seaweed broth, plant-based shrimp and fish analogues, allowed to obtain a dish that mimics the Portuguese traditional seafood rice in flavour and appearance, while remaining entirely plant-based. The combination of gelling polysaccharides texturizing systems with seaweed extracts constitutes a scientifically grounded strategy to replicate the textural and sensory attributes of the original dish (Mouritsen *et al.*, 2012; Roohinejad *et al.*, 2017; Liao *et al.*, 2021).
For the plant-based shrimp and fish analogues, yam and tofu formed the structural base, with cassava starch contributing to the desired texture of the shrimp analogue and viscoelasticity. Gelling polysacharides (xanthan gum, gellan gum, agar-agar, and iota carrageenan) provided gelation (Phillips and Williams, 2009), and a texture similar to that of cooked shrimp and fish. The infusion of seaweed, miso, and salt contributed with umami taste and marine flavour, while calcium chloride aided in the polysaccharides’s gelation. The use of smoked paprika added colour and visual realism to the shrimp analogue (Conroy, 2017).

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For the fish analogue portions, nori seaweed was used to simulate the fish skin, but it also introduced an extra flavour component.
The rice component of the dish, was prepared using a seaweed-infused stock, demonstrating that a combination of water, kombu, dried sea lettuce, onion, leek, and celery creates a flavourful base having a strong umami taste. The seaweed contributed with marine and minerals notes and monosodium glutamate, while the vegetables provided complex aromatic compounds.
Vegetables were sautéed in olive oil, followed by the addition of rice which was lightly toasted, to allow caramelization and amino-carbonyl reactions to enhance the flavour. White wine was incorporated for acidity and aroma. Cooking time was controlled to achieve the desired rice texture, without excessive starch gelatinization, while also ensuring a good flavour absorption. The preparation was finished with fresh herbs, olive oil, and lemon zest, which contributed with colour, additional aroma compounds, and freshness that enriched the sensory characteristics of the dish.
Regarding the results of the sensory analysis conducted by the focus group, all attributes analysed obtained averages above 8 (Figure 2), which indicates a positive sensory acceptance among the participants.

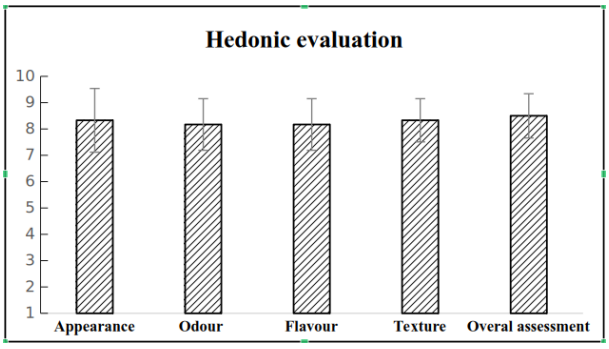

Figure 2. Results of the hedonic evaluation of the dish.

4. Conclusion

The results obtained in this project demonstrated the feasibility and potential of the approach followed. Plant-based seafood alternatives, such as shrimp and fish analogues, represent a promising approach to more sustainable, safe, and inclusive food systems. while preserving traditional gastronomy. Gelling polysaccharides were essential to reproduce the characteristic texture of seafood, while seaweed infusions provided marine and umami flavour. Visual cues were achieved using ingredients such as smoked paprika and nori. The resulting plant-based dish reinterprets the traditional *arroz de marisco*, mimicking its key sensory attributes (flavour, appearance, and texture). Positive hedonic evaluation further supports the potential of this approach to adapt traditional dishes to contemporary dietary demands while maintaining cultural identity.

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