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Optimization of extrusion cooking conditions for seasoning base production from sea mustard (*Undaria pinnatifida*)

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Abstract

Sea mustard (*Undaria pinnatifida*), an important edible seaweed belonging to the brown algal family of Alariaceae, contains copious physiologically active substances. It has long been popular in Korea as a food and is frequently consumed in the form of soup. It is also commercially available as a home meal replacement. In this study, we developed a seasoning key base with a high degree of sensory preference from sea mustard using the extrusion cooking process. Extrusion cooking conditions were optimized through response surface methodology. Barrel temperature (X_1, 140℃–160℃) and screw speed (X_2, 158–315 rpm) were set as independent variables, and overall preference was determined as the dependent variable (Y, points). An optimal condition was obtained at $X_1 = 148.5$℃ and $X_2 = 315$ rpm, and the dependent variable (Y, overall acceptance) was 7.95 points, similar to the experimental value of 7.81. Umami taste had a relationship with the overall acceptance of sea mustard seasoning. In the electronic nose and tongue, increased sourness and umami intensities were associated with the highest sensory score. The samples were separated well by each characteristic via principal component analysis. Collectively, our study provides imperative preliminary data for the development of various seasonings using sea mustard.

Keywords: Electronic nose and tongue, Extrusion cooking, Response surface methodology, Sea mustard (*Undaria pinnatifida*), Seasoning base

Introduction

Extrusion cooking, widely used in the manufacturing of snacks, cereals, and seasoning bases, is a process involving a combination of high temperature, pressure, and mechanical shear forces. It causes a thermal reaction in food raw materials within

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a short period and is simultaneously molded (Ilo et al., 2000; Lee, 2004). Being a high-temperature and less time-consuming process, extrusion cooking process has the advantage of considerably reducing the reaction time compared to the existing batch flavor manufacturing process. In addition, it can induce the formation of food flavors through the Maillard reaction of amino acids and sugars, which can be useful for developing seasoning materials (Riha & Ho, 1998; Yaylayan et al., 1992). In a similar study, clams were used to prepare seasoning materials, using an extruder (Shin et al., 2020).

Sea mustard (*Undaria pinnatifida*), which belongs to the brown algae of the Laminariales order, is distributed on the entire coastline of Korea and has been widely consumed as a food and dietary supplement. It contains various bioactive compounds, including polysaccharides, carotenoids, tocopherols, phycobilins, phycocyanins, vitamins, fatty acids, and sterols (Wang et al., 2018). Owing to these constituents, the products or extracts of sea mustard have been reported to exhibit antioxidant, anticancer, anticoagulant, anti-inflammatory, anti-diabetic, and anti-microbial properties (Ngo et al., 2011; Zhao et al., 2018). In particular, it is rich in iodine and calcium; therefore, women in Korea have long been consuming sea mustard soup postpartum for quick to recovery (Kolb et al., 2004; Prabhasankar et al., 2009; Shin, 2009). Sea mustard soup is one of the most consumed soups by Koreans and is commercialized and consumed as a home meal replacement.

In this study, we aimed to optimize the extrusion cooking conditions for preparing a high preference seasoning base from *U. pinnatifida*. The optimization of the extrusion cooking process for the sea mustard seasoning base was performed via a statistical technique, response surface methodology (RSM). In addition, we used an electronic nose and tongue to compare the changes in the sensory evaluation characteristics following extrusion cooking under different conditions.

Materials and Methods

Materials

For producing a seasoning base from sea mustard, dried sea mustard powder, purchased from BasisFood (Jincheon, Korea), was filtered using a vibration medium of 40-mesh before extrusion cooking. Corn starch (CJ Cheiljedang, Seoul, Korea), soybean protein (ISP, Solae LLC, St. Louis, MO, USA), skimmed soybean (Maeil Food, Suncheon, Korea), yeast extract (Samhyeon Hudis, Seongnam, Korea), and glucose (Weifang Shengtai Medicine, Shandong, China) were used as seasoning ingredients. The seasoning ingredients were constructed through pre-experiments to combine seaweed with extrusion cooking and maximize the flavor of the seasoning through the Maillard reaction. The pre-experiment was conducted according to Shin et al. (2020). All other reagents and chemicals used in the experiments were of analytical grade.

Extrusion cooking

Before the extrusion cooking process, sea mustard powder (36.0%), corn starch (44.0%), soybean protein (4.5%), skimmed soybean (4.5%), and other amino acid compounds (11.0%) were homogenized using a mixer and filtered through a 30-mesh net. A twin-screw extruder (model DNDL-44, Buhler Brothers, Uzill, Switzerland) and a circular injection port with a diameter of 2 mm were used for extrusion cooking. Sea mustard seasoning extrudate was prepared at different screw rotational speeds (158–315 rpm) and barrel temperatures (140℃–160℃), while maintaining the input speed and water content of sea mustard mixing at 17 kg/h and 22%, respectively. The extrudate that passed through the extruder was dried for 24 h at 55℃ and subsequently crushed using a mixer to prepare the final sea mustard seasoning base powder.

