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Research Article

Optimization of seafood crackers formulation as influenced by *Eucheuma cottonii* and *Caulerpa lentillifera* seaweed levels

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Abstract
Developing nutrient-enriched snack options, such as seafood crackers, and utilizing local resources are essential for promoting sustainable food innovations while meeting the growing consumer demand for healthier alternatives.This study seeks to optimize the formulation of seafood crackers, locally known as *korpek*, by evaluating the functional and sensory effects of incorporating different levels of *Eucheuma cottonii* and *Caulerpa lentillifera*, addressing the limited use of these underutilized seaweeds in value-added snack products. Nine treatments (T_1 to T_9) were formulated with different combinations of *Eucheuma cottonii* and *Caulerpa lentillifera* seaweeds, ranging from 1.5% to 6% (w/w). The treatments consisted of the following combinations: T_1 (1.5% E. cottonii, 1.5% C. lentillifera), T_2 (1.5%, 3%), T_3 (1.5%, 6%), T_4 (3%, 1.5%), T_5 (3%, 3%), T_6 (3%, 6%), T_7 (6%, 1.5%), T_8 (6%, 3%), and T_9 (6%, 6%). The mean sensory acceptability score was 7, which corresponds to "like moderately" on a 9-point hedonic scale. Using Response Surface Methodology (RSM), the values for the physicochemical properties of crackers used to determine the best formulation were >41% for linear expansion, <19% for oil absorption, and <0.54 for water activity. The best formulations having acceptable sensory and physicochemical responses were 5.6% *E.cottonii* and 1.6% *C.Lentillifera,* which resulted in standard levels of phosphorus (P), sodium (Na), and potassium (K). This study optimized the levels of two local seaweeds in the Philippines, namely *E. cottonii* and *C. lentillifera*, in producing seafood crackers, which can encourage the use of locally sourced seaweeds and contribute to agriculture and fisheries development.

Keywords: *Caulerpa lentillifera*, *Eucheuma cottonii,* Response Surface Methodology, Seafood, Seaweeds, Snack food

INTRODUCTION

In recent years, there has been a growing interest in the ability of food to influence physiological systems (immune, endocrine, neurological, circulatory, and digestive) beyond the established nutritional impacts. It is considered a functional food if it has a beneficial effect on one or more target functions in the body and provides enough dietary benefits in a way that is relevant to either improved health and well-being or reduced disease risk (Alongi and Anese, 2021; Granato *et al*., 2020). Consumers have shifted toward convenience and products that provide health benefits in addition to the basic organoleptic profile (Huppe *et al*., 2021; Imtiyaz *et al*., 2021). Promoting healthy behaviors to enhance immunity with functional food and nutritional agents may be a rational strategy for minimizing damages caused by viruses to global health (Thirumdas *et al*., 2021). Among the functional ingredients added to food are seaweeds. Given the diversity of bioactive components found in seaweeds, there is an increasing trend in the utilization of seaweed in functional food product development (Choudhary *et al*., 2021). Among the health benefits of seaweeds are weight control, as a digestive aid, anti-inflammatory, anticancer, and cholesterol and triglyceride-lowering effects, which may help prevent certain non-communicable diseases (NCD) (Lomartire *et al*., 2021). Risk factors such as poor nutrition and a sedentary lifestyle play a significant role in developing NCDs, which are on the rise around the globe, particularly in developing nations such as the Philippines (Kang and Lim, 2021).

As an archipelagic country, the Philippines boasts vast marine resources supporting high marine biodiversity, including the abundant growth of various seaweed species (Trono and Largo, 2019). *Eucheuma cottonii* and *Caulerpa lentillifera* are widely cultivated for their diverse industrial and nutritional applications. These seaweeds are particularly abundant in bioactive compounds, including phytochemicals (Syakilla *et al*., 2022; Purbosari *et al*., 2022), which have the potential to be incorporated into daily consumable products, such as snack foods.

Given the high consumption of snacks among Filipinos, there is growing interest in developing snack products that satisfy consumer preferences and address public health concerns, such as micronutrient deficiencies (Serafico *et al*., 2023). Seaweed-enriched snacks offer a promising avenue for enhancing nutritional intake while supporting the health benefits of these nutrient-dense marine resources. One of the most popular snack foods in the Philippines is seafood crackers, commonly known as kropek. Traditionally, these are made from starches such as cassava and rice, combined with spices, flavorings, and various protein sources (Neiva *et al*., 2011). The addition of functional ingredients such as *E.cottonii* and *C. lentillifera* seaweed to seafood crackers may address the needs of consumers for healthy and convenient snack foods.

