Processing Optimization of Restructured Jerky from Sea Rainbow Trout Frame Muscle

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Abstract This study determined optimal drying temperature and time on the moisture content, hardness, and overall sensory acceptance of restructured jerky from sea rainbow trout frame muscle (RJ-SRTF) using response surface methodology. The optimal drying conditions with respect to the above variables were 67.2°C for drying temperature and 8.6 h for drying time. The predicted values of response optimal conditions were 18.8 g/100 g for moisture content, 495.8 g/cm² for hardness, and a score of 7.2 for overall sensory acceptance. The actual values obtained in this experiment were 19.1±0.6 g/100 g for moisture content, 453.9±91.0 g/cm² for hardness, and a score of 7.4±0.5 for overall sensory acceptance. Both actual and predicted values were nearly identical. In conclusion, the models are adequately fitted to experimental data and suitable for optimization.

Keywords: jerky, fish jerky, restructured jerky, rainbow trout frame, rainbow trout

Introduction

In generally, jerky is a dried meat product from land animal, such as beef, pork and turkey, that are sliced, seasoned and dried. For the reason, the jerky is a popular convenient food for backpackers, campers and outdoor sports enthusiasts (1,2). The jerky sales have grown considerably in Korea as well as in Europe and the USA during the last decade (3). However, the commercial land animal jerkies contain the high content of saturated fatty acids, the addition of preservatives (i.e., sodium nitrite), and is not free from risk of bovine spongiform encephalopathy (BSE) and other animal related disease. In the sense, the raw materials used to produce the jerky are now receiving attention in an attempt to produce a more consumer-friendly product (4).

The main fish cultured across the Southern coast of Korea are the sea bream, black porgy, rock bream, common mullet, and filefish, all of which are warm-water fish (5). The extraordinary cold wave facts lead to the death of many warm-water fish. Salmonidae is known as cold-water fish, which includes rainbow trout, Pacific trout and salmon. Among the fishes, rainbow trout is an excellent source of protein, anserine, vitamin D, vitamin B₁₂ and selenium. It's also low in total fat and saturated fatty acids, and rich in polyunsaturated fatty acids (6,7). For these reasons, rainbow trout is a highly commercialized

fish in Europe and the USA. Although their natural habitat is approximately 12°C in the summer, these fish can tolerate water temperatures ranging from 0 to 25°C (8). Given its wide habitat temperature range, rainbow trout may be a suitable species to substitute for warm-water fish farmed off the Southern coast of Korea, where water temperatures frequently hit abnormal lows during the winter.

In Korea, the annual rainbow trout harvest exceeds 3,427 M/T and these fish are mainly used as a source of sliced raw fish. However, over 60% of the rainbow trout harvested is discarded as processing waste including bone, skin, fin, internal organs, and the head. Also discarded is the rainbow trout frame, which typically contains a considerable amount of muscle (9). This muscle could be used to produce restructured jerky, which are typically prepared from ground muscles so that they have a consistent appearance and texture. However, no study on the efficient uses of rainbow trout by-product, frame muscle, has been conducted yet. These issues necessitate the development of new methods for processing seafood waste; using some portion of this waste in preparing jerky may aid in this problem. With this in mind, optimizing the conditions necessary for creating palatable jerky from seafood by-products is a significant issue.

Response surface methodology (RSM) is a popular program for the

optimization of responses (output variables) with minimal experimental trials, which is influenced by several independent variables (input variables) (10–12). For these reasons, RSM is often applied to optimize drying conditions when preparing dried foods.

The aim of this study was to optimize the drying conditions (drying temperature and time) for processing good quality restructured jerky made from minced muscle of sea rainbow trout frame (RJ-SRTF) using RSM.

Materials and Methods

Material Sea rainbow trout (*Oncorhynchus mykiss*, body length 40.3–44.6 cm, body weight 0.9–1.1 kg) was purchased from Suduck Fisheries (fish farm, Tongyeong, Korea) in May 2014, and its frame muscle used for preparation of fish jerky in this experiment was obtained from frame separated after filleting.