Experimental design

To develop a sea mustard seasoning base with a high preference, the extrusion cooking process was optimized via RSM. The experiment was planned according to a central composite design (CCD). The CCD matrix in the experimental design consisted of four factorial points, four axial points, and three central points (Cho et al., 2005). The barrel temperature (X_1, ℃) and screw speed (X_2, rpm) of the extruder device were selected as independent variables. The range and center point values of the two independent variables were based on the results of preliminary experiments (Table 1). The overall acceptance (Y, points) was selected as the dependent variable, which was com-

Table 1. Experimental range and values of independent variables in the central composite design for production of the seasoning base from sea mustard (*Undaria pinnatifida*) via extrusion cooking

Independent variables	Symbol	Range and levels				
		–1.414	–1	0	+1	+1.414
Barrel temperature (℃)	X_1	140	143	150	157	160
Screw speed (rpm)	X_2	158	181	236.5	537	315

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bined with the independent variables presented in Table 2. The experimental run was conducted in random order to minimize the effects of unexpected variability.

Data analysis and optimization

The experimental data were analyzed using the MINITAB statistical program (version 16, Minitab, Harrisburg, PA, USA) and used to fit the following response model equation:

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum_{i=1}^{1} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j$$

where, Y is a dependent variable (overall acceptance); β_0 is a constant; β_i, β_{ii}, and β_{ij} are regression coefficients; and X_i and X_j are the levels of independent variables. The optimization of the extrusion cooking process conditions for developing the sea mustard seasoning base was performed using the response optimizer of the MINITAB statistical program. The value of the estimated dependent variable was verified by comparing it with the value of the dependent variable obtained through the actual experiment under statistically predicted optimal conditions. Moreover, a three-dimensional response surface plot was created using the MAPLE software (MAPLE version 7, Maple Soft, Waterloo, ON, Canada).

Sensory evaluation

Sensory evaluation was conducted by a panel comprising 13 trained professionals (six males and seven females) aged 22–27 years, belonging to the Department of Food Engineering at Pukyong National University. For sensory evaluation, sea mustard seasoning bases manufactured via the extrusion cooking process according to the RSM experimental design were dissolved in hot water at 75℃ at a concentration of 5% (w/v), heated to 100℃ for 3 min, and subsequently used in the form of warm soup. The contents were evaluated for overall acceptance as well as umami, and unpleasant seaweed flavor according to the characteristics of sea mustard-derived seasoning materials. Sensory evaluation was performed using a 9-point hedonic scale (1 point: very bad, 5 points: not bad, 9 points: very good).

Electronic tongue analysis

The taste components of each sample were analyzed using an electronic tongue system (ASTREE II, Alpha MOS, Toulouse, France). The electronic tongue system combined several sensors that detect individual taste components, including five basic tastes (UMS: umami, BRS: bitterness, STS: saltiness, SWS: sweetness, SRS: sourness) and two additional taste-related references (GPS: metallic, SPS: spiciness). For electronic tongue analysis, each sample manufactured via extrusion cooking was stirred with 200 mL of deionized water for 3 min at 100℃ and subsequently extracted by stirring for 1 h at 50℃ at 150 rpm. In addition, each sample was filtered to remove sediments. Thereafter, extracts were diluted 1:1 (w/w) with deionized water. The sample solution (100 mL) was mounted on the sampler of the

Table 2. Central composite design matrix and values of dependent variables for production of the seasoning base from sea mustard (*Undaria pinnatifida*) by extrusion cooking

Number		Independent variables				Dependent variables
		Coded values		Uncoded values		
		X_1	X_2	X_1	X_2	Y
Factorial portions	1	–1	–1	143	181.0	5.9
	2	1	–1	157	181.0	7.1
	3	–1	1	143	292.0	7.4
	4	1	1	157	292.0	7.4
Axial portions	5	–1.414	0	140	236.5	6.0
	6	1.414	0	160	236.5	6.6
	7	0	–1.414	150	158.0	6.6
	8	0	1.414	150	315.0	7.6
Center points	9	0	0	150	236.5	7.3
	10	0	0	150	236.5	7.3
	11	0	0	150	236.5	7.1

X_1, barrel temperature (℃); X_2, screw speed (rpm); Y, overall acceptance (points).

electronic tongue, and the strength of the taste components related to the sensor was measured by immersing the sensor in the sample solution for 120 s. Each sensor was sufficiently washed with deionized water to reduce errors caused by contamination between samples. The analysis was repeated five times per sample, and each sensor value was compared with the taste pattern using principal component analysis (PCA) (Lee et al., 2020).

Electronic nose analysis

An electronic nose system with flame ionization detectors and an MXT-5 column (HERACLES Neo, Alpha MOS) was used to analyze the volatile compounds in each sample. Following the production of extracts via the same method as for the electronic tongue samples, 5 mL of each extract was placed in a headspace vial for electronic nose analysis. Following stirring at 500 rpm for 10 min at a temperature of 50℃ to saturate volatile compounds in the headspace, 5 mL of volatile compounds was collected using a syringe. The volatile compounds were analyzed using an automatic sample collector installed in the electronic nose system. Briefly, the volatile components were injected into gas chromatography inlets mounted on the electronic nose system. The trap absorption and desorption temperatures were 40℃ and 250℃, respectively. The oven temperature program was initiated at 40℃ for 5 s, increased to 270℃ at a rate of 4℃/s, and maintained for 30 s. To confirm the odor pattern, the analysis was repeated thrice per sample. For the retention index, individual compounds were identified through the time of the separated peak using AroChemBase (Alpha MOS) based on Kovat's index library. In addition, the discriminatory patterns between samples were confirmed through multivariate analysis (Hong et al., 2021).