Response Surface Methodology (RSM) is used in the study to assess and optimize the effect of the two seaweed varieties and their interactions on key product qualities. RSM is a statistical and mathematical instrument suitable for modeling and analyzing scenarios where multiple variables affect one or more response variables (Khuri and Mukhopadhyay, 2010). RSM is known for its efficacy in optimizing multi-component formulations while minimizing experimental trials, so it offers a thorough comprehension of factor interactions and facilitates the identification of optimal combinations for enhanced product quality.

To the best of the authors' knowledge, no prior studies have investigated the utilization of *E.cottonii* and *C.lentillifera*, two locally abundant Philippine seaweeds, in producing seafood crackers. Therefore, this study aimed to optimize the formulation of seafood crackers by examining the effects of incorporating *E. cottonii* and *C. lentillifer*a powders, focusing on their impact on the product's sensory and quality attributes.

MATERIALS AND METHODS

Experimental Design

A 3x3 factorial design was used in the experiment using 1.5%, 3%, and 6% (w/w) *C. lentillifera* and *E. cottonii* seaweeds. A total of 9 treatments were used, as shown in Table 1.Response Surface Methodology (RSM) was applied to evaluate the effects and interactions of the seaweed levels on the product's quality attributes and to efficiently determine the optimal formulation.

Procurement of materials

Tilapia (*Oreochromis niloticus*), *E.cottonii,* and *C. lentillifera* seaweeds, and all ingredients were procured from the local market of Cebu City, Cebu, Philippines.

Processing of seaweed powder

The seaweeds were sorted, washed in potable water, and thoroughly cleaned. Seaweeds were dried at 60 °C for 17 hours in a cabinet dryer. The dried seaweed was milled into powder to pass through a 250 µ sieve. The seaweed powder was subsequently packaged in in High-Density Polyethylene (HDPE) bags, sealed, and stored in a refrigerator at 4^{o}C.

Formulation and production of seafood crackers

The crackers were formulated using a 3x3 factorial design from two seaweed species: *E.cottonii*and *C. lentillifera*. Apart from the seaweed, the proportion of other ingredients (salt and sugar) was kept constant in all nine treatments (Table 1).The treatments consisted of the following: T_1 (1.5% E. cottonii, 1.5% C. lentillifera), T_2 (1.5%, 3%), T_3 (1.5%, 6%), T_4 (3%, 1.5%), T_5 (3%, 3%), T_6 (3%, 6%), T_7 (6%, 1.5%), T_8 (6%, 3%), and T_9 (6%, 6%).

The process included weighing the needed ingredients, properly mixing the different Tilapia (*Oreochromis niloticus*) and seaweed levels, and steam cooking for 3 minutes to gelatinize the starch. The cooled paste was scooped into aluminum dishes and leveled before drying to produce crackers of 3 mm thickness. It was cut into rectangular shapes and finally dried at 60°C for 10 hr. It was then packed in polyethylene plastic and stored until use. Prior to sensory evaluation, the seafood crackers were fried. The dried pieces were flash fried (165– 175°C for less than 10 sec) in a deep frier filled with oil, producing golden brown and crispy crackers.

Sensory evaluation

The seafood crackers were evaluated by expert panelists through sensory evaluation to determine whether the product possessed the desirable sensory attributes.

Table 1. Seafood cracker treatments at varying levels of seaweed.

