Development of a Cooked Rice Model for Bibimbap and Resulting Physico-digestive Properties

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Abstract A cooked rice model for bibimbap was developed using response surface methodology (RSM). The ratio of brown rice (X_1), high amylose rice (X_2) based on a white rice ratio of 1.0, and the ratio of water to total rice weight (X_3), were independent variables. Stickiness (Y_1), elasticity (Y_2), and overall acceptability by sensory testing (Y_3) of cooked rice were dependent variables. Optimal RSM conditions were white rice:brown rice:high amylose rice=1:1.07:0.56, and the ratio of water to total rice weight was 1.6. Coefficient of determination (R^2) values of response surface equations were 0.909, 0.930, and 0.956 for Y_1 , Y_2 , and Y_3 , respectively ($p<0.05$). Experimental values measured under optimal conditions coincided with predicted values. Rapidly digestive starch (RDS) and expected glycemic index (eGI) values determined using the optimized rice model were much lower than for control white rice only.

Keywords: brown rice, high amylose rice, water ratio, stickiness, digestive property

Introduction

Bibimbap is a well known Korean dish of the one-bowl rice fare that has been spotlighted as a healthy food around the globe (1). The main ingredients of bibimbap are cooked rice, vegetables, ground meat, and hot pepper paste. A variety of toppings may also be used. As a staple food of Korea, rice constitutes the main source of carbohydrates and energy. For traditional bibimbap rice, the “*Beauty of Korean Food: With 100 Best-Loved Recipes*” released by Institute of Traditional Korean Food suggests white rice with 1.33× water to rice weight as a standard recipe. While white rice is the main energy source in bibimbap, the nutritional value of white rice is known to be lower than for whole grains.

The nutritional superiority of whole grains is due to high amounts of dietary fibers and resistant starch, and of several phytochemicals, including anti-oxidants, phenolics, vitamins, and minerals (2). Consumption of whole grains reportedly significantly decreases weight, the Body Mass Index (BMI), and body fat (%) (3). Whole grain products consumed in place of a portion of refined grains may decrease the risk of diabetes mellitus (4). In the United States, consumption of brown rice has increased due to perceptions as a nutritious healthy food that is a good source of vitamins, minerals, and fibers (2). However, bran in brown rice restricts water diffusion in cooking, resulting in a harder texture and lower palatability than for white rice (5).

High amylose rice contains a higher amount of amylose (28–33%) than regular rice with 18–20% amylose, and has high amounts of dietary fibers and gamma aminobutyric acid (GABA) (6). Consumption of high amylose rice is useful for weight loss and reductions in triglyceride levels in obese patients, and for glycemic control in diabetic patients (7). However, an undeveloped aleuronic layer in high amylose rice grains induces smaller starch granules with protein bodies between endosperm cells, resulting in a poor grain texture and palatability (8). The distinctive flavor of high amylose rice also has a negative effect on consumer sensory acceptability (9). For these reasons, brown rice or high amylose rice alone may be not acceptable as cooked rice.

The quality of cooked rice is affected by several factors, including appearance, texture, and flavor (10). Cooked rice for bibimbap needs to be mixed well with toppings, and the rice variety and the ratio of water to total rice weight are important. Response surface methodology (RSM) is a collection of mathematical and statistical technique in which several independent variables influence a dependent variable or response. It is a useful method for experimental product development and design and has been applied for optimization of several food processing operations (11). In this study, the quality of an optimized rice model for bibimbap was developed using white rice, brown rice, and high amylose rice with RSM, and the ratio of water to the total rice weight was also determined. Stickiness and elasticity based on physical measurement, and the overall acceptability based on

sensory testing were used as the main dependent variables in the design. The digestive properties of rapidly digestible starch (RDS), slowly digestible starch (SDS), resistant starch (RS), and expected glycemic index (eGI) of individual and optimized cooked rice, were also evaluated and compared.