Results and Discussion

Diagnosis checking of the fitted models

To fit the quadratic polynomial model equation, the experimental data were analyzed using the response surface regression procedure in MINITAB statistical software. Table 3 shows the coefficients and *p*-values of linear (X_1, X_2), quadratic (X_1X_1, X_2X_2), and interaction (X_1X_2). All linear, quadratic, and interaction coefficients, except the X_2X_2 term ($p = 0.961$), were significant ($p < 0.05$). The response surface model equations for dependent variables are presented in Table 4. The coefficient of determination (R^2) for Y was 0.945, indicating the suitability of the model (Islam Shishir et al., 2016). The response surface model had a high R^2 value and was statistically significant ($p = 0.004$). The high R^2 value was induced by an adequate experimental design established from the preliminary test (Cho et al., 2005).

Analysis of variance

The quality of the fitted response surface model was evaluated using an analysis of variance (ANOVA). The ANOVA for the model that explains the response of the dependent variable is shown in Table 5. All regression equations were significant ($p < 0.05$) at the 95% probability level. The *p*-value of the lack-of-fit test for the response surface model was higher than 0.05 ($p = 0.207$), indicating that the functional relationship between the dependent and independent variables was adequately explained through the response surface model (Isa et al., 2011).

Response surface plots and the effect of factors

The interrelationship between two independent variables and

Table 3. Estimated coefficients of the fitted quadratic polynomial equations for dependent variables based on *t*-statistic

Parameters		Constant	X_1	X_2	X_1X_1	X_2X_2	X_1X_2
Y	Coefficient	7.2330	0.2561	0.4018	–0.4042	–0.0042	–0.3000
	p-value	0.000	0.013	0.002	0.004	0.961	0.026

X_1, barrel temperature (℃); X_2, screw speed (rpm); *Y*, overall acceptance (points).

Table 4. Response surface model equations for monitoring effects of independent variables on dependent variables for the production of seasoning base from sea mustard (*Undaria pinnatifida*) via extrusion cooking

Quadratic polynomial model equation	R^2	*p*-value
$Y = 7.233 + 0.2561X_1 + 0.4018X_2 - 0.4042X_1^2 - 0.0042X_2^2 - 0.3000X_1X_2$	0.945	0.004

X_1, barrel temperature (℃); X_2, screw speed (rpm); *Y*, overall acceptance (points).

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Table 5. Analysis of variance for dependent variables

Dependent variables	Sources	DF	SS	MS	*F*-value	*p*-value
Y	Regression					
	Linear	2	1.81595	0.90798	24.45	0.003
	Square	2	1.00379	0.50189	13.51	0.010
	Interaction	1	0.36	0.36	9.69	0.026
	Residual					
	Lack of fit	3	0.15905	0.05302	3.98	0.207
	Pure error	2	0.02667	0.01333		
	Total	10				

Y, overall acceptance (points).
DF, degrees of freedom; SS, sum of square; MS, mean square.

one dependent variable is presented by a response surface plot, and the effect of independent variables on overall acceptance is depicted in Fig. 1. When the coded value of barrel temperature (X_1) was close to –0.3 (approximately 148℃), overall acceptance (Y) increased. The overall acceptance marginally increased with an increase in screw speed (X_2). Heat dissipation occurs because of the mechanical movement of the internal screw during the operation of the extruder (Verma et al., 2021). Therefore, the mechanical rotational energy of the motor is supplied, and part of it is converted into heat energy. Eventually, the raw food material receives additional heat energy (Chung & Lee, 1997). Therefore, the rotational heat of the screw is added to promote the Maillard reaction, which induces peculiar scents such as meat and savory scents, to increase the flavor of the product. However, as preference decreased after a certain screw speed in this study, excessive heat was supplied to the material, leading to excessive carbonation and low preference (Kim et al., 2006).

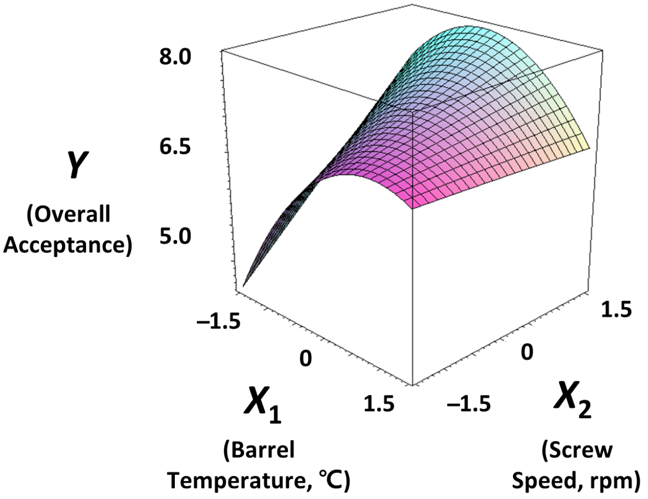


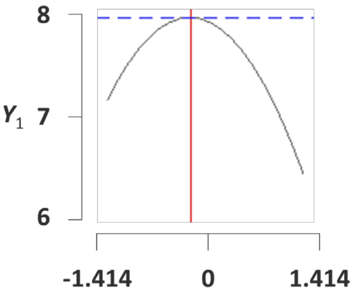
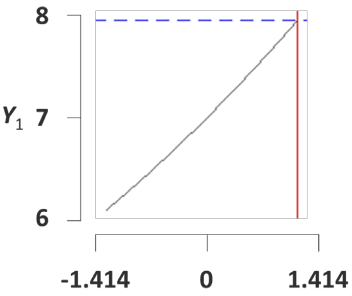
Fig. 1. Three-dimensional response surface plots for the dependent variable *Y* (points).