Treatment	*Eucheuma cottonii* (%) w/w	*Caulerpa lentillifera* (%) w/w
T_1	1.5	1.5
T_2	1.5	3
T_3	1.5	6
T_4	3	1.5
T_5	3	3
T_6	3	6
T_7	6	1.5
T_8	6	3
T_9	6	6

Note: T_1–T_9 represent combinations of *Eucheuma cottonii* (EC) and *Caulerpa lentillifera* (CL) levels ranging from:T_1 (1.5 EC, 1.5 CL), T_2 (1.5 EC, CL), T_3 (1.5 EC, 6 CL), T_4 (3 EC, 1.5 CL), T_5 (3 EC, 3 CL), T_6 (3 EC, CL), T_7 (6 EC, 1.5 CL), T_8 (6 EC, 3 CL), and T_9 (6 EC, 6 CL)

The sensory qualities considered include color, aroma, texture, flavor, and overall acceptability. It was evaluated using a combination of quality descriptions as perceived by sensory panellists using a 9-point hedonic scale for the acceptability of the product (Peryam and Pilgrim, 1957). An Incomplete Block Design (IBD), as laid out by Cochran and Cox (1957), was used during the presentation of the treatments. The set plan of t=9, k=5, r=10, b=18, E=.90, Type II where t refers to the number of treatments, k the number of samples presented to the panellists, r to the number of replications based on the plan IBD, b the number of blocks and E the efficiency factor. The plan was repeated ten times for 50 evaluations per treatment, requiring 90 trained sensory panellists.

Physicochemical analysis

Fat absorption

Nine pieces of seafood crackers from each treatment were weighed and fried in 180 ml vegetable oil heated at a uniform temperature of 180 ˚C. The weight of the fried sample was determined, and the data gathered was used to compute the percent fat absorption using the following formula;

$$\%FA = \frac{CF_f - CF_i}{W_i} \times 100\% \quad \text{Eq.1}$$

Where:
%FA – fat absorbed (%)
CF_i – Crude fat before frying (g)
CF_f – Crude fat after frying (g)
W_i – weight of sample before frying (g)

Linear expansion

Linear Expansion is the ratio of the thickness of the fried samples to the thickness of the unfried samples. For each treatment, the thickness of three randomly selected samples was measured using a Vernier calliper at three points in the sample before and after frying.

$$\%\text{Expansion} = \frac{T_f - T_i}{T_i} \times 100\% \quad \text{Eq.2}$$

Where:
%Expansion– Linear Expansion (%)
T_i – Thickness before frying (mm)
T_f – Thickness after frying (mm)

Water activity

The seafood crackers' water activity (Aw) was obtained by subjecting 5g of powdered sample to the water activity meter (WA 60-A, Japan).

Color Intensity determination

The surface color of seafood crackers was evaluated using 3NH colorimeter, in reflectance mode and in the CIE L*, a*, and b* color scale by subjecting five grams of each sample to the instrument.

Proximate analysis

Proximate analysis was conducted in a third-party laboratory to determine moisture, protein, fat, ash, carbohydrate, phosphorus (P), potassium (K) and sodium (Na) of the fish crackers according to AOAC method (2000). Moisture content was determined after drying the samples at 105°C. The protein and lipid content were determined by Kjedahl method, respectively while the ash content was calculated after the sample is fully dried in the muffle furnace for 500-600°C. The potassium and sodium contents were determined, in the fried samples only, using Flame Atomic Emission Spectroscopy (Flame AES). The phosphorus was determined using colorimetric method.

Statistical analysis

The experiment results were subjected to Response Surface Regression (RSREG) Analysis using the SAS statistical computer software ver. 6 to determine the effects of the independent variables on the sensory attributes and physicochemical analysis. Analysis of variance for the regression coefficients and parameter estimates was done to describe the regression models for each attribute.

Determination of the Optimum Formulation

Contour plots that are graphical presentations of surface models were generated by the computer through StatSoft (1984-1995) STATISTICA software to demonstrate the different effects of factor variables on each response studied. The acceptable cut-off sensory value within the trial range was established for each sensory attribute acceptability to define the range beyond which the seafood cracker is considered the best formulation.

RESULTS

Based on statistical analysis, the statistical model was adequate with no notable lack of fit, and R^2 values for all responses were satisfactory. The results in Table 2 show that *C. lentillifera* significantly affects the flavor attribute of the seafood crackers ($p<0.05$), but does not significantly influence color, aroma, texture, taste, or general acceptability. *E. cottonii* significantly affected texture and flavor ($p<0.05$), while its quadratic term is significant for texture. The interaction between *C. lentillifera* and *E. cottonii* is only significant for texture ($p<0.05$). The model's R-squared values indicated a high fit for all sensory attributes, ranging from 0.82 to 0.92.

