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Consumer Acceptance of Three Rice Varieties Formulated by a Simplex-Lattice Mixture Design

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Abstract

A simplex-lattice mixture design was applied to blend three varieties of rice; Ilpum (IP), Goami2 (G2) and Baegjinju (BJJ) all of which have very different physicochemical properties from one another. G2 and BJJ are mutant rice developed from IP. Increasing G2 portions in a rice blend increases indigestible carbohydrate contents. Blending at least 33.3% of G2 to either IP or BJJ increased indigestible carbohydrates, which were approximately 3.55±1.31 to 4.57±0.37 (g/100 g), respectively. Consumers rated higher than 6.0 (=like slightly) for the IP alone and binary blends of IP and BJJ, whereas less than 5.0 (=dislike moderately) for the blends containing G2 rice, indicating that consumers would not accept rice blends containing higher G2 portions. However, although blends with G2 were given lower consumer ratings, a rice blend with G2 could have health benefits in terms of nutritional and functional properties due to the higher indigestible carbohydrate contents.

Key words: rice blends, mutant rice, simplex-lattice mixture design, indigestible carbohydrates, consumer acceptance

INTRODUCTION

Rice is the most important cereal crop and the staple food of over half the world's populations. As the primary dietary source of carbohydrates, rice plays an important role in meeting energy requirements and nutrient intakes (1). Since rice is a staple food, rice breeders have been interested in developing a new rice variety focused on nutritional and functional properties. Goami2 (G2) and Baegjinju (BJJ) were developed by mutation breeding via *N*-methyl-*N*-nitrosourea (MNU) treatment of Ilpum (IP) – a high quality japonica rice. They have quite different physicochemical properties for starch structure and texture when cooked. It was also observed that G2 rice had a hard texture, probably due to high amylose, whereas BJJ had a half-waxy rice property due to very low amylose content (2,3).

Cooked rice is readily digested because it contains a high percentage of digestible starch and a low percentage of resistant starch. It was reported that resistant starch in ordinary cooked rice is typically less than 3% (4). However, current nutritional concepts consider rice with lower digestible starch and higher resistant starch to be most healthful (1). In addition to nutritional aspects, cooking quality of rice has been one of the determinants of consumer acceptability. Cooked rice quality is related to chemical and physical properties of rice. When determining cooking and eating quality, focusing on starch as a major factor is not surprising, considering that starch accounts for up to 95% of the dry matter in a milled rice grain (5). Amylose content, solubility of amylose and the structure of amylopectin molecules as well as lipids and proteins are considered major factors that influence cooking quality (5,6).

Mixture design and analysis are an important methodology for an experiment in which factors are the proportions of the components of a blend, and response variables vary as a function of these proportions. The major purpose of a mixture design is to fit an appropriate mathematical model, thus to express response variables, such as consumer attributes, as the function of proportions of mixture components (7). The objective of this study was to observe the indigestible carbohydrate contents of rice blends of IP, G2 and BJJ, formulated by a simplex-lattice mixture design, and to evaluate the cooking qualities of the rice blends by a consumer acceptance evaluation.

MATERIALS AND METHODS

Preparation of rice blend formula and its cooked rice

Three rice varieties, IP, G2 and BJJ, were grown at

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the National Institute of Crop Science, RDA in Suwon, Korea during the 2004 growing season. Rice paddies (14 ~15% moisture) were dehusked using a rice sheller (model SY88-TH, Sangyong Ltd., Incheon, Korea) making brown rice which was then milled into white rice by removing the bran layer, 8~9% by weight of the brown rice, using a rice mill (model MC-90A, Dongyang Co., Korea). Three rice varieties were mixed to formulate rice blends by a 3-components simplex- lattice mixture design (designated as {3,3} design) generating 10 rice blend formulations (7).

Each rice blend was placed in a stainless steel cup (60 mm in diameter and 70 mm in deep), and water was added to give a weight ratio of 1:1.25. After 30 min of soaking, the cup with rice was placed into a stainless round pot, which could hold 6 cups at a time. The rice blends were then cooked for 35 min in the ordinary cooking mode, with high heat for 8 min, medium heat for 10 min, low heat for 7 min and heat off for 10 min.