Preparation of restructured jerky from muscle of sea rainbow trout frame For preparing RJ-SRTF, the minced muscle of sea rainbow trout frame was added with 0.8 times (v/w) of seasoning solution, blended and formed in a die (5.5×10.5×0.3 cm) before drying (54–76°C, 6–11 h) in a hot-air blast dryer. Final sample was width 5.0 cm, length 9.5 cm, and thickness 0.3 cm.

The composition (w/w) of mix for preparing jerky seasoning solution was 0.7% red paper (hot flavor), 1.2% salt (salty flavor), 10.5% sugars [a ratio of 5:9 (w/w) in sugar and high fructose corn syrup] (sweet flavor), 9.8% amino basic material (umami taste), 2.0% onion (fish odor-masking) (13), 0.2% ginger powder (fish odor-masking) (13), 0.08% cassia powder (fish odor-masking) and 0.3% green tea powder (fish odor-masking), based on total raw meat weight. These mix was added into 56.3% processing water, blended and heated at 121°C for 1 min for dissolving, extracting and sterilizing. The sterilized mix was sieved with a 100 mesh sieve and cooled up to 50°C before adding with 0.5% smoke solution (fish odor-masking).

Moisture content Moisture content of RJ-SRTF was quantified by oven drying at 105°C according to AOAC (14) method.

Hardness Hardness of RJ-SRTF was determined with a rheometer (Rheometer Compac-100; Sun Scientific Co., Tokyo, Japan) and expressed as max force (kg/cm²) required for cutting sample. The max force was calculated using rheology data system ver. 2.01.

Overall sensory acceptance For evaluating overall sensory acceptance, RJ-SRTFs were assessed by a 10 member trained panel. Each sample was served to the panelists in random order, and the evaluations were performed by the panelists under fluorescence lighting. Panelists were instructed to cleanse their plates between samples using warm water. A 9-points hedonic scale (9, extremely desirable; 7, desirable; 5, fair; 3, undesirable; 1, extremely undesirable) was used to grade the overall sensory acceptance of jerkies.

Experimental design Central composite design (CCD) (15) was adapted in the optimizing for drying jerkies using minced muscle from sea rainbow trout frame. CCD in the experimental design consist of 2² factorial points, four axial points ($\alpha=1$) and three replicates of the central points. RJ-SRTF quality, such as flavor and texture is extensively affected by drying conditions, such as drying temperature and time. Drying temperature (53.7–76.3°C) and time (6.2–11.8 h) were chosen for independent variables. The range and center point values of two independent variables were based on the results of preliminary experiments (Table 1). In general, the texture of sliced, seasoned, and dried fish is hard. However, consumers tend to prefer fish with a softer texture. The texture of sliced, seasoned, and dried fish is strongly affected by the moisture content. The texture of the jerky is soft when the moisture content is high and becomes hard when the moisture content is low. The sensory quality indicators of jerky are flavor, nutrient content, texture, etc. Considering consumer preferences, the moisture content and texture, in terms of hardness, should also be included as sensory quality indicators. Thus, the present study selected moisture content and hardness as the quality indicators of jerky. Moisture content (g/100 g), hardness (kg/cm²) and overall sensory acceptance (sensory score) were selected as the dependent variables for the combination of the independent variables were given in Table 2. Experimental runs were randomized in order to minimize the effects of unexpected variability in the observed responses.