Materials and Methods

Materials Both white and brown Japonica type rice harvested in 2011, in Chulwon, Korea were purchased from a local market in Seoul, Korea. High amylose rice (Goami 2, apparent amylose content 38%) developed in 2010 at the National Institute of Crop Science (Suwon, Korea) was used.

Measurement of protein, lipid, and dietary fiber contents The protein content of rice was calculated from the nitrogen content using a Kjeltect^{TM} 840 apparatus (Foss, Hillerod, Denmark), and the lipid content was determined using a Soxhlet extraction apparatus. The total dietary fiber content in rice was measured following AOAC method 991.43 (12).

Water absorption Twenty g of rice kernels (dry basis) of each rice variety were soaked in 40 mL of water at 23°C for up to 24 h. At regular intervals, water was drained and kernels were quickly blotted with paper towels 6 to 7 times to remove residual surface moisture, then weighed. The absorbed water amounts for each rice variety was determined based on the weight difference before and after soaking.

Experimental design using response surface methodology (RSM) A central composite design (CCD) (13) was used to develop of optimum rice model for bibimbap. In the experimental design, CCD matrix consisted of 2³ factorial points, 6 axial points ($\alpha=1.682$) and 3 replicates of center points (Table 1). When assuming the ratio of white rice to be 1, the brown rice ratio (X_1), the high amylose rice ratio (X_2), and the ratio of water to total rice weight (X_3) were assigned as independent variables (IV). The range and center point values of the 3 IV values were based on the results of preliminary experiments. Stickiness (Y_1) and elasticity (Y_2) based on textural property measurement, and the overall acceptability (Y_3) based on sensory testing, were assigned as dependent variables (DV) for the combination of IVs. Experimental runs were randomized in order to minimize the effects of unexpected variability in observed responses.

Rice cooking Each of 17 rice samples designed by RSM was soaked for 2 h, then cooked in an automatic rice cooker (CR-0632FV; Cuckoo, Yangsan, Korea). The cooking time was measured from the time the rice cooker was switched on to automatic shut-off.

Measurement of textural properties of cooked rice After cooking, the upper portion of cooked rice was removed and approximately

Table 1. Central composite design and response of dependent values for bibimbap rice to independent variables

Run No.	Coded levels of variables			Response		
	$X_1^{1)}$	X_2	X_3	Y_1	Y_2	Y_3
Factorial portion						
1	-1	-1	-1	56.3	126.2	3.57
2	1	-1	-1	50.7	124.4	3.97
3	-1	1	-1	43.3	118.1	3.13
4	1	1	-1	44.7	110.4	4.03
5	-1	-1	1	56.1	72.1	2.73
6	1	-1	1	64.9	91.2	3.07
7	-1	1	1	44.0	86.8	3.17
8	1	1	1	43.1	89.0	3.63
Axial portion						
9	-1.682	0	0	43.1	86.7	3.40
10	1.682	0	0	54.9	89.9	3.53
11	0	-1.682	0	66.4	99.2	4.13
12	0	1.682	0	40.1	97.1	3.97
13	0	0	-1.682	38.2	116.9	4.10
14	0	0	1.682	49.5	87.7	2.67
Center portion						
15	0	0	0	51.5	95.4	4.00
16	0	0	0	49.3	95.2	4.13
17	0	0	0	48.9	89.2	4.37

¹⁾ X_1 , brown rice ratio; X_2 , high amylose rice ratio; X_3 , water ratio to total rice weight; Y_1 , stickiness; Y_2 , elasticity; Y_3 , overall acceptability

300 g was taken from the center, covered with plastic wrap and then kept for 30 min at 25°C in a thermo-humidistat (Daihan Scientific Co., Seoul, Korea) prior to measurement of physical properties. Ten g of cooked rice in the bowl was transferred into a container. The stickiness and elasticity of the cooked rice were measured using a Tensipresser (Myboy System, TaketomoElectric Inc., Tokyo, Japan) with a 10 kg load cell and a 25 mm diameter cylindrical probe. Measurement conditions for the instrument were a distance 30 mm, a bite speed 2.0 mm/sec, a 2nd distance of 2.0 mm, and deformation of 23%. Each measurement was repeated 20x with different rice kernels, and average values were reported.

