Changes in physical properties of Yukwa (fried rice snack) by soybean extract concentration and incubation time

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Abstract This study assessed the effects of soybean extract concentration and incubation time on the physical properties of Yukwa, a traditional Korean oil-puffed snack. Notably, whiteness decreased, while redness and yellowness increased as the soybean extract concentration increased. The expansion rate of Yukwa increased as the soybean extract concentration increased. Moreover, that in the 0 and 7% soybean extract groups decreased, followed by slight increase as the incubation time increased, and the 14% soybean extract treatment group showed increased expansion with incubation time. The oil absorption rate of Yukwa increased with soybean extract concentration and incubation time, and the hardness of Yukwa was decreased as the soybean extract concentration and incubation time increased. Peak number increased with soybean extract concentration, but decreased with incubation time. Finally, response surface analysis showed that a soybean extract concentration of 7.69% and incubation time of 6.41 h were optimal for achieving the desired peak number.

Keywords Yukwa · Soybean extract · Incubation time · Physical properties · Response surface methodology

Introduction

Yukwa, a traditional Korean snack, is made from waxy rice that is puffed in oil; it has a distinct taste and texture and is therefore used in ancestral memorial services or as a seasonal food [1, 2]. Yukwa is characterized by its porous tissue, sterility due to production at a high temperature, lightness, and low density. Moreover, Yukwa is considered a fermented food since the activity of microorganisms is involved in the incubation process [3–5]. Yukwa is also high in calories since it has high oil content, i.e., due to cooking in oil. Furthermore, since Yukwa is porous, moisture absorption changes its properties and results in fragility upon handling. Indeed, oxidation of fat at high temperatures could reduce Yukwa quality during storage [3, 6].

To date, studies on Yukwa have assessed production methods [4, 7], puffing methods [8, 9], waxy rice soaking time, physical and chemical changes [9, 10], quality characteristics [11–13], and storage [14–16]. Moreover, recent papers have discussed the quality characteristics of Yukwa produced with different additives, such as chlorella powder [17], curry powder [18], prickly pear [19], peach seed [20], Gugija (*Lycii fructus*) powder [21, 22], and green tea powder [13, 23]. In particular, previous studies related to the Yukwa production process have focused primarily on the time of waxy rice soaking. Thus, changes that occur during soaking and related mechanism have been identified, providing the basis for standardization.

However, studies on the effects of soybean extracts, the primary supplementary material, on the quality of Yukwa have only been conducted in the context of Yukwa characteristics. No studies have assessed the mechanisms of action of soybean extracts [24].

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In general, the waxy layer is soaked for 7–14 days, supplementary materials, such as soybean extract and *cheongju* (clear rice-wine), are added, the dough is kneaded and steamed to make bandegi, and the bandegi is then dried and subjected to a frying process to produce Yukwa. A long soaking process is essential to produce Yukwa; during soaking, changes in the amylopectin structure arising from the degradation effect of waxy rice starch due to α -amylase secreted by microorganisms softens the texture and induces puffing [24, 25].

However, the reason for adding soybean extract as supplementary material during Yukwa kneading is to enhance Yukwa quality through the action of α -amylase in soybean extract on starch degradation. Thus, instead of adding soybean extract followed by immediate kneading, the temperature at which starch degradation enzymes in soybean extract have the maximum activity should be determined, and the dough should be incubated for 0–24 h at this optimum temperature to increase the time for starch degradation. This would reduce the inconvenience of prolonged soaking and produce Yukwa with a soft texture and high overall acceptance [24].

Accordingly, in this study, we aimed to determine the optimum soybean extract concentration and incubation time for efficient production and quality enhancement of Yukwa. Our findings provided important insights into the effects of various parameters on Yukwa production [24].

Materials and methods

Materials

Raw materials for waxy rice and soy beans were obtained from a commercial source in Korea. Soybean extract was produced by soaking the beans in water to remove the skin, followed by addition of distilled water to produce bean contents of 7 and 14% (w/v); the soybean extract was then ground with a blender and filtered with 80-mesh sieve for use.