Data analysis The response surface regression (RSREG) procedure of the Statistical Analysis System software (Version 8.01, SAS Institute Inc., Cary, NC, USA) was used to fit the following quadratic polynomial equation

$$Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j$$

where Y is the dependent variable (moisture content, hardness and sensory overall acceptance), β_0 is constant, β_i , β_{ii} , and β_{ij} are

Table 1. Symbol, experimental range and values of the independent variables in the central composite design for preparing restructured jerky from sea rainbow trout frame muscle

Independent variable	Symbol	Range level				
		-1.414	-1	0	+1	+1.414
Drying temperature (°C)	X_1	53.7	57	65	73	76.3
Drying time (h)	X_2	6.2	7	9	11	11.8

regression coefficients, and X_i and X_j are levels of the independent variables. Ridge Max option of RSREG procedure was used to compute the estimated ridge of optimum response for increasing radii from the center of the origin design. Multiple response optimization was heuristically calculated by desirability function of MINITAB statistical software (Version 14, Minitab Inc., State College, Pennsylvania, PA, USA), to search for the condition simultaneously satisfying two dependent variables (Y_1 , Y_2 , and Y_3). The response surface plots were developed using the Maple software (Maple 7, Maple Inc., Waterloo, ON, Canada) and represented a function of two independent variables while keeping the other independent variables at the optimal values.

Results and Discussion

Model fitting and verification of predicted values The RSREG procedure of the Statistical Analysis System software was adapted for fitting the experimental data (Table 2) to the quadratic polynomial equation. All regression coefficients of linear, quadratic, and interaction terms and the significances in the polynomial regression equation are shown in Table 3. Regardless of the response variables and coefficients, all the regression coefficients were significant at $p < 0.05$, which indicate the considerable effect on the responses. Thus, all the respective response variables, such as Y_1 , Y_2 , and Y_3 , were thought to be affected by all the terms, such as linear (X_1 and X_2), quadratic (X_1X_1 and X_2X_2), and interaction terms (X_1X_2). Quadratic regression equation was developed for predicting response variables, such as the moisture content, hardness, and overall sensory acceptance of RJ-SRTF within selected experimental conditions using RSM. The quadratic regression equation can be expressed as the following equations:

$$Y_1 = 19.4 - 4.7X_1 - 3.2X_2 - 0.5X_1^2 + 0.2X_2^2 + 0.9X_1X_2 \quad (R^2 = 0.999, p = 0.013)$$

$$Y_2 = 476.5 + 118.6X_1 + 73.2X_2 + 23.0X_1^2 + 7.0X_2^2 - 22.1X_1X_2 \quad (R^2 = 0.998, p = 0.039)$$

$$Y_3 = 7.4 - 0.4X_1 - 0.4X_2 - 1.5X_1^2 - 1.2X_2^2 + 0.1X_1X_2 \quad (R^2 = 0.999, p = 0.000)$$

where Y_1 is moisture content (g/100 g), Y_2 is hardness (g/cm²), Y_3 is overall sensory acceptance (score), X_1 is drying temperature (°C), and

Table 2. Central composite design of independent variables and responses of dependent variables for preparing restructured jerky from sea rainbow trout frame muscle

Run no.	Independent variable ¹⁾		Response variable ²⁾		
	X_1	X_2	Y_1	Y_2	Y_3
1	57	7	28.1	296.4	5.6
2	73	7	16.8	571.7	4.5
3	57	11	19.8	481.2	4.6
4	73	11	12.2	668.3	4.0
5	53.7	9	24.8	352.8	4.9
6	76.3	9	11.7	696.6	3.8
7	65	6.2	24.3	384.9	5.5
8	65	11.8	15.3	600.2	4.4
9	65	9	19.4	476.6	7.3
10	65	9	19.5	475.2	7.4
11	65	9	19.4	477.8	7.4

¹⁾Independent variable: X_1 (drying temperature, °C), X_2 (drying time, hour)

²⁾Response variable: Y_1 (moisture, g/100 g), Y_2 (hardness, g/cm²), Y_3 (sensory overall acceptance, score)

X_2 is drying time (h).