Optimization and verification

The optimal extrusion cooking conditions with maximum overall acceptance (Y) were statistically determined using the response optimizer of MINITAB statistical software. The optimal values of X_1 (barrel temperature) and X_2 (screw speed) had the coded values of –0.214 (148.5℃) and 1.414 (315 rpm), respectively (Fig. 2). Under optimal conditions, the predicted value of the dependent variable Y was 7.81. A verification test was conducted according to the optimal conditions to compare the predicted values of dependent variables (Cho et al., 2005; Yoon et al., 2017). The experimental value of Y was 7.95 ± 0.5, which was close to the predicted value. Therefore, the estimated response surface model was adapted to the manufacturing conditions of the sea mustard seasoning base.

Sensory characteristics

While designing the experiment to optimize extrusion cooking conditions for the production of sea mustard seasoning bases, the overall acceptance (Y) was considered as a dependent variable. Moreover, to better understand the effects of extrusion cooking on the sensory properties of sea mustard seasoning base, umami taste, and unpleasant seaweed flavor were evaluated together with overall acceptance. The appearances of the samples are shown in Fig. 3, and the color difference between the control and RSM sample groups is clear. However, as the difference within the RSM sample group was subtle, appearance was excluded from the sensory characteristic evaluation. Fig. 4 shows the correlations between umami taste, unpleasant seaweed flavor, and overall acceptance. In the RSM experiments,

Optimal conditions		X_1		X_2	
		Coded value	Actual value	Coded value	Actual value
		−0.214	148.5	1.414	315.0
Y	Target value Max				
Predicted values		7.81			
Experimental values		7.95 ± 0.5			

X_1, barrel temperature (℃); X_2, screw speed (rpm); Y, overall acceptance (points).

Fig. 2. Response optimization for the production of seasoning key base from sea mustard (*Undaria pinnatifida*) via extrusion cooking.

the unpleasant seaweed flavor did not significantly correlate ($R^2 = 0.2913$) with overall acceptance, whereas overall acceptance was proportional to the umami taste ($R^2 = 0.8626$). The Maillard reaction increased the intensity of umami taste by generating flavor or peptides that increase the flavor, and these results have also been reported by others as changes in the taste components of soybean protein, peanut protein, shellfish, and bovine bone marrow (Normah & Noorasma, 2018; Ogasawara et al., 2006; Xu et al., 2018; Zhang et al., 2019). These results clearly suggest that extrusion cooking increases the overall acceptance by increasing the umami taste, although it does not reduce the unpleasant seaweed flavor.

Subsequently, we compared the sensory characteristics of samples No. 8, No. 9, and No. 1 with the highest, middle, and lowest overall acceptance, respectively, to the untreated control sample (Fig. 5). The four samples were compared for unpleasant seaweed flavor, umami taste, and overall acceptance. Samples No. 8, No. 9, and No. 1 exhibited a higher umami taste and overall acceptance, and a lower unpleasant seaweed flavor than the control. In addition, for unpleasant seaweed flavor, sample No. 1, No. 9, and No. 8 were similar. This result indicated that extrusion cooking reduces the unpleasant seaweed flavor and increases the umami taste and overall acceptance, similar to the results of Wang et al. (2020). Therefore, the optimization of the extrusion cooking process is necessary for manufacturing sea mustard seasoning bases with a high degree of overall acceptance.

Electronic tongue and nose analysis

Electronic tongue analysis has complementarity for threshold values that exhibit differences between panels, and has the characteristic of showing relative strength to basic taste ingredients. Moreover, it is widely used for food quality evaluation by providing a pattern of comprehensive taste ingredients and the relative taste strength of a large amount of food in a short time (Peris & Escuder-Gilabert, 2016). In this study, to compare the relative strengths of taste components between samples, the five basic taste components of the control, No. 1, No. 8, and No. 9 samples were analyzed (Fig. 6). Samples No. 1, No. 8, and No. 9 had the lowest, best, and intermediate preferences among the RSM experimental groups, respectively. In the case of sample No. 8, which had the best overall preference, high sourness (9.1 level) and umami (7.2 level) were confirmed in the comparison between the control and other RSM samples. In the case of sourness, the higher the sensory preference among the RSM experimental groups, the greater the sourness intensity. Saltiness was considerably less in the RSM sample group that underwent the extrusion cooking process than in the control. For umami, which is a major characteristic of seaweed taste, RSM No. 8 was the highest (7.2 level). Bitterness was highest in the control sample (8.5 level), and the better the sample preference, the less the bitter intensity. These results confirmed that extrusion cooking reduces bitterness, saltiness, and sweetness, which is similar to the results of sensory evaluation.