Yukwa production

Ground waxy rice powder (700 g), *cheongju* (clear rice-wine, 150 mL), and water (270 mL) were mixed to produce the control group, and 7 or 14% soybean extract was added instead of water for the treatment groups. Each mixture was kneaded for 5 min and incubated at 60 °C for 0, 3, 6, 9, or 12 h, followed by heating for 10 min in a Convothrm oven at 100 °C. After steaming, the dough was transferred to a container to be punched 320 times with a wooden bar. Then, the dough was rolled and cut to a size of 6 cm × 6 cm with a thickness of 0.3 cm and dried at

room temperature (23 ± 2 °C), during which the dough was flipped over every 30 min, until reaching a moisture content of 11–13%. Dried bandegi was placed in oil for 2 min at 30 °C for puffing, followed by 20 s of frying at 170 °C to produce Yukwa.

Experimental design

Soybean extract concentration (X1) and incubation time (X2) were used as factor variables. A Three coded level of X1 and a five-coded level of X2 were incorporated in the design. Response variables (Yn) were expansion rate, hardness, peak number, oil absorption, and color parameters. Experiments were repeated three times, and the average was used in the regression analysis. In model estimation for regression analysis, SAS was used to verify significance. Furthermore, expansion rate, hardness, peak number, and colors were analyzed using a response surface analysis method to determine the optimum condition.

Physical analysis

The color of Yukwa was measured using a color-difference meter (Minolta CR-210, Minolta, Osaka, Japan) with Hunter colors, L, a, b, and ΔE values. As a standard, we used a white board with L = 97.23, a = −1.02, and b = 2.16 values. To measure the expansion rate, the weight of dry Yukwa bandegi before expansion was measured, and the volume of Yukwa bandegi that underwent puffing in oil, followed by drainage for 30 min, was measured to calculate the expansion rate using the substitution method. The expansion rate is shown as the volume (mL) of oil puffed Yukwa per 1 g dry weight of Yukwa bandegi.

The oil absorption was obtained by measuring the weight of Yukwa bandegi samples before and after frying. The difference was calculated as the oil absorption, as follows:

$$\begin{aligned} \text{Oil Absorption (\%)} \\ &= \frac{\text{Yukwa weight after frying (g)} - \text{Yukwa bandegi weight before frying (g)}}{\text{Yukwa bandegi weight before frying (g)}} \\ &\quad \times 100 \end{aligned}$$

Yukwa texture was measured using a texture analyzer (TA), and the measured area was from the center of the Yukwa to 2 cm from the two diagonal ends. Texture profiles were calculated from the force-distance obtained when pressurized in order to measure hardness and peak number. Yukwa hardness was the region with the highest peak in the first bite of force-distance curve from TA. Peak number was calculated to reflect crispiness. Pre-, test, and post-speed were set to 5.0, 0.5, and 10.0 mm/s, respectively. All analyses were performed in triplicate.

Statistical analysis

The experimental data were analyzed using the RSREG procedure in SAS 9.4 (SAS Institute Inc. Cary, NC, USA).

Results and discussion

Color

Changes in Yukwa color according to soybean extract concentration and incubation time are shown in Table 1. The measured colors did not differ dramatically between 0 and 7% soybean extract treatment groups in terms of L values; however, the 14% treatment group showed a significantly lower L value ($p < 0.05$), reflecting a decrease in the whiteness of Yukwa as the concentration of soybean extract increased. Furthermore, a and b values increased as the soybean extract concentration increased, indicating that the redness and yellowness of the product increased as the soybean extract concentration increased. L, a, and b values were used to calculate ΔE values, which was similar in 0 and 7% soybean extract treatment groups, but significantly

higher in the 14% treatment group ($p < 0.05$), reflecting the darker color of the 14% soybean extract treatment group. Lee et al. [26] reported increased coloration compared with the no treatment group when soybean oil was added during the last stage of rice polishing, consistent with our current results. Furthermore, Kim et al. [27] reported that the addition of soybean slurry and hot water extract in Yukwa production resulted in distinct changes in coloration and suggested that this result could be explained by the presence of pigments such as isoflavonoids in soybeans and the browning reaction of sugars, such as glucose, under high temperature conditions.

Therefore, the observed darker color in the 14% soybean extract treatment group in this experiment could be due to the sharp increase in the amount of reduced sugar from the starch degradation effect of the soybean extract. Moreover, color changes in Yukwa according to increased incubation time were not significant, with an exception of b values.

