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Textural Properties of Processed Foods Produced from Newly Developed Non-Glutinous Rice Cultivars

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Abstract This study was undertaken to investigate the producibility of processed foods utilizing 6 newly developed non-glutinous rice cultivars. First, cooked rice, cake, cookies, bread, and slender rice cake sticks were prepared with the newly developed cultivars; then their physicochemical and textural properties were evaluated. The rice samples had similar pasting temperatures and peak times, but different viscosities and other pasting properties. The textural analysis results suggested that 'Chucheong' was appropriate for cooked rice due to its low amylose content, hardness, and springiness; 'Ilphumbyeo' for rice cakes due to its high amylose content, moderate cohesiveness and adhesiveness, and low hardness; 'Ilphumbyeo' for cookies due to its high amount of protein, and low cohesiveness and adhesiveness; 'Ilphumbyeo' for bread due to its high amylose content, moderate hardness, and low consistency; and 'Ilphumbyeo' for the slender rice cake sticks due to its low hardness, moderate breakdown, paste viscosity, and setback.

Keywords: textural property, pasting property, processed rice product

Introduction

After wheat rice is the second most widely cultivated cereal in the world, and is a staple food for over half the world's population. In Asia, rice is so central to the culture that the word is almost synonymous with food (1, 2). Because it is also nutritious and economical, rice is being hailed as a 'healthy food'. Its rising popularity in the world coincides with an increasing number of types and varieties being developed (3). Depending primarily upon the type of processing it has undergone, rice ranks high on the list of most nutritious foods. Rice provides significant levels of fiber, complex carbohydrates, several B vitamins, and vitamin E, as well as the minerals calcium, iron, phosphorus, and lysine (2, 3). Since rice has no cholesterol, only a trace of fat, and provides about 160 calories per cooked cup, it is not surprising that it's the backbone of a successful weight-loss regimen. The 'rice diet' has improved the health of many thousands of people over the past 50 years. This diet is low in protein, salt, cholesterol, and fat, yet high in complex carbohydrates and fiber (4). Since milled rice grains are contained of approximately 90% starch granules, their physicochemical properties (e.g., pasting and gelatinization characteristics) have been used for a long time to predict the textural properties of rice (1-3). Different cultivars of rice are typically classified based on their grain dimensions, amylose contents, and viscosities, as well as the gelatinization properties of the extracted starches, and the textural properties of the cooked rice (4-8). Rice cultivars differ significantly in their morphological, chemical, and cooking properties, and these differences are caused by combinations of aroma, texture, palatability, and digestibility. Furthermore, these factors strongly depend on the kernel morphology, as well as the components of the rice such as starch, proteins, lipids, and minerals (9-11). Although the major component of rice is starch, protein, and lipid can also influence textural properties in processed food products. Texture profile analysis has shown fair correlations between Rapid Visco-Analyzer (RVA) measurements and cooked rice texture. Murugesan *et al.* (12) characterized several properties of commercial starches (maize, wheat, potato, and sweet potato). However, reports addressing the suitability of various rice cultivars for processed rice foods are very scarce. Recently, varieties of rice possessing textural properties different from ordinary rice were developed by cross-breeding, yet they have similar amylose contents and pasting characteristics. The objectives of this study were to characterize 6 newly developed non-glutinous rice cultivars ('IR-50', 'IR-36', 'Chucheong', 'Ilphumbyeo', 'Junambyeo', and 'Saechucheong'), and to identify the processing suitability of the 6 newly developed cultivars for processed rice food products.

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Materials and Methods

Materials The 6 newly developed non-glutinous rice cultivars: 'IR-50', 'IR-36', 'Chucheong', 'Ilpumbyeo', 'Junambyeo', and 'Saechucheong' were supplied by the School of Applied Life Science at Konkuk University in Korea. The rice cultivars were soaked for 2 hr and ground into flour. The rice flour was then passed through a 120 mesh standard sieve with 125 μm openings.

Proximate analysis and physical characteristics Moisture, lipid, ash, carbohydrate, and protein were determined according to AOAC methods (13). The amylose contents of the powdered samples were determined by William's

iodine colorimetric method (14). The results are the mean values of 3 replicates. Length and breadth were measured using a vernier caliper. The bulk density was determined as the weight of grains per unit volume for a paddy.