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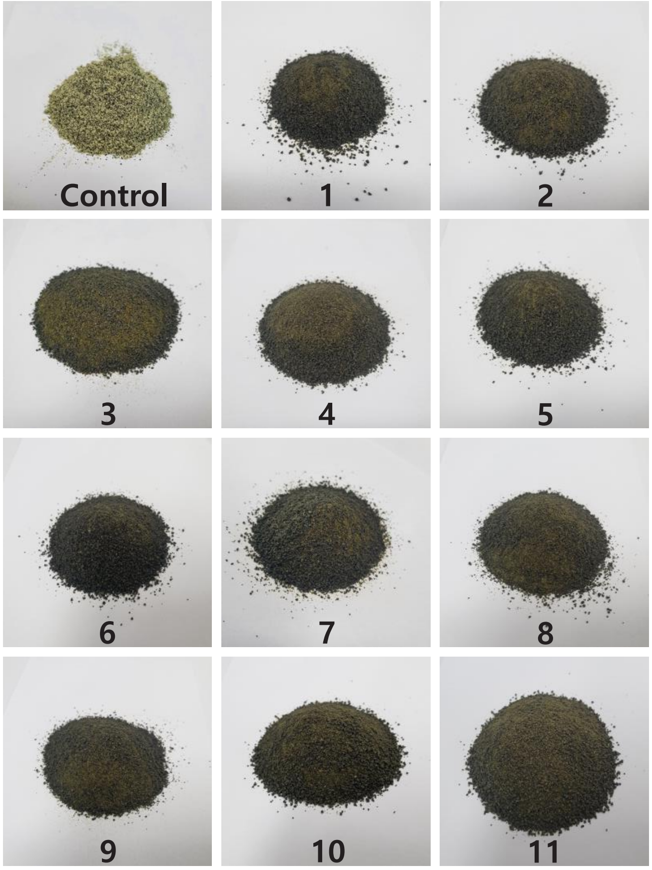

Fig. 3. Seaweed seasoning image of the control and response surface methodology sample group. The control sample refers to a product not subjected to extrusion cooking.

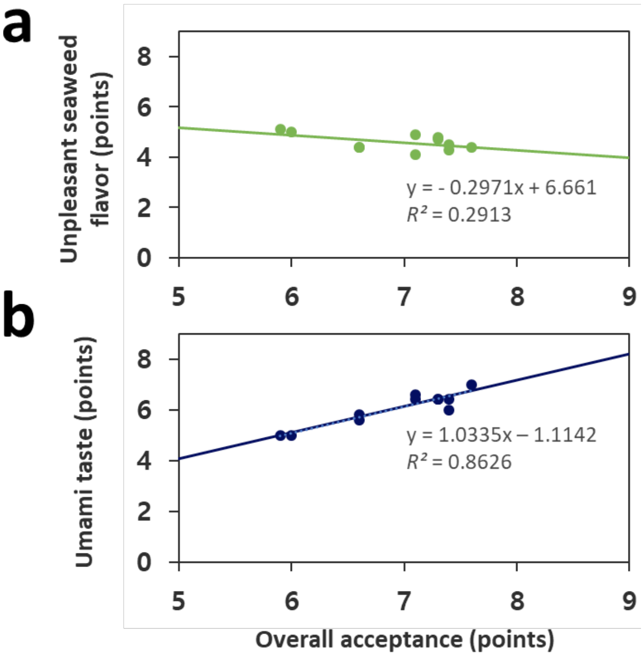

Fig. 4. Correlations between overall acceptance (a) and unpleasant seaweed flavor (b) and umami taste.

The volatile compounds in the four samples were analyzed using an electronic nose, and the results are presented in Table 6. Eighty-eight components in eight groups were detected, including five volatile furans, 14 volatile aldehydes, four volatile heterocyclic compounds, 12 volatile hydrocarbons, 17 volatile acids and esters, 18 volatile alcohols, 10 volatile ketones, and eight volatile sulfur-containing compounds. Among these volatile compounds, furans were most abundant in the control sample, followed by RSM No. 1. Overall, the RSM sample group identified that the number of furans exhibited a tendency of relative decrease compared to the control sample. Among the RSM sample groups, RSM No. 8 exhibited the highest number of aldehydes and heterocyclic compounds, with hexanal and aniline being the most abundant, respectively. Among the hydrocarbons, RSM No. 9 was the most abundant, particularly β-caryophyllene, which has a sweet odor. RSM No. 9 and No. 1 exhibited similar detection amounts for acids and esters, alcohols, ketones, and sulfur-containing compounds, respectively, and exhibited relatively higher contents than RSM No. 8 and the control.

The taste and volatile components of samples identified through the electron tongue and the electron nose were separated via PCA, a multivariate analysis (Fig. 7). In the PCA, the horizontal axis (PC1) and vertical axis (PC2) exhibited variances of 48.28% and 39.63 %, respectively, and a total of PCs exhibited 87.91% variance. Most samples were separated by PC1, and the control sample was on the positive axis of PC1, far from RSM sample groups. Thus, extrusion cooking can influence odor activation in sea mustard seasoning bases (Hong et al., 2021). RSM No. 9 and No. 1 were located along the positive axis of PC2. Alternatively, RSM No. 8 was located on the negative axis of PC2. RSM No. 8 was separated by volatile compounds of aldehydes and heterocyclic compounds and tastes of umami and sourness; thus, RSM No. 8 was located in the 3rd quadrant. RSM No. 1 and No. 9 were separated by acids, esters, ketones, sulfur-containing compounds, and alcohols; thus, these RSM samples were located in the 2nd quadrant. The control was separated by volatile furans and the taste of sweetness and saltiness; thus, the control sample was located in the 4th quadrant. In

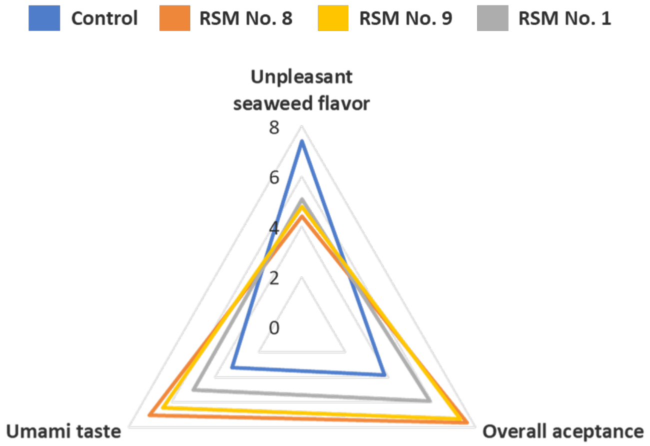

Fig. 5. Sensory characteristics of the control, RSM No. 1, RSM No. 8, and RSM No. 9 samples. The control sample refers to a product not subjected to extrusion cooking. RSM, response surface methodology.