Sensory evaluation results

Seafood crackers were produced based on 9 (T_1- T_9) treatments for experimental combinations. All other variables were set constant. Figure 1 shows the color and appearance of the cooked crackers. High color acceptability can be observed at levels of *C. lentillifera* and *E.cottonii* at 1-6% and decreases after the addition of more seaweeds. However, the color attribute for seafood crackers is not significant in all regression effects (Table 2).

Surface plots and equations for sensory attributes

COLORACC = 7.0241+0.1092*x-0.037*y-0.019*x*x-0.0073*x*y-0.0018*y*y Eq.3

AROMAACC = 6.7902+0.2835*x-0.1485*y-0.0328*x*x-0.0243*x*y+0.019*y*y Eq.4

TASTEACC = 7.8654+0.4703*x-0.8499*y-0.0788*x*x+0.0322*x*y+0.0837*y*y Eq.5

FLAVORACC = 6.9099+0.4211*x-0.2892*y-0.0532*x*x-0.0075*x*y+0.0281*y*y Eq.6

As for the the texture of the cracker, the mean acceptability is 7, However, both linear and quadratic terms were found to be not significant for texture attributes.

Eqn (5) TEXTURE = 7.6275+0.0957*x-0.3606*y 0.0214*x*x+0.006*x*y+0.0381*y*y Eq.7

The mean general acceptability is 7.47 corresponding to like moderately in the 9-point hedonic scale. The 3D surface plot of general acceptability as affected by different levels of *E.cottonii* and *C. lentillifera* is shown in Fig. 2.

GENACC=7.4797+0.1383*x0.1712*y-0.0228*x*x 0.00*x*y+0.0159*y*y Eq. 8

Physico-chemical analysis results

The physicochemical analysis results are shown in Table 3. The linear expansion of seafood crackers was found to be not significant in different levels of

Table 2. Parameter estimates of sensory attributes of seafood crackers

Regression	Color	Aroma	Texture	Taste	Flavor	Gen Acc
Intercept	7.02407	6.79015	7.62746	7.86540	6.90988	7.47970
C. lentillifera (%) w/w	0.10919 ^{ns}	0.28354 ^{ns}	0.09571 ^{ns}	0.47034 ^{ns}	0.42114*	0.13825 ^{ns}
C. lentillifera(%) w/w^2	-0.01903 ^{ns}	-0.03279 ^{ns}	-0.02138 ^{ns}	-0.07875 ^{ns}	-0.05315*	-0.02278 ^{ns}
E.cottonii. (%) w/w	-0.03697 ^{ns}	-0.14847 ^{ns}	-0.36064*	-0.84993 ^{ns}	-0.28915*	-0.17117 ^{ns}
E.cottonii. (%) w/w^2	-0.00178 ^{ns}	0.01896 ^{ns}	0.03809*	0.08373 ^{ns}	0.02810 ^{ns}	0.01594 ^{ns}
C. lentillifera(%) w/ w*E.cottonii*. (%) w/w	-0.00725 ^{ns}	-0.02425 ^{ns}	0.00604*	0.03221 ^{ns}	-0.00750 ^{ns}	-0.00076 ^{ns}
R^2	0.90156	0.92482	0.86123	0.87461	0.824826	0.924826

^{ns} :not significant (p>0.05); * :significant (p<0.05)