Production of processed food products with newly developed rice cultivars In order to produce cooked rice with the newly developed cultivars, 30 g of rice was washed 4 times with tap water, boiled with 90 g of water for 30 min, and then cooled for 1 hr (15). For the rice cakes, 30 g of rice flour, 1 g of salt, and 10 g of water were mixed and steamed for 30 min, and then cooled for 1 hr. Most procedures for making the slender rice cake sticks were similar to those for the rice cake, with the exception of a final extrusion for the rice cake sticks (16). The ingredients of the rice cookies were as follows: rice flour (30 g), water (12 g), salt (0.3 g), sugar (5 g), active gluten (10 g), and baking powder (1.2 g). The dough was produced by mixing the ingredients, and then ripened for 30 min at 4°C, baked for 20 min at 180°C, and finally, cooled for 30 min (17). The ingredients of the rice bread were as follows: rice flour (30 g), water (15 g), yeast (1 g), salt (0.25 g), sugar (5 g), egg (3 g), butter (4 g), and active gluten (10 g). Subsequently, the dough was produced by mixing the ingredients, and then fermented for 2 hr at 37°C, baked for 20 min at 180°C, followed by cooling for 1 hr (18).

Pasting properties The pasting properties were measured with a Rapid Visco Analyzer model 3-D RVA (Newport Scientific, Sydney, Australia). The rice flour (3 g) was weighed directly into the aluminium RVA canister; 25 mL of distilled water was added and mixed with the rice flour. The sample was held at 50°C for 1 min, heated to 95°C at a rate of 12°C/min, held at 95°C for 2.5 min, cooled to 50°C at a rate of 12°C/min, and finally held at 50°C for 2.5 min. The rotating speed of the paddle was 960 rpm during the first 10 sec, and then it was kept at 160 rpm throughout the remainder of the run. All measurements were replicated twice.

Textural properties The textural properties of the processed food products prepared with the 6 newly developed cultivars were measured using a texture analyzer (TAXT2; Stable Micro System, Haslemeres, England). The processed foods were compressed to 50% of their original height at 10 mm/sec, except the cooked rice was compressed at 5 mm/sec. The texture profile analysis was replicated 8 times (19).

Sensory properties The sensory evaluation was performed by 15 trained panelists. The prepared samples were served to the panelists in a random sequence, and rated with a score from 1 (very poor) to 5 (very good). The sensory attributes of the rice products were luster, color, taste, texture, and overall acceptability.

Statistical analysis Statistical analysis was conducted using the SPSS 10.0 package. The relationships between various properties were determined using Pearson's correlation. The correlation was followed by Duncan's multiple range tests and the significance level was set at $p<0.05$.

Results and Discussion

Proximate compositions The moisture, ash, crude fat, protein, and carbohydrate contents of the 6 newly developed cultivars are described in Table 1. The moisture, ash, and crude fat were high in 'Ilpumbyeo', and carbohydrate content was highest in 'Chucheong'. Protein content was highest in 'Saechucheong', followed by 'Ilphumbyeo' and 'Junambyeo'. It was reported that protein-rich rice is much firmer than ordinary rice (20); therefore, the proteins in rice are generally thought to be related to its stickiness and surface hardness.

Physical characteristics of non-glutinous rice The kernel weights, bulk densities, length-breadth (L/B) ratios, and amylose contents of the 6 cultivars varied greatly (Table 2). 'Junambyeo', 'Ilphumbyeo', and 'IR-50' showed the highest values in kernel weight, bulk density, and L/B ratio, respectively. Generally, cultivars with a larger grain size showed lower bulk densities (Fig. 1). Similarly, Fan *et al.* (21) reported that medium-grain cultivars showed much higher bulk densities than long-grain cultivars. The amylose contents of the cultivars ranged from 18.55 ('Junambyeo') to 22.66% ('IR-50').

Pasting properties The pasting properties of starch are generally recognized as an indirect indicator of the eating quality of rice for sensory evaluation (22). The rice samples had similar pasting temperatures and peak times; however, they had distinct viscosities and other pasting properties (Table 3). Among them, 'IR-36' had higher viscosity, setback, and consistency than the other cultivars.