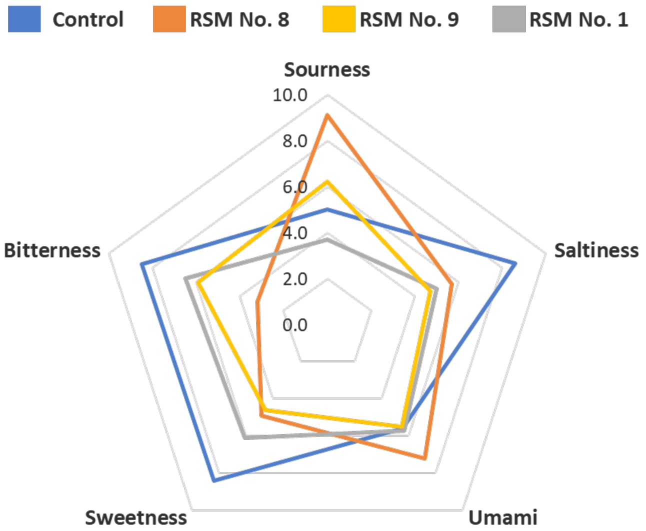

Fig. 6. Measurement of taste intensity of samples using an electronic tongue. The control sample refers to a product not subjected to extrusion cooking. RSM, response surface methodology.

Table 6. Volatile compounds in seasoning base from sea mustard (*Undaria pinnatifida*) produced via extrusion cooking and untreated sea mustard seasoning using electronic nose (Peak area × 10^3)

Compounds	RT (RI)	Sensory description	Control	RSM No. 8	RSM No. 9	RSM No. 1
Furans (5)						
2-Methylfuran	23.81 (615)	Acetone, burnt	0.28 ± 0.02	0.34 ± 0.01	ND	0.31 ± 0.01
Furfural	48.19 (847)	Almond	0.93 ± 0.03	ND	ND	ND
2-Furanmethanol	49.61 (861)	Alcoholic	0.49 ± 0.07	ND	ND	ND
2-Butylfuran	53.15 (895)	Sweet	ND	ND	ND	0.09 ± 0.07
5-Methylfurfural	61.49 (992)	Acidic	2.87 ± 0.29	ND	ND	ND
Aldehydes (14)						
Propenal	16.44 (466)	Almond	ND	4.90 ± 0.05	6.23 ± 0.24	ND
Propanal	17.61 (492)	Earthy	ND	5.21 ± 0.46	ND	5.16 ± 0.32
2-Methylpropanal	18.71 (517)	Fresh, aldehydic	0.85 ± 0.04	0.45 ± 0.01	1.62 ± 0.05	0.76 ± 0.03
2-Butenal	25.19 (630)	Green	1.23 ± 0.05	ND	2.82 ± 0.21	ND
2-Pentenal	35.99 (739)	Oily	ND	ND	ND	0.19 ± 0.03
Hexanal	43.50 (802)	Aldehydic, fatty	6.61 ± 0.19	12.13 ± 0.98	ND	ND
2-Hexanal	49.50 (860)	Aldehydic, bitter	ND	0.78 ± 0.17	ND	ND
Heptanal	53.12 (895)	Aldehydic, fresh	0.04 ± 0.03	1.24 ± 0.15	ND	ND
2-Heptanal	59.10 (964)	Earthy	ND	1.13 ± 0.25	ND	ND
Nonanal	69.76 (1,110)	Citrus, fresh	1.09 ± 0.03	1.44 ± 0.16	1.84 ± 0.23	1.26 ± 0.21
2-Nonenal	71.68 (1,142)	Fatty	0.16 ± 0.02	0.14 ± 0.02	0.16 ± 0.02	0.17 ± 0.07
2-Decanal	77.27 (1,238)	Aldehydic, earthy	ND	ND	ND	4.06 ± 0.68
Pentadecanal	99.20 (1,709)	Fresh	ND	ND	2.77 ± 0.48	0.50 ± 0.07
Heptadecanal	107.60 (1,900)	Sweet	ND	ND	0.28 ± 0.03	0.16 ± 0.01