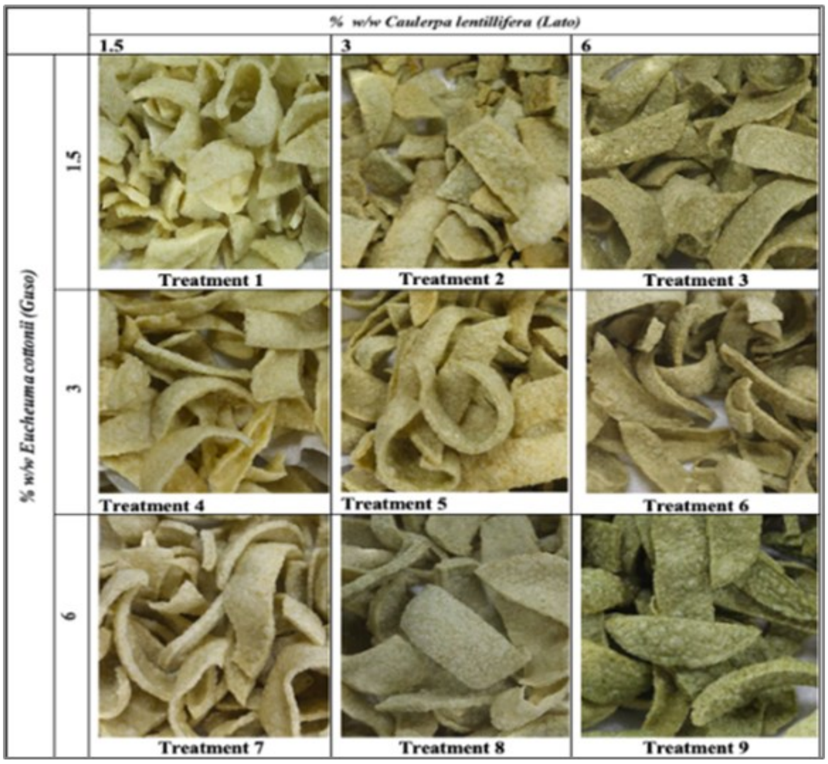

Fig.1. Appearance of the 9 seafood cracker treatments as influenced by the levels of *Eucheuma cottonii* and *Caulerpa lentillifera powder ; Crackers transition from a pale, smooth surface (Treatments 1–3) to progressively darker green hues and more pronounced granular texture (Treatments 4–9)*

Table 3. Parameter estimates of physicochemical attributes of seafood crackers

Regression	Linear Expansion	Oil Absorption	Aw	Color Values L	a	b
Intercept	41.2121^{ns}	19.01366^{ns}	0.422315^{ns}	54.7222**	-1.72204^{ns}	11.53759^{ns}
C. lentillifera(%) w/w	0.77169^{ns}	0.22234^{ns}	0.011508^{ns}	-8.1957*	0.3457^{ns}	1.30714^{ns}
C. lentillifera(%) w/w^2	-0.12763^{ns}	-0.21402^{ns}	-0.001975^{ns}	0.6303*	-0.08617^{ns}	-0.13646^{ns}
E.cottonii. (%) w/w	-1.06790^{ns}	-2.09544^{ns}	0.002619^{ns}	1.20095^{ns}	-1.22095^{ns}	0.72159^{ns}
E.cottonii. (%) w/w^2	0.11029^{ns}	0.17389^{ns}	-0.001152ns	-0.33877^{ns}	0.1362^{ns}	-0.12123^{ns}
C. lentillifera(%) w/ w**E.cottonii*. (%) w/w	0.08866^{ns}	0.10129*	0.001791ns	0.37666^{ns}	0.0414^{ns}	0.01023^{ns}

^{ns} :not significant (p>0.05); * :significant (p<0.05)

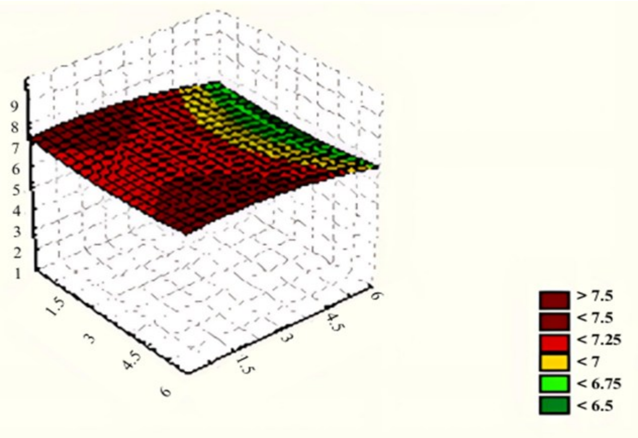

Fig. 2.*Surface plot for general acceptability as a function of Eucheuma cottonii and Caulerpa lentillifera*