Sensory analysis Sensory evaluation of cooked rice was performed by 30 panelists aged 20-40 years with 14 males and 16 females. Panelists were provided cooked rice samples and asked to evaluate overall acceptability for bibimbap based on taste, texture, and mixing characteristics using a 5 point hedonic scale where 1=extremely dislike and 5=extremely like. Because sensory properties of cooked rice can be different or masked by toppings, sensory testing was performed using cooked rice without toppings, and testing was replicated.

Data analysis The response surface regression procedure of Statistical Analysis System software (SAS, ver. 8. 01, SAS Institute Inc., Cary, NC, USA) was used to fit the quadratic polynomial equation:

$$Y = \beta_0 + \sum_{i=1}^4 \beta_i X_i + \sum_{i=1}^4 \beta_{ii} X_i^2 + \sum_{i=1}^3 \sum_{j=i+1}^4 \beta_{ij} X_i X_j \quad (1)$$

where Y is the dependent variable, β_0 is a constant, β_i , β_{ii} , and β_{ij} are regression coefficients, and X_i and X_j are levels of the independent variables. The coefficient of determination (R^2), indicating that model equations described experimental designs adequately, was also obtained. The Ridge Max option of the response surface regression procedure was used to compute the estimated ridge of the optimum response for increasing radii from the center of the origin. Multiple response optimizations were heuristically calculated using the desirability function of MINITAB software (ver. 13, Minitab Inc., State College, PA, USA) in order to search simultaneously for conditions satisfying the 3 dependent variables Y_1 , Y_2 , and Y_3 . Response surface plots were developed using Maple software (Maple 7; Waterloo Maple Inc., Waterloo, Canada) and represented a function of 2 IVs while keeping the other 1 DV.

Digestive properties of cooked rice Digestive properties of cooked rice were evaluated following a method described by Englyst *et al.* (14). Briefly, 0.5 g of cooked rice was mixed with 10 mL of a guar gum solution (for keeping the sample in suspension), 0.1 g of pepsin (Sigma P-7000), and 10 mL of an enzyme solution of pancreatine (Sigma P-7545) and amyloglucosidase (Sigma A-7255) in turn, and incubated in a shaking water bath (BS-11; Jeio Tech Co. Ltd., Seoul, Korea) at 37°C. Then, 3 different fractions of starch were quantified as: rapidly digestible starch (RDS) defined as the glucose amount released after 20 min incubation, slowly digestible starch (SDS) defined as the glucose amount after a further 100 min of incubation, and resistant starch (RS) defined as unhydrolysed starch after a total of 120 min of incubation. Digestion kinetics and expected glycemic indices (eGI) of cooked rice were calculated following the procedure established by Goñi *et al.* (15). A nonlinear model following the equation [$C = C_{\infty} (1 - e^{-kt})$] was applied to describe the kinetics of starch hydrolysis, where C , C_{∞} , and k are the concentration at time (t), the equilibrium concentration, and the kinetic constant, respectively. The hydrolysis index (HI) was obtained by dividing the area under the hydrolysis curve by the area obtained using a white bread reference. The expected glycemic index (eGI) was calculated as (15):

$$GI = 39.71 + 0.549 \text{ HI} \quad (2)$$

Statistical analysis All experimental data were analyzed using general linear models of SAS System version 8.1 (SAS Institute). An analysis of variance (ANOVA) was conducted with Turkey's test at $p < 0.05$.