Indigestible carbohydrate contents analysis

Indigestible carbohydrate contents of the each rice blend was determined by total dietary fiber (TDF) contents, which were analyzed by the official method of AOAC 991.43. After cooking, the cooked rice was freeze-dried, ground and sieved (100 mesh) for preparation of cooked rice flour for TDF measurement. The ground rice flour (1.0 g) was suspended in MES−TRIS buffer (pH 8.2), and digested sequentially with heat-stable α-amylase (from *Bacillus licheniformis*) in a water bath at 95°C, protease (from *Bacillus licheniformis*) at 60°C and amyloglucosidase (from *Aspergillus niger*) at 60°C. These enzyme digestates were mixed with 4 volumes of 95% ethanol, and then the residues were filtered, dried and weighed. Total dietary fiber value was corrected for ash and protein contents. Analysis was conducted in triplicate using dietary fiber extraction equipment (Fibertec™ System, 1023 Filtration Module, Foss Tecator Co., Hillerod, DK).

Consumer acceptance evaluation

Sensory evaluation of consumer acceptability was conducted in accordance with the procedure of Chambers and Wolf (8) at the National Institute of Crop Science (NICS). Each rice blend was evaluated by 40 consumer panelists, and each consumer evaluated all 10 cooked rice blends. These were presented in random order determined by a randomized complete block design (9). The forty panelists who participated, were mostly house wives, ranging in age from 35 to 55 years. Panelists were asked to evaluate the consumer attributes of appearance, texture and overall acceptability properties. Paper ballots were provided for each rice blend sample, and consumers rated it using a 9-point hedonic scale (10) wherein 9=like extremely, 8=like very much, 7=like moderately, 6=like slightly, 5=neither like nor dislike, 4=dislike slightly, 3=dislike moderately, 2=dislike very much, and 1=dislike extremely. Two sets of five samples in each set of 10 cooked rice blends were presented without a side-dish to a panelist. Participants were instructed to take a compulsory 3 min break between each set of 5 samples. They were also told to rinse their mouth with water between samples.

Statistical analysis

The data were analyzed for mean values by a SAS version 8.01 (SAS Institute Inc., Cary, NC, USA). ANOVA and Duncan's multiple range comparison tests were conducted at the 5% significance level. Predicted regression models for each consumer attribute were generated and further used to construct contour plots using a Minitab Release 14 statistical software (Minitab® Inc., State College, PA, USA).

RESULTS AND DISCUSSION

Rice blend formulas by a simplex-lattice mixture design

According to a simplex-lattice mixture design, 10 rice formulas were generated by blending three rice varieties shown in Table 1. The formulas were 3 pure blends (F1~F3) at the design points of the vertices estimating main effects, 6 binary blends at the edges estimating 2-way interaction (F4~F9) effect and 1 center point blend of three components in equal proportions (F10).

The proximate compositions (Table 2) of Ilpum (IP), Goami2 (G2) and Baegjinju (BJJ) were in the range of published reports (3). G2 rice is high in protein, lipid and amylose compared to those of IP and BJJ. The amylose content in G2 rice (33.96±1.16 g/100 g) indicated that G2 could be classified as a high-amylose rice variety (11). In contrast, the amylose content in BJJ was very low (6.43±0.23 g/100 g) having half-waxy properties, whereas IP had an amylose content of 18.63±0.67 (g/100 g), which was in the range of ordinary rice varieties. Besides the higher content of amylose in G2, the rice was found to have higher resistant starch compared to IP (12). As three rice varieties had quite different physicochemical properties, blending them in adequate proportions could change the cooking quality of the three rice varieties, expecting an enhancement of the cooking quality of G2 and BJJ, which exhibited quite hard and sticky texturese when cooked, respectively.

Table 1. Levels and compositions of rice in formulation

Formula	Levels			Compositions (g)		
	X1	X2	X3	Goami2	Ilpum	Baegjinju
F1	1	0	0	30	0	0
F2	0	1	0	0	30	0
F3	0	0	1	0	0	30
F4	1/3	2/3	0	10	20	0
F5	1/3	0	2/3	10	0	20
F6	0	1/3	2/3	0	10	20
F7	2/3	1/3	0	20	10	0
F8	2/3	0	1/3	20	0	10
F9	0	2/3	1/3	0	20	10
F10	1/3	1/3	1/3	10	10	10

X1= Goami2, X2= Ilpum, X3= Baegjinju.