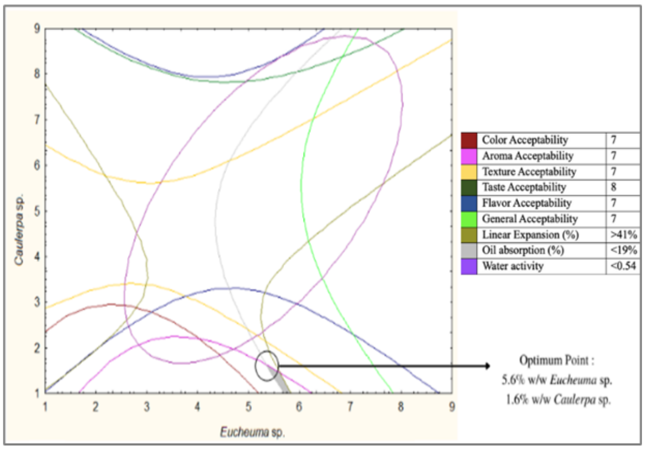

Fig. 3. *Best point formulation region (gray-shaded region) for seaweed seafood cracker*

seaweed. Fat absorption for seafood crackers is not affected by different levels of seaweeds but is significant in *E.cottonii* and *C. lentillifera* combinations. Water activity of the seafood crackers ranged from 0.41- 0.54 and is not significant at any levels of *E.cottonii* and *C. lentillifera*. The lightness and darkness of the cracker are significant in both linear and quadratic effects of *C. lentillifera.*

Overlay for Best point formulation

The overlay response of *E.cottonii* and *C. lentillifera* seaweed-seafood crackers can be seen in Fig. 3. The figure shows the overlay of 6 sensory attributes color, aroma, texture, taste, flavor, and general acceptability) and three physicochemical properties (linear expansion, oil absorption, and water activity). The overlays were determined by the expected value of the panelist's preference, which was a value of 7 to 8 and general acceptability of 7 (like moderately). Linear expansion was 41% and above, oil absorption was less than 19%, and water activity was less than 0.54. The result of this overlay suggested that the best product formulation can be generated by using the scatter values in the gray-shaded region. The amount of *E.cottonii* and *C. lentillifera* can be generated by putting points in the gray shaded area and then drawing a line to the x-axis and y-axis. Hence, from these experiments, the suggested amounts of *E.cottonii* and *C. lentillifera* are 5.6 % and 1.6%, respectively.

Proximate analysis

The proximate analysis results of the seaweed crackers are shown in Table 4. The moisture content of the seafood crackers decreased from 9.81% in the unfried samples to 5.86% in the fried samples, as indicated by the proximate analysis. After frying, the crude protein content increased considerably from 11.9% to 30.82%, while the carbohydrate content decreased from 59.62% to 40.65%. The fat content increased from 4.07% in the unfried samples to 40.24% in the fried samples. Sodium (Na) levels were 537.8 mg per 100 g, phosphorus (P) levels were 102 mg per 100 g, and potassium (K) at 358 mg/100g for the fried samples.

The predicted results indicated that the overall optimized region for the seaweed seafood crackers was achieved by formulation comprising of 5.6% *E.cottonii* and 1.6% *C. lentillifera* under the optimized condition. The experimental values of all sensory attributes showed no significant difference (p>0.05) against the predicted values.

DISCUSSION

The study presents the effect of adding different levels of *E.cottonii*and *C. lentillifera* in the sensory attributes, acceptability, and physico-chemical properties of seafood crackers. The appearance of the seafood crackers

Table 4. Proximate composition of the best formulation for fried and unfried seafood cracker

Analysis	Unfried	Fried
Moisture (%)	9.81	5.86
Ash (%)	9.78	5.54
Crude Fiber (%)	0.577	0.528
Crude Protein (%)	11.9	30.82
Carbohydrate (%)	59.62	40.65
Fat (%)	4.07	40.24
Phosphorus (P) (mg/100g)		102
Potassium (K) (mg/100g)		358.4
Sodium (Na) (mg/100g)		337.8

*unfried samples were not tested for P, K, and Na

among treatments, as shown in Fig. 1, exhibited notable variations in color and surface texture, affected by differing concentrations of seaweeds. As seaweed levels increased from 1.5 to 6 % (left to right, top to bottom), the crackers transitioned from a pale, smooth surface (Treatments 1–3) to progressively darker green hues and more pronounced granular texture (Treatments 4–9). For visual sensory attributes, it is observed from the plot that to achieve color acceptability of 6.75, and above (like moderately), the seafood crackers should be processed at lower levels of *E.cottonii* and *C. lentillifera*. The lower levels of seaweeds are likely preferred for color acceptability because seaweeds contain pigments, such as chlorophyll (Saikia *et al*., 2020), that can darken or alter the natural lightness of the crackers when used in higher concentrations.