Expansion rate

The expansion rate measurement results of Yukwa are shown in Table 1. Although the expansion rate showed an

Table 1 Summary of response surface models

Attribute	Model
Expansion rate	$Y = 10.38 + 0.39(X1) - 0.05(X2) - 0.02(X1^2) + 0.01(X2^2) + 0.02(X1X2)$
Hardness	$Y = 2561.77 - 396.68(X1) - 59.71(X2) + 17.14(X1^2) - 2.02(X2^2) + 5.74(X1X2)$
Peak number	$Y = 58.66 + 2.28(X1) + 4.03(X2) - 0.14(X1^2) - 0.30(X2^2) - 0.02(X1X2)$
Oil absorption	$Y = 0.18 + 0.02(X1) + 0.01(X2) - 0.0004(X1^2) + 0.0002(X2^2) - 0.001(X1X2)$
Color (L)	$Y = 77.11 + 0.50(X1) + 0.19(X2) - 0.06(X1^2) + 0.01(X2^2) - 0.02(X1X2)$
Color (a)	$Y = -0.93 + 0.28(X1) + 0.10(X2) - 0.003(X1^2) - 0.0005(X2^2) - 0.01(X1X2)$
Color (b)	$Y = 12.45 + 0.70(X1) - 0.22(X2) - 0.01(X1^2) + 0.03(X2^2) - 0.02(X1X2)$
Color (ΔE)	$Y = 22.61 - 0.04(X1) - 0.29(X2) + 0.05(X1^2) + 0.03(X2^2) - 0.02(X1X2)$

The independent variable Y is the response. Variables for actual levels are X1 (soybean extract) and X2 (incubation time)

Table 2 Analysis of variance showing the effects of treatment variables on the response variables

Regression	df	F value							
		Expansion rate	Hardness	Peak number	Oil absorption	Color			
						L	a	b	ΔE
Linear	2	5.73**	195.78**	7.86**	49.95**	30.61**	38.14**	43.27**	0.83
Quadratic	2	1.65	75.15**	2.12	1.24	21.18**	0.3	1.68	3.26
Cross product	1	1.48	15.05**	0.5	4.28	1.36	4.8*	2.45	26.17**
Lack of fit	9	5.7**	3.93**	1.7	1.85	31.58**	64.35**	31.66**	10.35**
Total regress	5	3.25**	110.58**	4.09**	21.33**	20.99**	16.33**	18.47**	6.87**

* Significant at $p < 0.05$

** Significant at $p < 0.01$

Table 3 Changes in expansion rate, texture parameters, oil absorption, and the color of Yukwa by soybean extract and incubation time