Results and Discussion

Crude lipid, protein, and dietary fiber contents of rice varieties

Crude lipid, protein, and dietary fiber contents of each rice variety are shown in Table 2. The crude lipid content was highest in brown rice at 2.03%, followed by high amylose rice at 1.38%, and white rice at 0.84%. Brown rice and high amylose rice contained 7.19 and 7.00% protein, respectively, with no significant difference between the values, and white rice contained 6.63%, similar to the value range of 6.6–9.3% reported by Cameron and Wang (16). Total dietary fiber was highest in high amylose rice at 9.87%, followed by 4.43% and 1.32% for brown rice and white rice, respectively.

Properties of cooked rice are largely related to components. A high amylose content causes a decrease in tenderness, stickiness, and polish, resulting in less palatability (17). Choi (6) also reported that cooked high amylose rice showed relatively lower adhesiveness, springiness, and cohesiveness values than white rice. Minor elements in rice, such as proteins and lipids, also affect the properties of cooked rice. Although protein is an important nutrient in rice, the stickiness of cooked rice has a fairly strong negative correlation with protein contents (18) because a high protein content can prevent water adsorption and thus, a starch/water interaction results in less adhesion (19). Rice with a high lipid content may have a softer texture after cooking (16). Also, lipids may complex with amylose molecules during cooking, resulting in a less sticky texture (20). Champagne *et al.* (21) reported that the taste of cooked rice with low amylose and protein contents scored higher than rice with high amylose and protein contents. Nutrients in brown rice and high amylose rice have negative effects on taste and texture of cooked rice. Therefore, conditions of mixing with white rice need to be optimized for maximization of nutritional values and minimization of a decrease in palatability.

Table 2. Nutrient contents and digestive properties of the individual rice variety and optimized cooked rice model

	Nutrient content (per 100 g)			Digestive properties			
	Crude lipid (%)	Crude protein (%)	Total dietary fiber (%)	RDS ¹⁾ (%)	SDS (%)	RS (%)	eGI
White rice	0.84 ^c	6.63 ^b	1.32 ^c	48.45 ^a	38.10 ^a	13.46 ^c	89.09 ^a
Brown rice	2.03 ^a	7.19 ^a	4.43 ^b	34.06 ^b	23.86 ^b	42.08 ^b	67.22 ^b
High amylose rice	1.38 ^b	7.00 ^a	9.87 ^a	33.06 ^b	7.58 ^c	59.36 ^a	62.86 ^b
Optimization cooked rice model	1.44 ^b	6.94 ^a	4.36 ^b	27.76 ^c	25.19 ^b	47.05 ^{ab}	67.00 ^b

¹⁾RDS, rapidly digestion starch; SDS, slowly digestion starch; RS, resistant starch; eGI, estimated Glycemic Index

Fig. 1. Absorbed water amounts for each rice variety during soaking at 23°C (WR, white rice; BR, brown rice; HAR, high amylose rice)

Water absorption during soaking The soaking process of rice is important for increasing the palatability of cooked rice. The main component of rice is starch, and changes in starch during the soaking process are related to the final palatability of rice. Water absorption values for each rice variety are shown in Fig. 1. Water absorption can be affected by several factors, such as the amylose content, water temperature, or minor components. The initial moisture contents of all 3 rice varieties was approximately 15%, and water absorption increased and reached a plateau after approximately 40 min for white rice and high amylose rice, and 8 h for brown rice. Rapid water absorption in the initial soaking stage for high amylose rice was probably related to capillary action of endosperm micro-pores for rapid hydration (22). Choi and Shin (23) reported water absorption amounts of 179.4% and 255.0% for white rice and high amylose rice, respectively. High water absorption values during soaking increases gelatinization with effective heat transfer. For brown rice; however, bran inhibits initial water absorption. Herein, high amylose rice showed the highest water absorption value during soaking, in agreement with a report of Choi and Shin (23).