In addition to visual appeal, the generation of flavors from food during the mastication process is important, which further affects the overall acceptability of a food product. The chemical composition of a snack, as perceived by the aroma and taste of food, influences the flavor quality perception (Schwartz *et al*., 2023). The significant linear and quadratic effects of *C. lentillifera* and *E. cottonii* on the flavor and texture of seafood crackers can be attributed to the distinct biochemical compositions of these seaweeds. The highly significant linear effect of *C. lentillifera* on flavor acceptability suggests that increasing its concentration consistently enhances the sensory perception of flavor, likely due to its rich profile of umami compounds and unique marine flavors (Nurkolis *et al*., 2023) that complement the overall taste of the product.

For texture, the significant linear and quadratic effects of *E. cottonii* suggest that its incorporation alters the structural properties of the seafood crackers. These findingsaligns with the study of Yakhin *et al*. (2015), which demonstrated seaweed's high carrageenan content influences the gelation, water-binding capacity, and overall firmness of food products. The quadratic effect indicates that at certain levels, *E. cottonii* could either enhance or diminish the desirable textural qualities, such as crispness or hardness, depending on its interaction with other ingredients and the processing conditions. This may be due to the seaweed's ability to modify the starch matrix, affecting the final texture of the crackers (Egodavitharana *et al*., 2023).

The intrinsic properties of food products, which include attributes such as flavor, texture, and appearance, significantly influence their sensory acceptability. General acceptability is frequently regarded as the most comprehensive measure among these, as it consolidates panellist responses to numerous sensory attributes into a single score. The general acceptability of seafood crackers was found (7 on the 9-point hedonic scale), particularly at lower levels of *E.cottonii*powder, regardless of the quantity of *C. lentillifera* powder used. The regression analysis revealed a significant impact on flavor and textural acceptability among all sensory attributes. The linear and quadratic effects for other sensory attributes, including appearance, aroma, taste, and general acceptability, were not statistically significant.

For the physicochemical properties of the seafood cracker, the linear expansion of seafood crackers was found to be not significant in different levels of seaweed. The average linear expansion of the cracker is 41.21%. During frying, the crackers expand into a low-density porous product. The results agree with previous studies, wherein a moderate to the high degree of expansion is often desirable in snack products, particular-

Table 5. Predicted and experimental data for the responses at the optimum point of the seafood crackers

Responses	Predicted Value	Experimental Value[a]	P-value (T-test)[b]
Color	7	7.5±0.25	0.081
Aroma	7	7.25±0.12	0.125
Texture	7	7.1±0.25	0.081
Taste	8	7.89±0.45	0.099
Flavor	7	6.81±0.68	0.349
General Acceptability	7	7.21±0.18	0.378
Linear Expansion	>41%	39±1.25	0.504
Oil absorption	<19%	17±3.25	0.216
Water Activity	<0.64	0.65±0.25	0.181

[a] Mean ± S.D.;[b] No significant (p>0.05) difference between the experimental and predicted value

ly those made from starchy materials, because it correlates with a light, crispy texture that consumers generally prefer. Linear expansion ratio (LER) is one of the important quality parameters of crackers since it indicates porosity and bulk density quantifying the extent of puffing for a fried cracker (Maisont *et al*., 2021; Wang *et al*., 2012).

For ideal crispness, a seafood cracker should have a linear expansion higher than 77% (Huda *et al*., 2010; Siaw *et al*., 1985). However, 30-50% expansion levels are commonly acceptable and show improved crispiness and a light texture. Generally, the more the degree of the expansion of the crackers, the more air cells will form, and the more oil is trapped (Saeleaw and Schleining, 2011).

The average oil absorption of 19.01% in the seafood crackers suggests a moderate fat uptake during frying, typical for snack products, and varying levels of E. cottoniiand C. lentillifera did not significantly influence this. Similarly, the water activity, which ranged from 0.41 to 0.54, remained stable across all levels of seaweed addition, showing no significant effects. This stability is beneficial for developing shelf-stable products (Schmidt and Fontana, 2020), as it indicates that the seaweed powders do not disrupt the moisture balance of the crackers and ensure they remain within an optimal range for preventing microbial growth.