Table 2. Proximate compositions of Ilpum, Goami2 and Baegjinju milled rice

Varieties	Proximate compositions (g/100 g)[1)]			
	Moisture	Protein	Lipid	Amylose
Ilpum	9.85±0.10	6.66±0.16	0.44±0.00	18.63±0.67
Goami2	11.69±0.92	7.61±0.03	1.89±0.03	33.96±1.16
Baegjinju	10.02±0.36	7.12±0.01	1.07±0.02	6.43±0.23

[1)]Mean±SD (n=3).

Indigestible carbohydrate fractions (ICF) in rice blends

Indigestible carbohydrate fractions (ICF) in rice blends measured by total dietary fiber (TDF) content are shown in Table 3. Significant mean differences in ICF depending on the proportion of G2 rice in the blend were found at 5% level of significance. The highest ICF content was found in the pure blend of G2 (10.83±2.07 g/100 g). Accordingly, it was observed that the ICF contents varied depending on the proportions of G2 rice in a blend; the more G2 rice contained in the formula, the higher the ICF when the rice blend was cooked. The ICF in rice blends without G2 rice were approximately 2.49±0.39 to 2.59±0.21 (g/100 g), but adding at least 33.3% of G2 to either IP or BJJ increased ICF to approximately 3.55±1.31 to 4.57±0.37 (g/100 g). Thus, blending G2 rice could increase the indigestible carbohydrates in a rice blend, thereby imparting health benefits and functional properties.

Unavailable or slowly digestible carbohydrates have been considered to be important nutritional factors, due to the physiological benefits of reducing caloric contents and glycemic response, which could have beneficial implications in the management of diabetes (13). Lee and Shin (12) examined the effect of resistant starch (RS-I) of G2, referred to Suwon 464 in the study, on blood response in a group of healthy males by measuring blood glucose levels 60 min after feeding a rice meal. They reported that the blood glucose levels were significantly reduced in the group fed with Suwon 464 compared

Table 3. Mean differences in consumer attributes and indigestible carbohydrate contents of 10 rice formulas

Formula	Consumer attributes			TDF (g/100 g)
	Appearance	Texture	Overall acceptability	
F1	1.22±0.49[e1)]	1.22±0.42[f]	1.22±0.42[f]	10.83±2.07[a]
F2	7.31±1.26[a]	7.19±1.35[a]	7.34±1.21[a]	2.59±0.21[ef]
F3	7.72±1.20[a]	6.59±1.74[a]	6.88±1.62[a]	2.49±0.39[ef]
F4	3.34±1.41[cd]	2.78±1.45[cd]	2.91±1.51[cd]	3.55±1.31[de]
F5	4.25±1.92[b]	3.81±1.47[b]	3.78±1.54[b]	4.57±0.37[cd]
F6	7.88±1.13[a]	6.84±2.05[a]	7.41±1.64[a]	2.75±0.55[ef]
F7	1.59±0.71[e]	1.69±0.78[ef]	1.69±0.90[ef]	6.14±0.60[bc]
F8	2.69±1.77[d]	2.25±1.41[de]	2.28±1.51[de]	6.27±0.97[b]
F9	7.47±1.39[a]	7.03±1.62[a]	7.34±1.58[a]	2.65±0.34[ef]
F10	4.00±1.61[bc]	3.31±1.42[bc]	3.38±1.43[bc]	4.13±0.95[de]

Means within a column with different letters are significantly different at $p \leq 0.05$.

to IP. In addition to the varied ICF contents in rice blends, the cooking qualities were quite different among the 10 rice blends, because the mutant G2 and BJJ rice varieties had quite different physicochemical properties from their IP mother variety.

Consumer evaluations of rice blends

Forty consumer panelists evaluated 10 cooked rice blends for the consumer attributes of appearance, texture and overall acceptability. There were significant differences among the cooked rice blends by Duncan's multiple test (Table 3). Rice blends rated higher than 6.0 (=like slightly) were the pure and binary blends of IP and BJJ (F2, F3, F6, F9), which was blended with no G2 rice. Whereas, very low scores, less than 5.0 (=dislike moderately), were given to the blends containing G2 rice. The most acceptable blend to consumers was the binary blend of IP (33.3%) and BJJ (66.6%), which was rated as 7.41±1.64 (F6) on overall acceptability. Whereas, the pure G2 only (F1) was the least acceptable to consumers. On the other hand, upon blending 33.3% of G2 rice to either IP or BJJ, consumers were favored BJJ (F5) to IP (F4).