The response surface model's accuracy should be checked to draw excellent results of the fitted response surface model (16). The p values for the fitted models for the moisture content, hardness, and overall acceptance of RJ-SRTF were less than 0.01 (Table 4). However, values on the lack of fit were 0.091 for moisture content, 0.029 for hardness and 0.758 for overall sensory acceptance, which also indicate the adaptability of these models to experimental data of moisture content and overall sensory acceptance. The coefficient of determination (R^2) is a relative comparison criterion between the experimental and predicted values (15). The R^2 values from the three models for moisture content, hardness, and overall sensory acceptance of RJ-SRTF were very highly significant at $p < 0.05$. The higher values of R^2 produced here suggest that the models justified a good correlation between the dependent variables (drying temperature and time) and the independent variables (moisture content, hardness and overall sensory acceptance) (17).

Drying temperature (65°C) and time (9 h) were adopted as the central conditions of the central composite design for optimizing RJ-SRTF drying conditions. Optimal conditions of coded and actual

Table 3. Estimated coefficient of the fitted quadratic polynomial equation of different responses for preparing restructured jerky from sea rainbow trout frame muscle based on t -statistic statistic

	Y_1 ²⁾		Y_2		Y_3	
	Coefficient	p -value	Coefficient	p -value	Coefficient	p -value
Intercept	19.4	0.000	476.5	0.000	7.4	0.000
X_1 ¹⁾	-4.7	0.000	118.6	0.000	-0.4	0.000
X_2	-3.2	0.000	73.2	0.000	-0.4	0.000
X_1X_1	-0.5	0.000	23.0	0.000	-1.5	0.000
X_2X_2	0.2	0.013	7.0	0.039	-1.2	0.000
X_1X_2	0.9	0.000	-22.1	0.001	0.1	0.003

¹⁾Independent variable: X_1 (drying temperature, °C), X_2 (drying time, h).

²⁾Response variable: Y_1 (moisture, g/100 g), Y_2 (hardness, g/cm²), Y_3 (sensory overall acceptance, score)

Table 4. Analysis of variance (ANOVA) for response of dependent variables for preparing restructured jerky from sea rainbow trout frame muscle

Independent		DF	SS	MS	F-value	p-value
$Y_1^{1)}$	Model	5	263.221	52.644	2440.98	0.000
	Linear	2	257.189	128.594	5962.61	0.000
	Square	2	2.610	1.305	60.51	0.000
	Interaction	1	3.423	3.423	158.69	0.000
	Residual	5	0.108	0.022	-	-
	Lack of fit	3	0.101	0.034	10.12	0.091
	Pure error	2	0.007	0.003	-	-
	Total	10	263.329	-	-	-
Y_2	Model	5	1603228	32065.6	908.28	0.000
	Linear	2	155389	77694.4	2200.74	0.000
	Square	2	2995	1497.3	42.41	0.000
	Interaction	1	1945	1944.8	55.09	0.001
	Residual	5	177	35.3	-	-
	Lack of fit	3	173	57.7	34.08	0.029
	Pure error	2	3	1.7	-	-
	Total	10	160505	-	-	-
Y_3	Model	5	18.8691	3.77382	1729.72	0.000
	Linear	2	2.4920	1.24600	571.10	0.000
	Square	2	16.3146	8.15729	3738.88	0.000
	Interaction	1	0.0625	0.06250	28.65	0.003
	Residual	5	0.0109	0.00218	-	-
	Lack of fit	3	0.0042	0.00141	0.42	0.758
	Pure error	2	0.0067	0.00333	-	-
	Total	10	18.8800	-	-	-