Soybean extract (%)	Incubation time (h)	Expansion rate	Hardness (kg)	Peak number	Oil absorption (%)	Color	L			ΔE
							a	b		
0	0	10.24 ± 3.00 ^{defgh}	2.40 ± 0.76 ^b	59.56 ± 13.09 ^e	0.20 ± 0.04 ^{fg}	76.93 ± 0.52 ^{de}	− 1.15 ± 0.10 ^f	11.77 ± 0.28 ^f		22.45 ± 0.58 ^g
	3	8.65 ± 2.88 ^{gh}	2.93 ± 0.58 ^a	67.89 ± 9.77 ^{abcde}	0.19 ± 0.05 ^g	75.80 ± 0.32 ^f	0.63 ± 0.24 ^d	15.57 ± 0.94 ^d		25.34 ± 0.78 ^e
	6	11.26 ± 0.65 ^{cdefgh}	1.85 ± 0.81 ^c	80.56 ± 11.08 ^{ab}	0.24 ± 0.04 ^{efg}	79.68 ± 0.24 ^a	− 1.25 ± 0.02 ^f	9.75 ± 0.13 ^g		19.12 ± 0.17 ⁱ
	9	12.03 ± 2.86 ^{cdefg}	1.98 ± 0.36 ^c	60.75 ± 16.50 ^e	0.25 ± 0.05 ^{efg}	76.07 ± 0.38 ^{ef}	0.05 ± 0.10 ^e	13.42 ± 0.52 ^e		24.00 ± 0.58 ^f
	12	10.70 ± 3.01 ^{defgh}	1.42 ± 0.53 ^d	63.00 ± 21.17 ^{de}	0.26 ± 0.08 ^{defg}	76.94 ± 0.21 ^{de}	− 0.18 ± 0.05 ^e	12.88 ± 0.15 ^e		22.97 ± 0.21 ^{fg}
7	0	16.38 ± 2.75 ^a	0.57 ± 0.14 ^e	65.00 ± 12.75 ^{bcdle}	0.28 ± 0.07 ^{cde}	77.50 ± 0.31 ^{de}	0.70 ± 0.41 ^d	16.20 ± 1.94 ^{cd}		24.29 ± 2.22 ^{ef}
	3	9.87 ± 2.09 ^{fgh}	0.40 ± 0.08 ^e	71.22 ± 17.73 ^{abcde}	0.27 ± 0.13 ^{def}	78.60 ± 0.11 ^b	0.68 ± 0.09 ^d	15.75 ± 0.15 ^{cd}		23.13 ± 0.05 ^{fg}
	6	10.11 ± 3.29 ^{efgh}	0.43 ± 0.09 ^e	81.22 ± 8.67 ^a	0.30 ± 0.06 ^{bcdle}	80.23 ± 0.23 ^a	0.08 ± 0.14 ^e	13.64 ± 0.69 ^e		20.55 ± 0.31 ^h
	9	15.53 ± 3.77 ^{ab}	0.32 ± 0.05 ^e	79.63 ± 7.60 ^{abc}	0.38 ± 0.07 ^a	78.09 ± 0.54 ^{bd}	1.28 ± 0.31 ^c	16.25 ± 0.32 ^{cd}		23.88 ± 0.63 ^f
	12	13.46 ± 1.42 ^{abcde}	0.28 ± 0.07 ^e	76.67 ± 8.85 ^{abcd}	0.35 ± 0.04 ^{abc}	75.41 ± 0.24 ^{fg}	2.07 ± 0.05 ^b	19.65 ± 0.20 ^a		28.13 ± 0.31 ^c
14	0	8.41 ± 2.44 ^h	0.44 ± 0.08 ^e	64.44 ± 11.83 ^{cde}	0.40 ± 0.06 ^a	72.16 ± 0.34 ^h	2.51 ± 0.23 ^a	20.51 ± 0.25 ^a		31.27 ± 0.39 ^a
	3	12.89 ± 3.27 ^{bcddef}	0.48 ± 0.06 ^e	73.90 ± 17.85 ^{abcde}	0.33 ± 0.04 ^{abcd}	73.10 ± 0.51 ^h	1.54 ± 0.06 ^c	18.59 ± 0.18 ^b		29.31 ± 0.43 ^{bc}
	6	14.45 ± 2.97 ^{abc}	0.32 ± 0.05 ^e	77.44 ± 15.96 ^{abcd}	0.35 ± 0.09 ^{abc}	70.80 ± 0.43 ⁱ	2.57 ± 0.17 ^a	19.90 ± 0.17 ^a		32.04 ± 0.45 ^a
	9	13.58 ± 3.71 ^{abcd}	0.38 ± 0.06 ^e	66.89 ± 11.47 ^{abcde}	0.39 ± 0.12 ^a	72.74 ± 0.87 ^h	2.44 ± 0.09 ^a	18.59 ± 0.19 ^b		29.70 ± 0.30 ^b
	12	13.69 ± 2.91 ^{abcd}	0.28 ± 0.04 ^e	63.88 ± 18.76 ^{cde}	0.36 ± 0.08 ^{ab}	74.79 ± 0.53 ^g	0.66 ± 0.23 ^d	16.85 ± 0.61 ^c		26.87 ± 0.78 ^d

Values are represented as mean ± standard deviation (n = 3)

Values with different letters in same column are significantly different ($p < 0.05$)

increasing trend as the soybean extract concentration and incubation time increased, this change was not substantial. Shin et al. [28] compared the expansion rate of Yukwa production with the addition of some additives, such as soaked soybean, soybean extract, baking powder, modified starch, and various alcoholic beverages. They reported that the addition of soaked soybeans increased the expansion rate of Yukwa compared with bean soup treatment or no treatment; however, there were no differences in the baking powder treatment group. Furthermore, Shin and Choi [29] reported that prolonged incubation of dough at 60 °C resulted in the degradation of starch by starch-degrading enzymes in beans, which in turn led to reduced elasticity of the dough and reduced expansion rate. However, adding

soaked soybean slowed down the quality deterioration rate. That is, the addition of soybeans resulted in a better expansion rate than that without soybeans at the same incubation time. Therefore, these results were consistent with the other finding in this study.