To illustrate the consumer's response to the attributes, predicted regression models were generated and further used to plot contour maps. The estimated regression coefficients for linear and interaction effects are shown in Table 4. The magnitude of the coefficients for the linear effect of X1, X2 and X3 shows that IP (X2) and BJJ (X3) ranked significantly higher than G2 (X1) for consumer attributes, indicating that G2 rice is the lowest ranking factor for affecting consumer attributes. Accordingly, to improve consumer acceptance G2 portions in the blending should be lowered, whereas IP and BJJ should be increased to maximize consumer ratings. On the other hand, the presence of significant interaction terms indicates the existence of nonlinear blending effects. But, as the estimated coefficient for the cross product of G2 and IP was negative, blending G2 and IP would be less effective for improving consumer preference. Also, the blending of G2 and BJJ produced antagonistic effects, lowering the scores for consumer acceptance. Whereas, the positive coefficients of interaction term of IP and BJJ act synergistically, increasing the sensory scores on consumer acceptability. Using the predicted regression models, the consumer evaluation for the attributes of appearance (Fig. 1), texture (Fig. 2) and overall acceptability (Fig. 3)

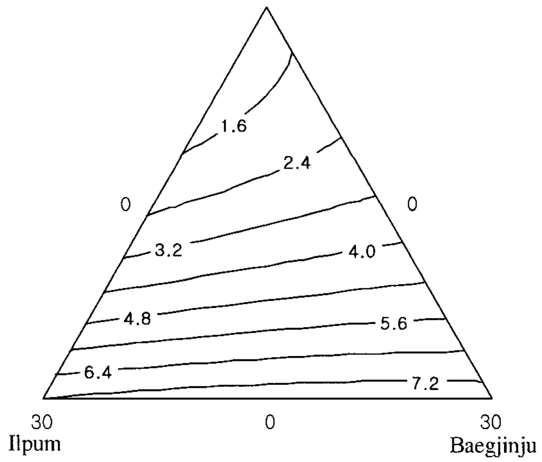

Fig. 1. Contour plot of consumer attribute of appearance.

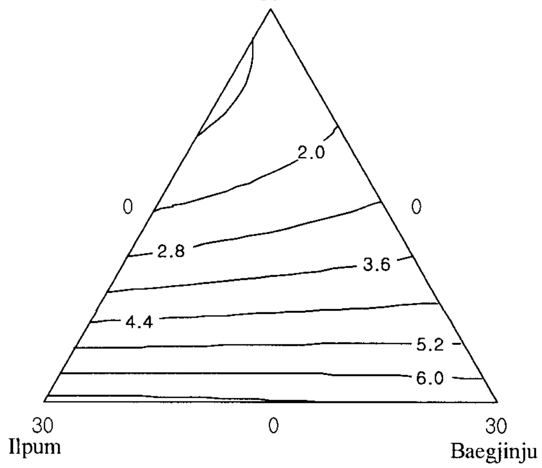

Fig. 2. Contour plot of consumer attribute of texture.

Table 4. Estimated regression coefficients for consumer attributes of 10 rice formulas

Components	Regression coefficients		
	Appearance	Texture	Overall acceptability
X1	0.045***	0.047***	0.048***
X2	0.241***	0.236***	0.241***
X3	0.256***	0.219***	0.230***
X1*X2	-0.009***	-0.010***	-0.011***
X1*X3	-0.005***	-0.005***	-0.006***
X2*X3	0.001	0.0002	0.001
R^2	0.94***	0.92***	0.93***

X1: Goami2, X2: Ilpum, X3: Baegjinju. ***Significant at $p \leq 0.01$.