¹⁾Response variable: Y_1 (moisture, g/100 g), Y_2 (hardness, g/cm²), Y_3 (sensory overall acceptance, score)

values of multiple responses are shown in Table 5. The optimal drying temperatures and times were 0.84 and 1.41, respectively, for moisture content, -0.30 and 0.09, respectively, for hardness, and both 0 for overall sensory acceptance score, in coded values. The optimal drying conditions were also 71.7°C and 7.0 h for moisture content, respectively, 62.6°C and 9.2 h, respectively, for hardness, and 65.0°C and 9.0 h, respectively, for overall sensory acceptance score, in actual values. The MINITAB statistical software was used to concurrently optimize three dependent variables, the desirability function was put as follows: moisture content=19.0 g/100 g, hardness=450 g/cm², and overall sensory acceptance=maximum. The optimal independent variables regarding the dependent variables (moisture content, hardness, and overall sensory acceptance) were 0.27 for drying temperature and -0.22 for drying time in coded values and 67.2°C for drying temperature and 8.6 h for drying time in actual values. The predicted values of the RJ-SRTF dried under multiple response optimal drying conditions (67.2°C, 8.6 h) were moisture content=18.8 g/100 g, hardness=495.8 g/cm², and overall sensory acceptance=7.2 score.

The RJ-SRTF prepared under multiple response optimal drying conditions (67.2°C, 8.6 h) showed moisture content=19.1±0.6 g/100 g, hardness=453.9±91.0 g/cm², and sensory overall acceptance score=7.4±0.5. Both actual and predicted values were nearly identical, and thus, the estimated response surface model was adopted for the optimization of RJ-SRTF processing.

Response surface plots and the effects of factors The estimated response function and the effect of drying temperature and time on moisture content, hardness, and overall sensory acceptance are shown in Fig. 1. The RJ-SRTF processing needs one important process of drying process (18). Drying temperature and drying time are major factors in the treatment of any dried food (19,20). The response surface plots shown in this study present the interrelationship between drying temperature and time with one jerky property (i.e., moisture content, hardness, or overall sensory acceptance). As the coded values of both drying temperature and time were closed to +1.414, moisture content decreased (Fig. 1A), but hardness increased (Fig. 1B). This increased hardness was attributed to the decrease in moisture content. However, the effect of drying temperature and time on overall sensory acceptance was distinct from the other variables (Fig. 1C). As the coded values of both drying temperature and time were closed to zero, overall sensory acceptance increased. However, as the coded values of drying temperature and time closed to +1.414, the overall sensory acceptance decreased. This pattern was attributed to the soft or hard textures of RJ-SRTF formed by changing the moisture content.

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Table 5. Optimal conditions predicted for preparing restructured jerky from sea rainbow trout frame muscle obtained by MINITAB program

Target of independent ²⁾	Independent	
	$X_1^{1)}$	X_2
Y_1 : 19 g/100 g	Coded value 0.84	-1.41
	Actual value 71.7°C	7.0 h
Y_2 : 450 g/cm ²	Coded value -0.30	0.09
	Actual value 62.6°C	9.2 h
Y_3 : Maximum	Coded value 0.0	0.0
	Actual value 65.0°C	9.0 h
Multiple response optimization	Coded value	0.27
	Actual value	67.2
	Predicted	Y_1 : 18.8 g/100 g, Y_2 : 495.8 g/cm ² , Y_3 : 7.2 score
Experimental value		Y_1 : 19.1±0.6 g/100 g, Y_2 : 453.9±91.0 g/cm ² , Y_3 : 7.4±0.5 score

¹⁾Independent variable: X_1 (drying temperature, °C), X_2 (drying time, h)²⁾Response variable: Y_1 (moisture, g/100 g), Y_2 (hardness, g/cm²), Y_3 (sensory overall acceptance, score) **Fig. 1.** Three dimensional response surface plots for preparing restructured jerky from sea rainbow trout frame muscle based on the moisture (A), hardness (B) and sensory overall acceptance (C). Independent variable: X_1 (drying temperature, °C), X_2 (drying time, h). Response variable: Y_1 (moisture, g/100 g), Y_2 (hardness, g/cm²), Y_3 (sensory overall acceptance, score)**Disclosure** The authors declare no conflict of interest.

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