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Table 6. Continued

Compounds	RT (RI)	Sensory description	Control	RSM No. 8	RSM No. 9	RSM No. 1
Heterocyclic compounds (4)						
Pyrrole	38.44 (759)	Sweet	ND	0.42 ± 0.05	ND	ND
4-Pentanolide	57.60 (946)	Sweet	ND	ND	0.14 ± 0.08	ND
Aniline	61.36 (990)	Amine, pungent	ND	5.90 ± 0.98	ND	ND
Ambroxide	104.86 (1,837)	Sweet	ND	1.10 ± 0.26	ND	ND
Hydrocarbons (12)						
Ethyl chloride	15.91 (454)	-	ND	ND	ND	0.09 ± 0.01
2-Methylbutane	16.45 (466)	-	0.22 ± 0.01	ND	ND	ND
Hexane	22.57 (601)	Alkane	1.84 ± 0.06	ND	4.25 ± 0.81	ND
Trichloroethane	27.21 (653)	Chloroform	0.45 ± 0.01	2.03 ± 0.05	ND	1.43 ± 0.10
Cyclohexane	28.22 (664)	Chloroform	0.67 ± 0.03	1.19 ± 0.04	ND	ND
Heptane	29.96 (684)	Alkane	ND	1.35 ± 0.08	0.70±0.18	1.23 ± 0.06
Trichloroethylene	31.51 (701)	Sweet	0.96 ± 0.01	ND	ND	ND
Octane	41.52 (785)	Alkane	ND	0.42 ± 0.08	ND	ND
Ethylbenzene	51.01 (874)	Sweet	0.42 ± 0.08	ND	ND	ND
α-Pinene	57.53 (945)	Citrus, earthy	ND	ND	ND	0.08 ± 0.08
1,2-Dichlorbenzene	64.52 (1,033)	Aromatic	ND	0.70 ± 0.14	ND	ND
β-Caryophyllene	88.40 (1,464)	Sweet	ND	18.10 ± 1.80	22.52 ± 1.09	ND
Acids and esters (17)						
Diisopropyl ether	21.97 (589)	-	0.92 ± 0.07	ND	1.74 ± 0.06	ND
Acetic acid	25.20 (631)	Acidic	ND	0.73 ± 0.03	1.26 ± 0.04	ND
Methyl propanoate	25.21 (631)	Fresh	ND	ND	ND	1.06 ± 0.03
Methyl isobutyrate	29.89 (683)	Sweet	0.59 ± 0.02	ND	ND	ND
Ethyl propanoate	31.99 (705)	Acetone	ND	ND	ND	0.92 ± 0.15
Ethyl isobutyrate	37.85 (754)	Alcoholic	0.15 ± 0.01	0.80 ± 0.06	0.50 ± 0.17	0.32 ± 0.02
2-Methylpropanoic acid	41.71 (787)	Acidic	0.20 ± 0.02	ND	ND	ND
Butanoic acid	45.19 (819)	Sweet	ND	0.08 ± 0.08	0.09 ± 0.02	0.11 ± 0.07
Ethyl trans-2-butenoate	45.99 (826)	Pungent	0.20 ± 0.04	ND	ND	ND
Ethyl 2-methylbutyrate	48.72 (852)	Sweet	ND	0.84 ± 0.01	ND	ND
3-Methylbutanoic acid	49.57 (861)	Acidic, sour	ND	ND	ND	0.91 ± 0.13
2-Methylbutanoic acid	50.95 (874)	Sweet	ND	ND	ND	1.10 ± 0.17
Isoamyl acetate	51.10 (875)	Ester, fresh	ND	ND	0.50 ± 0.10	ND
Butyl propanoate	54.89 (914)	Earthy	0.09 ± 0.01	0.51 ± 0.03	ND	ND
Amyl propanoate	59.28 (966)	Sweet	ND	ND	1.47 ± 0.60	ND
Butyl butanoate	61.43 (991)	Sweet	ND	ND	ND	6.00 ± 0.77
Ethyl phenylacetate	77.22 (1,237)	Sweet	ND	4.20 ± 0.44	4.13 ± 0.94	ND
Alcohols (18)						
Ethanol	15.21 (439)	Alcoholic	0.27 ± 0.01	ND	ND	ND
2-Propanol	17.59 (492)	Acetone, alcoholic	2.32 ± 0.07	ND	ND	ND
1-Propanol	20.36 (553)	Alcoholic	ND	1.38 ± 0.05	ND	ND
Propylenglycol	36.00 (739)	Alcoholic	0.15 ± 0.02	0.13 ± 0.02	ND	ND
3-Methyl-1-butanol	36.66 (744)	Alcoholic	ND	ND	0.05 ± 0.04	ND
Pentanol	37.84 (754)	Alcoholic	ND	0.37 ± 0.05	0.44 ± 0.08	0.45 ± 0.04
1-Hexen-3-ol	40.48 (777)	Green	ND	ND	0.96 ± 0.11	ND