For the color values, significant linear and quadratic effects were observed in the crackers' lightness (L* values), which could indicate that the combination of *E.cottonii* and *C. lentillifera* levels substantially influenced the product's overall appearance. This is likely due to the contrasting colors between the white tapioca flour and the pigments present in the seaweed, such as chlorophyll, which impact the final color intensity as the seaweed levels vary. However, the lack of significance in the a* (red-green) and b* (yellow-blue) values suggest that while the overall brightness or darkness of the crackers is affected, the specific hue shifts related to red-green or yellow-blue coloration remain minimal.

The overlay response of *E.cottonii* and *C. lentillifera* seaweed-seafood crackers can be seen in Fig. 3. The overlays were determined by the expected value of the panellist's preference, which was a value of 7 to 8 and general acceptability of 7 (like moderately). Linear expansion was 41%, oil absorption was 19%, and water activity was 0. 54. The result of this overlay suggested that the best product formulation can be generated by using the scatter values in the grey-shaded region. The amount of *E.cottonii* and *C. lentillifera* can be generated by putting points in the gray shaded area and then drawing a line to the x-axis and y-axis. Hence, these results suggest optimal inclusion levels of 5.6% *E.cottonii* and1.6% *C. lentillifera*.

The best formulation of the seafood crackers was subjected to proximate analysis. The moisture content decreased from 9.81% in the unfried crackers to 5.86% in the fried samples, which was expected as moisture was lost during frying, enhancing the product's crispness and extending shelf life. This also aligns with the study of Tokarczyk *et al.* (2025), wherein the moisture of carp-starch crackers was reduced after frying.

The crude protein content exhibited a notable increase from 11.9% to 30.82% after frying, suggesting that the frying process concentrated the protein, likely due to the nutrient-rich nature of the incorporated seaweed powders. This result is similar to that of Rahmawati *et al*. (2024) and Tokarczyk *et al*.(2025), which observed increased protein content after fryng. In contrast, the carbohydrate content decreased significantly from 59.2% in the unfried samples to 40.65% in the fried samples. According to studies, any loss of moisture (and some soluble solids) results in a decreased carbohydrate content (Sharma *et al*., 2024; Tokarczyk *et al*., 2025), which agrees with the results of the present study.

In addition to these changes, the fat content increased from 4.07% in the unfried crackers to 40.24% in the fried ones, showing a substantial absorption of cooking oil during frying. The ash content decreased from 9.78% to 5.54%, which may indicate a reduction in mineral content attributable to the frying process. For minerals, phosphorus, potassium, and sodium contents were determined in fried samples only. Phosphorus levels were 102 mg per 100g, potassium at 358 mg per 100 g, and sodium at 537.8 mg per 100 g, the standard seafood crackers levels.

In optimization studies, verification was used to verify the accuracy and reliability of the predicted optimal conditions by comparing experimental results with the model's predictions. The results of the models' verification are shown in Table 5. The adequacy of the response surface equations was demonstrated by the comparison between the fitted values predicted by the response regression models and the experimental values. There was no significant difference ($p>0.05$) between these values. The experimental response values were found to agree with the predicted values found in Table 5. This implies that deviations between model predictions and experimental data are within the expected experimental error, indicating the adequacy of the quadratic model.

Conclusion

By utilizing two locally sourced Philippine seaweeds and employing Response Surface Methodology (RSM) to determine the optimal formulation, this study successfully developed and optimized seafood crackers that included 5.6% *E.cottonii*and 1.6% *C. lentillifera* powders. The mean sensory acceptability score was 7, corresponding to "like moderately" on a 9-point hedonic scale. The values for the physicochemical properties of crackers used in the overlay to determine the best formulation were >41% for linear expansion, <19% for oil absorption, and <0.54 for water activity. The best formulation having acceptable sensory and physicochemical resulted in standard levels of phosphorus (P), sodium (Na), and potassium (K). The results indicated that adding seaweed powders without sacrificing texture or flavour can enhance snack products' physico-chemical profile and overall acceptability. The potential of this study to significantly impact agriculture and fisheries was significant, as it encourages the use of locally sourced seaweeds, contributes to sustainable resource utilization, and can potentially provide added value to seaweed farming communities.

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Conflict of interest
The authors declare that they have no conflict of interest.

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