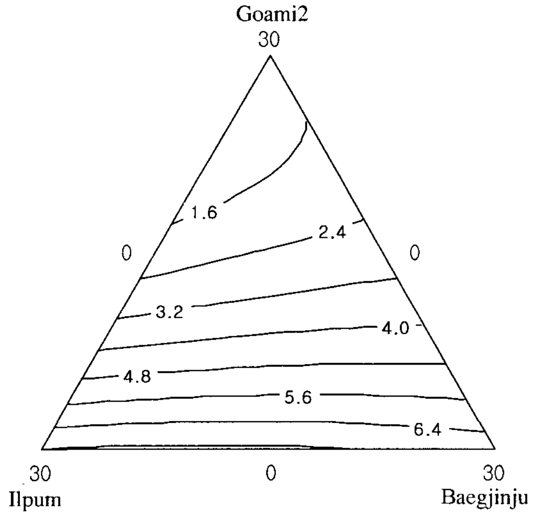

Fig. 3. Contour plot of consumer attribute of overall acceptability.

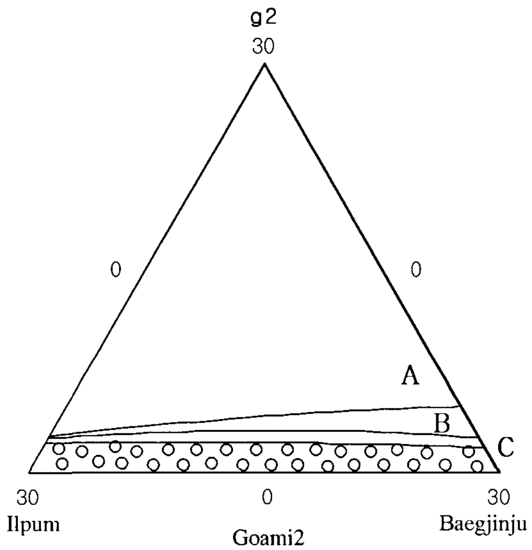

Fig. 4. Optimized region by superimposing the contour plots of appearance (A), texture (B) and overall acceptability (C). The dotted area with small circle was identified as the optimized region.

were illustrated on the triangular surface of contour plots. Contour plots illustrated that increasing G2 rice decreased the consumer scores on appearance, texture and overall acceptability. In contrast, increasing IP and BJJ increased the consumer ratings on the consumer attributes. To determine the overall acceptance for a rice formula, the portions of three rice varieties in a blend were optimized by superimposing the three contour plots, and the optimized region (dotted area with small circle) was identified as shown in Fig. 4. The critical value, which is the limit of acceptance, of 6.0 (=like slightly) was used to determine the overall acceptance for the rice formula. It is predicted that any rice blending in this area would result in a rice formula obtaining higher than 6.0 on the consumer evaluation rating.

The role of rice components in milled rice on organoleptic quality has been elucidated in many rice studies. One study observed that the best predictor for the eating quality of cooked rice was amylose content, because starch was the major component of rice. Also, some relationships between the cooking qualities and the protein content have been reported (14,15). Kim et al. (16) reported that a rice variety with low eating quality had the highest protein content, suggesting a negative relationship between protein content and eating quality. A study on the relationship between texture and amylose content of rice varieties observed that hard cooking rice had higher amylose content compared to soft cooking rice (17).

CONCLUSION

G2 and BJJ mutated from IP—a high quality japonica rice—were blended according to a simplex-lattice mixture design generating 10 rice formulas. Increment of G2 rice in the blends increased the indigestible carbohydrate fractions (ICF) in the cooked rice. Blending at least 33.3% of G2 rice to either IP or BJJ resulted in more ICF in the cooked rice mixtures compared to the blends formulated without G2 rice, indicating a nutritional improvement. As the physicochemical properties of three rice varieties were quite different from one another, consumer ratings on 10 rice blends varied depending on the rice proportions in a blend. Consumers rated higher than 6.0 (=like slightly) for the pure and binary blends of IP and BJJ, which were formulated without G2 rice. Whereas, they rated very low scores, less than 5.0 (=dislike moderately), for the blends containing G2 rice. Also, the triangular surface of contour plots of consumer attributes illustrate that increasing G2 rice in the blends decreased the consumer ratings for all the attributes. Although rice blends containing G2 rice were given lower consumer ratings, it would be expected that blending with G2 rice could have health benefits in terms of nutritional and functional properties due to the high contents of indigestible carbohydrates.

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