Table 6. Continued

Compounds	RT (RI)	Sensory description	Control	RSM No. 8	RSM No. 9	RSM No. 1
2-Hexanol	43.55 (803)	Fatty	ND	ND	16.69 ± 3.80	11.69 ± 0.39
2-Methyl-1-pentanol	45.16 (818)	Sweet	0.04 ± 0.04	ND	0.36 ± 0.02	ND
2-Hexen-1-ol	49.70 (862)	Fresh	ND	ND	0.96 ± 0.34	ND
1-Hexanol	50.90 (873)	Alcoholic, fatty	ND	0.98 ± 0.22	ND	ND
2-Heptanol	54.13 (905)	Fresh, green	0.74 ± 0.04	ND	1.74 ± 0.25	ND
3-Methyl-3-sulfanylbutanol-1-ol	57.57 (946)	Vegetable	0.07 ± 0.01	ND	ND	ND
Phenol	61.52 (992)	Sweet	ND	ND	4.95 ± 1.33	ND
Benzyl alcohol	64.66 (1,035)	Phenolic	ND	ND	0.84 ± 0.17	ND
1-Octanol	67.36 (1,074)	Fresh, aldehydic	1.26 ± 0.16	1.89 ± 0.40	1.93 ± 0.64	1.90 ± 0.45
2,6-Dimethoxy-phenol	75.91 (1,213)	Phenolic	2.71 ± 0.40	ND	ND	ND
1-Dodecanol	88.53 (1,467)	Earthy	ND	ND	ND	13.38 ± 0.91
Ketones (10)						
Propan-2-one	17.60 (492)	Sweet	ND	ND	6.73 ± 0.90	ND
Butane-2,3-dione	21.90 (588)	Creamy, sweet	ND	1.41 ± 0.12	ND	1.21 ± 0.06
1-Hydroxy-2-propanone	28.25 (665)	Sweet	ND	ND	1.77 ± 0.03	1.09 ± 0.05
1-Penten-3-one	29.87 (683)	Sweet	ND	0.81 ± 0.13	ND	0.87 ± 0.12
2,3-Pentanedione	31.56 (701)	Burnt	ND	ND	2.30 ± 0.19	ND
3-Hydroxybutan-2-one	32.00 (705)	Creamy, sweet	ND	0.93 ± 0.17	ND	ND
1-Hexen-3-one	40.29 (775)	Vegetable	0.72 ± 0.01	ND	ND	0.90 ± 0.04
3-Hexanone	41.55 (786)	Fresh	ND	ND	0.53 ± 0.09	0.40 ± 0.02
3-Octen-2-one	64.59 (1,034)	Earthy, vegetable	0.54 ± 0.06	ND	ND	0.76 ± 0.19
Bezeophenone	99.19 (1,708)	Balsamic	0.66 ± 0.19	ND	ND	ND
Sulfur-containing compounds (8)						
Methanethiol	15.22 (439)	Fishy, sulfurous	ND	0.94 ± 0.01	1.06 ± 0.07	0.56 ± 0.03
Carbon disulfide	20.33 (553)	Burnt, sulfurous	0.75 ± 0.02	ND	1.71 ± 0.08	1.30 ± 0.04
2-Methyl-2-propanethiol	22.58 (601)	Sulfurous	ND	1.66 ± 0.06	ND	1.99 ± 0.03
3-Methyl-2-butene-1-thiol	45.90 (825)	Amine, sulfurous	ND	0.32 ± 0.04	ND	0.31 ± 0.04
Dimethyl sulfoxide	48.15 (847)	Oily, sulfurous	ND	ND	1.30 ± 0.04	1.02 ± 0.04
Methional	54.11 (905)	Earthy, musty	ND	ND	ND	1.08 ± 0.06
1-Hexanethiol	54.96 (915)	Burnt	ND	ND	0.59 ± 0.03	ND
Dimethyl trisulfide	59.17 (964)	Fishy, sulfurous	0.71 ± 0.10	ND	ND	1.26 ± 0.20

Data represent the mean ± SD in triplicate.
RT, retention time; RI, retention indices; ND, not detected, RSM, response surface methodology.

particular, bitterness was located in the 1st quadrant, which was opposite to RSM No. 8, and the preference was improved by greatly reducing the bitterness via optimization of the extrusion cooking conditions. The PCA results were similar to those of the sensory evaluation, and the RSM design of this study was confirmed suitable for optimization to manufacture sea mustard seasoning base.

In summary, this study presents the successful development of a high preference sea mustard seasoning base via extrusion cooking. Statistically, optimization was also successfully performed. In addition, using an electronic nose and tongue, it was confirmed that the flavor compounds were strengthened by extrusion cooking. In addition, the changes in the flavor compound profile due to extrusion cooking were confirmed. Overall, our study provides important basic data for developing various seasonings using seaweed.

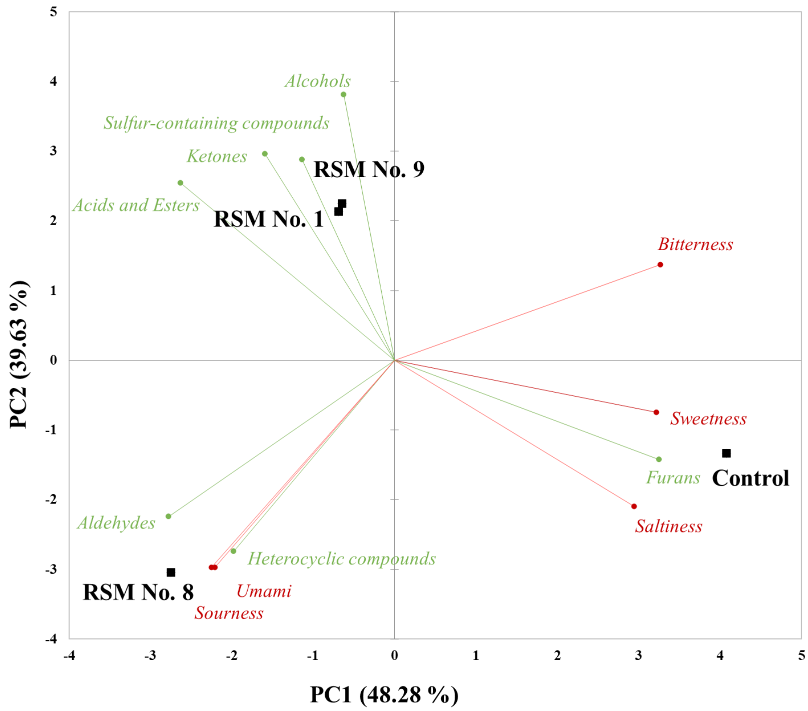

Fig. 7. Principal component analysis plot for taste and odor patterns in seaweed samples assessed by an electronic tongue and nose. RSM, response surface methodology.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and materials

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval and consent to participate

This article does not require IRB/IACUC approval because there are no human and animal participants.

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