The ratio of water to total rice weight is an important factor for determination of the texture of cooked rice. Juliano and Pascual (24) used different water ratios for cooked rice based on amylose contents of 1.3 for milled rice, 1.7 for waxy rice, 1.9 for low (12-20%)-amylose rice, and 2.1 for high (>25%)-amylose rice. Kim (1) suggested 1.2 as an adequate water to rice amount ratio for Japonica type rice, and 1.4-1.5 for Indica type rice. Roy *et al.* (25) also reported that the recommended water-rice ratio was 1.5 for white rice. However, 1.9 was recommended for brown rice because of bran that negatively affected adhesiveness and reduced stickiness after cooking. For bibimbap, cooked rice needs to be well mixed with toppings and a hard texture resulting from insufficient water and excess stickiness resulting from excess water should be avoided. In this study, the ratio of water to total rice weight was designed from 1.5 to 2.0, and within the range, the optimum water ratio was determined by RSM.

Diagnostic checking of the fitted models The response surface regression procedure was performed to fit the quadratic polynomial equation to the experimental data. The estimated coefficients of each model are presented in Table 3. All the coefficients of linear (X_1 , X_2 , X_3), quadratic (X_1X_1 , X_2X_2 , X_3X_3) and interaction were calculated for significance with *t*-statistic. All the constant coefficients were highly significant ($p < 0.01$) in all models. The X_2 term of Y_1 (stickiness) and Y_3 (overall acceptability) was significant at 99% and 95% probability, respectively. Also, X_3 in terms of Y_2 (elasticity) was significant ($p < 0.01$). On the other hand, all the interaction coefficients except the X_1X_2 term of Y_3 (overall acceptability) were not significant ($p < 0.05$).

Equation of the fitted model Equations of the fitted model are shown in Table 4. R^2 values for Y_1 , Y_2 , and Y_3 were 0.909, 0.930, and 0.956, respectively, and were statistically significant ($p < 0.05$), indicating that the experimental design was sufficient to account for observed results.

Analysis of variance (ANOVA) Statistical significance of the quadratic polynomial model equation was evaluated using an analysis of variance (ANOVA). Results that explained the response of the 3

Table 3. Estimated coefficients of the fitted quadratic polynomial equation for responses based on the *t*-statistic

Parameter	Y_1		Y_2		Y_3	
	Coefficient	<i>p</i> value	Coefficient	<i>p</i> value	Coefficient	<i>p</i> value
Constant	47.9936	0.000	92.8900	0.000	53.1012	0.000
$X_1^{1)}$	1.7241	0.166	1.2581	0.562	-0.2197	0.765
X_2	-7.1123	0.000	-0.9616	0.656	-2.1834	0.017
X_3	2.3508	0.073	-13.8471	0.000	0.8354	0.275
X_1X_1	0.6848	0.594	-0.4586	0.846	1.0658	0.212
X_2X_2	2.1874	0.118	3.0239	0.226	0.7122	0.389
X_3X_3	-1.1360	0.385	4.4912	0.089	-0.8788	0.295
X_1X_2	-0.3375	0.823	-2.8500	0.326	-3.8750	0.004
X_1X_3	1.5125	0.33400	3.8500	0.197	-0.3750	0.696
X_2X_3	-1.8625	0.242	4.3250	0.153	0.8750	0.374

¹⁾ X_1 , brown rice ratio; X_2 , high amylose rice ratio; X_3 , water ratio to total rice weight; Y_1 , stickiness; Y_2 , elasticity; Y_3 , overall acceptability

dependent variables Y_1 (stickiness), Y_2 (elasticity), and Y_3 (overall acceptability) are shown in Table 5. The linear terms X_1 , X_2 , and X_3 for all dependent variables Y_1 , Y_2 , and Y_3 were significant ($p=0.002$, $p=0.002$, and $p=0.014$, respectively) at $p<0.01$ and $p<0.05$, whereas cross-product terms for all DVs (Y_1 , Y_2 , Y_3) were not significant ($p=0.478$, $p=0.218$, and $p=0.365$, respectively). The DV quadratic terms (X_1X_1 , X_2X_2 , X_3X_3) for DV Y_3 (overall acceptability) and the total regression model, except for the DV Y_1 (stickiness) value, were significant ($p<0.05$). Lack-of-fit testing for the dependent variables Y_1 , Y_2 , and Y_3 showed insignificant p values of 0.515, 0.145, and 0.522, respectively, indicating that this RSM model equation was adequate for prediction in an optimized cooked rice model.