Table 1. Proximate compositions[1)] of rice cultivars

Cultivar	Moisture (%)	Ash (%)	Crude fat (%)	Protein (%)	Carbohydrate (%)
'IR-50'	10.83^{a}±0.29	0.70^{b}±0.05	1.63^{abc}±0.15	7.66^{a}±0.47	79.28^{a}±0.57
'IR-36'	10.40^{a}±0.11	0.69^{b}±0.11	2.3^{bc}±0.22	7.99^{a}±0.50	78.63^{a}±0.61
'Chucheong'	9.92^{a}±0.33	0.43^{a}±0.04	1.56^{ab}±0.34	8.50^{a}±1.69	79.93^{a}±2.18
'Ilphumbyeo'	13.23^{b}±0.75	0.42^{a}±0.04	1.21^{a}±0.22	8.92^{a}±1.72	76.23^{a}±2.31
'Junambyeo'	9.97^{a}±0.34	0.75^{b}±0.07	2.19^{bc}±0.15	8.12^{a}±0.27	78.98^{a}±0.23
'Saechucheong'	10.56^{a}±0.33	0.58^{ab}±0.06	2.37^{c}±0.21	9.57^{a}±0.1	76.92^{a}±0.23

[1)]Values reported as means±SD; Values with similar letters (a-c) in a column do not differ significantly ($p<0.05$).

Table 2. Physical characteristics[1)] of non-glutinous rice cultivars

Cultivar	Thousand kernel weight (g)	Bulk density (g/mL)	L/B ratio	Amylose content (%)
'IR-50'	16.44^{a}±0.09	1.36^{a}±0.00	3.20^{c}±0.02	22.66^{b}±0.67
'IR-36'	19.09^{bc}±0.03	1.38^{a}±0.01	3.04^{b}±0.10	19.30^{a}±0.52
'Chucheong'	19.50^{c}±0.06	1.43^{b}±0.00	1.59^{a}±0.01	20.49^{a}±1.04
'Ilphumbyeo'	18.70^{b}±0.12	1.45^{b}±0.01	1.56^{a}±0.02	22.65^{b}±0.90
'Junambyeo'	22.71^{c}±0.36	1.43^{b}±0.01	1.65^{a}±0.04	18.55^{a}±0.16
'Saechucheong'	20.05^{c}±0.02	1.44^{b}±0.05	1.71^{a}±0.01	19.50^{a}±0.20

[1)]Values reported as means±SD. Values with similar letters (a-e) in a column do not differ significantly (p<0.05).

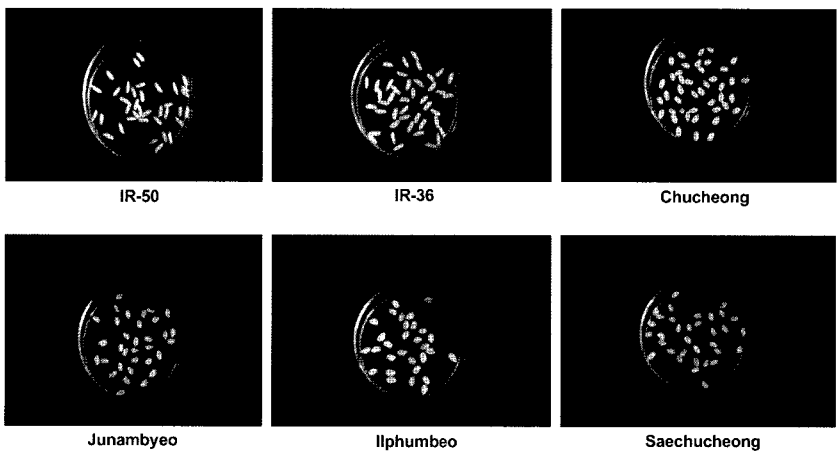

Fig. 1. Shapes of 6 non-glutinous rice cultivars.

On the other hand, 'Ilphumbyeo' took a long time (6.27 min) to reach maximum viscosity. This might be due to slow water-absorption and starch granule swelling. These results suggest that the rice materials would behave differently during cooking and processing. Additionally, differences in the protein compositions of the rice could affect the pasting viscosity and properties (23).

Rice palatability is highly dependent on the pasting properties, which are closely related to the textural properties. High quality rice varieties generally have higher paste breakdown and lower paste consistency than those of low quality (22). Therefore, the pasting property results were necessary for comparisons with the textural properties of the processed rice products, to identify the processing suitability of the 6 newly developed cultivars.

Textural properties of cooked rice All the textural properties had significant correlations with each other, and they had very strong positive correlations with the amylose contents of the cultivars, indicating that amylose content is one of the most important factors influencing the textural properties (24).

