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 (*X₁, 140°C–160°C*) and screw speed (*X₂, 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 *X₁ = 148.5°C* and *X₂ = 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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In this study, we aimed to optimize the extrusion cooking process for preparing a high preference seasoning base from Undaria pinnatifida. The optimization of the extrusion cooking process for the sea mustard seasoning base was performed via a statistical technique, response surface methodology (RSM). 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 ($X_1$, °C) 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-

### 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 °C–160 °C) 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 °C 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 ($X_1$, °C) 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 (°C) $X_1$ |        | 140 | 143 | 150 | 157 | 160 |
| Screw speed (rpm) $X_2$ |        | 158 | 181 | 236.5 | 537 | 315 |
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:

\[
Y = \beta_0 + \sum_{i=1}^{p} \beta_i X_i + \sum_{i=1}^{p} \sum_{j=1}^{q} \beta_{ij} X_i X_j
\]

where, \(Y\) is a dependent variable (overall acceptance); \(\beta_0\) is a constant; \(\beta_i\), \(\beta_{ij}\) and \(\beta_{ij}\) 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°C at a concentration of 5% (w/v), heated to 100°C 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°C and subsequently extracted by stirring for 1 h at 50°C 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 system.

**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 | Uncoded values | 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 (°C); \(X_2\), screw speed (rpm); \(Y\), overall acceptance (points).
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Results and Discussion

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°C 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°C and 250°C, respectively. The oven temperature program was initiated at 40°C for 5 s, increased to 270°C at a rate of 4°C/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).

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

| Parameters | Coefficient | \(X_1\) | \(X_2\) | \(X_1X_2\) | \(X_1X_1\) | \(X_2X_2\) |
|------------|-------------|---------|---------|------------|------------|------------|
| \(Y\)      | 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      |

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      |

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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 \(X_1X_1\) 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
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 °C), 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).

### 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 °C) 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,

### Table 5. Analysis of variance for dependent variables

| Source          | DF | SS           | MS   | F-value | p-value |
|-----------------|----|--------------|------|---------|---------|
| 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.

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

Fig. 2. Output results of response optimizer (MINITAB) for extrusion cooking parameters.
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.
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-carophyllene, 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.
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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   |
|--------------------|---------|---------------------|-------------|-------------|-------------|-------------|
| Furfural (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          | ND          |
| 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 |
| Heptadecan         | 107.60 (1,900) | Sweet               | ND          | ND          | 0.28 ± 0.03 | 0.16 ± 0.01 |

https://www.e-fas.org
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            | 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               | 0.42 ± 0.08 | ND            | ND            | ND            |
| Ethylbenzene               | 51.01 (874) | Sweet                | 0.42 ± 0.08 | ND            | ND            | ND            |
| α-Pinene                   | 57.53 (945) | Citrus, earthy       | ND          | ND            | 0.08 ± 0.08   |               |
| 1,2-Dichlorobenzene        | 64.52 (1,033) | Aromatic             | ND          | 0.70 ± 0.14   | ND            | ND            |
| β-Caryophyllene            | 88.40 (1,464) | Sweet               | 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            | 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            | 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) | Acetic               | 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            | 0.91 ± 0.13   |               |
| 2-Methylbutanoic acid      | 50.95 (874) | Sweet                | ND          | ND            | 1.10 ± 0.17   |               |
| Isoamyl acetate            | 51.10 (875) | Ester, fresh         | ND          | 0.50 ± 0.10   | ND            | ND            |
| Butyl propanoate           | 54.89 (914) | Earthy               | 0.09 ± 0.01 | 0.51 ± 0.03   | ND            | ND            |
| Amyl propanoate            | 59.28 (966) | Sweet                | ND          | 1.47 ± 0.60   | ND            |               |
| Butyl butanoate            | 61.43 (991) | Sweet                | ND          | ND            | 6.00 ± 0.77   |               |
| Ethyl phenylacetate        | 77.22 (1,237) | Sweet              | 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            |
| Propylglycol               | 36.00 (739) | Alcoholic            | 0.15 ± 0.02 | 0.13 ± 0.02   | ND            | ND            |
| 3-Methyl-1-butanol         | 36.66 (744) | Alcoholic            | ND          | 0.05 ± 0.04   | ND            |               |
| Pentanol                   | 37.84 (754) | Alcoholic            | ND          | 0.44 ± 0.08   | 0.45 ± 0.04   |               |
| 1-Hexen-3-ol               | 40.48 (777) | Green                | 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                          | 49.79 (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                            | 54.12 (907) | 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           | 13.38 ± 0.91 | ND           |
| 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        | 2.30 ± 0.19  | ND           | 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           | 0.90 ± 0.04  | ND           |
| 3-Hexanone                            | 41.55 (786) | Fresh               | ND        | 0.53 ± 0.09  | 0.40 ± 0.02  | ND           |
| 3-Octen-2-one                         | 64.59 (1,034) | Earthy, vegetable  | 0.54 ± 0.06 | ND           | 0.76 ± 0.19  | ND           |
| 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        | 1.30 ± 0.04  | 1.02 ± 0.04  | ND           |
| Methional                             | 54.11 (905) | Earthy, musty       | ND        | ND           | 1.08 ± 0.06  | ND           |
| 1-Hexanethiol                         | 54.96 (915) | Burnt               | ND        | 0.59 ± 0.03  | ND           | 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.
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.

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.

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