Response surface plots and factors The 3-dimensional response surface plots (Fig. 2) showed the estimated response function and

the effect of the independent variables X_1 , X_2 , and X_3 on the dependent variables Y_1 , Y_2 , and Y_3 . The stickiness of cooked rice decreased with an increase in the high amylose rice ratio, in agreement with the suggestion that cooked rice with a high amylose content has a less sticky texture (26). Cameron and Wang (16) also reported that a high soluble solid content during cooking, mainly amylose in high amylose rice herein, corresponded to reduced cooked rice stickiness. An increase in the brown rice ratio decreased the stickiness; however, the influence was least strong among the independent values. The stickiness slightly increased with an increase in the ratio of water (Fig. 2A).

Protein is known to decrease the elasticity value of cooked rice (27). High amylose rice and brown rice contain more protein than white rice, so an increase in those rice ratios significantly ($p<0.05$) decreased the elasticity values of cooked rice, compared with

Table 4. Response surface model equations based on a central composite design

Response	Quadratic polynomial model equation	R^2	p value
$Y_1^{1)}$	$Y_1=47.9936+1.7241X_1-7.1123X_2+2.3508X_3+0.6848X_1^2+2.1874X_2^2-1.1360X_3^2-0.3375X_1X_2+1.5125X_1X_3-1.8625X_2X_3$	0.909	0.012
Y_2	$Y_2=92.8900+1.2581X_1-0.9616X_2-13.8471X_3-0.4586X_1^2+3.0239X_2^2+4.4912X_3^2-2.8500X_1X_2+3.8500X_1X_3+4.3250X_2X_3$	0.930	0.012
Y_3	$Y_3=4.0792+0.1698X_1+0.0257X_2-0.3299X_3-0.2559X_1^2-0.0491X_2^2-0.2842X_3^2+0.0775X_1X_2-0.0625X_1X_3+0.1725X_2X_3$	0.956	0.028

¹⁾ X_1 , brown rice ratio; X_2 , high amylose rice ratio; X_3 , water ratio to total rice weight; Y_1 , stickiness; Y_2 , elasticity; Y_3 , overall acceptability

Table 5. Analysis of variance (ANOVA) for responses of dependent variables

Response	Source	DF	SS	MS	F value	p value
Y_1	Regression	Linear	3	806.89	268.96	15.85
		Quadratic	3	95.75	31.92	1.88
		Cross-product	3	46.96	15.65	0.92
		Total model	9	949.60	105.51	6.22
	Residual	Lack of fit	5	88.94	17.79	1.19
		Pure error	2	29.84	14.92	0.515
		Total error	7	118.75	16.97	
	Total	16	1068.38			
Y_2	Regression	Linear	3	2652.85	884.28	15.15
		Quadratic	3	324.45	108.15	1.85
		Cross-product	3	333.20	111.07	1.90
		Total model	9	3310.51	367.83	6.30
	Residual	Lack of fit	5	383.70	76.74	6.18
		Pure error	2	24.83	12.41	0.145
		Total error	7	408.53	58.36	
	Total	16	3719.04			
Y_3	Regression	Linear	3	1.8887	0.62957	7.39
		Quadratic	3	1.3473	0.44908	5.27
		Cross-product	3	0.3173	0.10578	1.24
		Total model	9	3.5533	0.39481	4.63
	Residual	Lack of fit	5	0.4442	0.08885	1.17
		Pure error	2	0.1525	0.07623	0.522
		Total error	7	0.5967	0.08524	
	Total	16	4.1500			