Oil absorption

The results of oil absorption measurements of Yukwa are shown in Table 1. The oil absorption was significantly ($p < 0.05$) increased as the soybean extract concentration increased, and those in the 0 and 7% soybean extract treatment groups tended to increase with longer incubation times. The increase in oil absorption with soybean extract

Fig. 1 Changes in physical properties of Yukwa at different soybean extract concentrations and incubation times. (A) Expansion rate, (B) hardness, (C) peak number, (D) oil absorption, (E) color L, (F) color a, (G) color b, (H) color ΔE . (Color figure online)

concentration could be due to the emulsion action of lecithin in beans [28].

Texture

The texture of Yukwa was measured and compared using a TA by measuring the hardness and peak number, which represents crispiness. In terms of hardness, the 0% soybean extract treatment group showed five- to six-fold higher hardness compared with the 7 and 14% treatment groups. These findings indicated that the addition of soybean extract softened the Yukwa tissue. Hardness was significantly ($p < 0.05$) decreased as the incubation time of the dough increased. Peak number showed an increasing trend as the soybean extract concentration increased from 0 to

7% and a decreasing trend as the soybean extract concentration increased from 7 to 14%, suggesting that addition of 7% soybean extract would result in crispier Yukwa. In contrast, peak number decreased when Yukwa was incubated for more than 6 h; this could be due to the decreased crispiness owing to the degraded molecular structure of starch from prolonged exposure of dough at high temperatures [29].

Response surface analysis

We aimed to determine the optimal values of objective measurements, such as expansion rate, hardness, and peak number using response surface models for each property (Table 2), where X1 and X2 are independent variables for

Fig. 1 continued

response surface analysis, representing soybean extract concentration and incubation time, respectively. The dependent variable Y was the objective measurement value, i.e., expansion rate, hardness, peak number, oil absorption, and colors. Higher values for expansion rate, peak number, and color L are known to improve the properties of Yukwa. Moreover, the color values a, b, and ΔE were further from the baseline value, including poor quality, and Yukwa with white coloration was considered better than that with red or yellow coloration.

The verification results for significance of the regression equation for each property are shown in Table 3. The *p* value of total regression was used to verify the significance of the response surface models, and all parameters, including expansion rate, hardness, peak number, oil absorption, and colors, showed significant differences. Finally, the response surface model was used to analyze each property. As shown in Fig. 1, the response surface model results indicated that the saddle point for expansion rate, hardness, oil absorption, and color (a, b) was the stationary point, while the minimum point of color ΔE was found to be the stationary point, and the maximum point of peak number and color L was found to be the stationary point.

With respect to optimal soybean extract concentration and incubation time, optimal values for hardness were found at a concentration of 11.35%, time of 1.34 h, and response value of 270.53. Optimal values for peak number were found at a soybean extract concentration of 7.69% and time of 6.41 h, at which point the response value was 80.33. For oil absorption, the optimal values were concentration of 18.10% and time of 8.63 h, with a response value of 0.37. For analysis of colors, color L showed an optimum value of 78.76 at a concentration of 4.46% and time of 5.50 h. Color values a, b, and ΔE showed optimal values of 1.18, 19.52, and 21.94 at concentrations of 7.43, 23.86, and 1.34%, respectively, and at times of 22.52, 11.09, and 4.48 h, respectively.

With respect to expansion rate, the concentration and time under optimal conditions were 6.88% and – 3.09 h, respectively, with an optimal response value of 11.80. Although the response time could not be a negative number, the model fit but had a very low R^2 value of 0.14. Moreover, no other coefficients in the estimated regression analysis, except the constant term, were significant, and the lack of fit value was also not significant, indicating the need for third and fourth response surface analyses with other variables added.

Finally, the optimum levels of soybean extract concentration and incubation time were found at the peak number, yielding values of 7.69% and 6.41 h, respectively.

Many studies have been conducted to reduce the soaking time of waxy rice using grinding methods, microorganisms,

and enzyme treatment during Yukwa production; however, there are many challenges related to industrialization, including cost, equipment, and facilities. In this experiment, we evaluated the methods for enhancing Yukwa quality and reducing rice incubation time by maximizing the effects of soybean extract, a supplementary material, during Yukwa production. Our results provide important insights into the process of Yukwa production. However, further studies are required to compare sensory profiles of Yukwa from new process in this study with those from conventional processes.

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Compliance with ethical standards

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

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