Fig. 2. Response surface 3D plots for optimization of the cooked rice model for bibimbap (BR, brown rice; HAR, high amylose rice; WR, water ratio)

controls (Fig. 2B). The brown rice ratio (X_1) and the ratio of water to total rice weight (X_3) significantly ($p < 0.05$) influenced the overall acceptability of cooked rice (Fig. 2C); overall acceptability values increased in a range of brown rice ratio values from 0.5 to 1, and a water ratio range of 1.5 to 1.75. However, outside the ranges, as the coded values of the independent variables (brown rice and water ratio) were close to zero, the overall acceptability increased. An increase in the value of the high amylose ratio decreased overall acceptability scores.

Optimal conditions and verification of predicted values Optimal conditions included coded and uncoded values of the dependent variables Y_1 , Y_2 , and Y_3 (Table 6). Based on canonical analysis of the response surface regression procedure, eigenvalues of Y_2 and Y_3 were negative, and the eigenvalue of Y_1 was positive and; therefore, the stationary points were the target values. To obtain the optimum proportion of three rices, each of the target values for Y_1 (stickiness), Y_2 (elasticity), and Y_3 (overall acceptability) were considered as decisive parameters. Multiple optimal conditions for coded and actual values of X_1 (brown rice content) and X_2 (high amylose content) were 1.07 and 0.56, respectively, assuming a ratio of white rice to 1: and X_3 (the water to total rice ratio) value was 1.60. Predicted values of Y_1 (stickiness), Y_2 (elasticity), and Y_3 (overall acceptability) under optimal conditions were 59.3, 125.7, and 4.25, respectively. Experimental verification was conducted under optimal conditions for comparison of predicted and actual values. Actual values were close to predicted values of 57.2, 127.4 and 4.37, respectively, and estimated response surface models were adapted for preparation of a rice model for bibimbap.

Digestive properties of the optimized rice model Digestive properties

Table 6. Multiple response optimization for bibimbap rice: predicted and experimental values under optimized conditions

Multiple response optimization	Dependent variables		
	$Y_1^{1)}$	Y_2	Y_3
Target value	69.8	129.4	4.5
Optimal conditions	$X_1=1.07$, $X_2=0.56$, $X_3=1.60$		
Predicted value	59.3	125.7	4.25
Experimental value	57.2±1.2	127.4±2.9	4.37±0.5

¹⁾ X_1 , brown rice ratio; X_2 , high amylose rice ratio; X_3 , water ratio to total rice weight; Y_1 , stickiness; Y_2 , elasticity; Y_3 , overall acceptability

(RDS, SDS, RS, and eGI values) of individual and optimized cooked rice are shown in Table 2. For cooked white rice, the RDS value was highest at 48.45%, and the RS value was lowest at 13.46%. The eGI value of cooked white rice was also highest at 89.09. Similar RDS and GI values were measured for cooked brown rice and high amylose rice. The SDS value was higher in brown rice, and the RS value was higher in high amylose rice. For optimization of the rice model, the RDS value was lowest at 27.76%, and the eGI value was similar to cooked brown and high amylose rice. Because dietary fiber and amylose contents both have strong impacts on the glycemic index of rice (28), and foods containing high levels of SDS results in low GI values (29), the optimization rice model has the health benefit than the traditional white rice bibimbap.

A functional cooked rice model for Korean bibimbap was optimized using response surface methodology (RSM). Optimum conditions were white rice/brown rice/high amylose rice values of 1.00:1.07:0.56, corresponding to 38, 41, and 21%, respectively, and an optimum water ratio to total rice weight of 1.6. The optimized rice model produced a higher bibimbap nutritional value; 3.3 and 1.7× more dietary fiber and lipids per 100 g rice, compared with traditional bibimbap composed of white rice only. The digestive characteristics of rice model developed were also improved; RDS and eGI values decreased and RS values increased with use of the model. Optimization of cooked rice can increase the quality of Korean bibimbap and aid in a further popularization of bibimbap for the global community.

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