The cooked rice made from 'Ilphumbyeo' showed the highest hardness (0.86 kg_f) and springiness (0.42 kg_f), whereas the cooked rice from 'Saechucheong' and 'Chucheong' showed the lowest hardness (0.51 kg_f) and springiness (0.21 kg_f). In addition, cohesiveness values ranged from 0.02 to 0.04 kg_f for the cooked rice made from the 6 cultivars (Table 4). The textural property differences of the cooked rice may be attributed to the differences in amylose content of the cultivars. According

Table 3. Pasting characteristics of 6 rice cultivars with different eating properties

Cultivar	Pasting temp. (°C)	Peak time (min)	Peak viscosity (cp)	Trough viscosity (cp)	Final viscosity (cp)	Breakdown (cp)	Setback (cp)	Consistency (cp)
'IR-50'	69.8	5.67	364.25	279.67	498.25	84.58	134	218.58
'IR-36'	68.1	5.93	420.83	354.75	628.67	66.08	207.83	273.92
'Chucheong'	68.0	6.20	306.1	185.1	285.2	121.0	20.9	100.1
'Ilphumbyeo'	68.2	5.93	355.08	210.92	366.50	144.17	11.42	155.58
'Junambyeo'	68.0	6.27	287.8	195.6	307.4	92.2	19.7	111.8
'Saechucheong'	68.1	5.8	346.42	207.5	372.67	138.92	26.25	165.17

Table 4. Textural properties of cooked rice prepared from non-glutinous rice cultivars

	'IR-50'	'IR-36'	'Chucheong'	'Ilphumbyeo'	'Junambyeo'	'Saechucheong'
Hardness (kg_f)	0.067	0.736	0.560	0.863	0.687	0.507
Cohesiveness (kg_f)	0.036	0.015	0.025	0.023	0.029	0.018
Chewiness (kg_f)	0.006	0.002	0.003	0.003	0.005	0.005
Adhesiveness (kg_f)	0.001	0	0.001	0	0.001	0.002
Springiness (mm)	0.251	0.301	0.209	0.421	0.237	0.378
Gumminess (kg_f)	0.023	0.014	0.012	0.013	0.100	0.013

to Chuang and Yeh (16) and Sowbhagya *et al.* (25), a positive correlation was observed between amylose content and the firmness of cooked rice. Additionally, Thind and Sogi (11) and Juliano *et al.* (8) reported that rice with higher amylose content, and with long chain amylopectin, tended to have a hard texture, while rice with lower amylose content and short chain amylopectin tended to have a softer texture. The hardness of rice is also attributed to the size of the starch granules. It was reported that higher hardness resulted in smaller sized starch granules for rice cultivars (24, 25). Therefore, the low amylose content, hardness, and springiness of 'Chucheong' would be considered preferred qualities for cooked rice in Korea.

Textural properties of rice cakes Traditional Korean rice cakes were produced using the newly developed rice cultivars. The cohesivenesses and adhesiveness of the rice cakes were low compared to the other processed products prepared with the cultivars (Fig. 2). 'Junambyeo' and 'Saechucheong', however, had relatively high cochesiveness and adhesiveness, respectively, whereas chewiness and springiness were high in 'Junambyeo'. The textural property differences of the rice cakes are likely attributed to differences in amylose content and granule structure (26). As mentioned previously, amylose content can influence textural properties such as changes in viscosity and leaching behavior (15). Additionally, starch granule size can influence the hardness of the rice cake. The peak-time of starch with small granules tends to be short (26), which is consistent with the data for 'IR-50' (Table 2 and 3, Fig. 2). As a result, textural properties consisting of a high amylose content, moderate cohesiveness and adhesiveness, and low hardness and springiness are highly recommended for Korean rice cakes. Therefore, 'Ilphumbyeo' is a suitable choice for rice cakes with regards to textural properties. The chewiness and adhesiveness of the rice cakes made with the 6 newly developed cultivars were not significantly different.

Textural properties of rice cookies The cookies were also produced using the newly developed rice cultivars. The textural properties of the cookies are described in Fig. 3. Although the cookies showed the highest hardness among the processed foods produced in this study, cohesiveness, adhesiveness, and gumminess were remarkably low (ranging from 0 to 0.02 kg_f), with the exceptions of 'IR-36' and 'Ilphumbyeo'. On the other hand, the highest springiness and hardness (16.52 kg_f) values were observed in the rice cookies produced from 'IR-36' and 'Ilphumbyeo', respectively. According to Dreher and Patek (27), there was a decreasing trend in breaking strength with increasing high-protein bean flours. Chen *et al.* (28) also found that the hard texture of cookies was attributed to higher protein content, along with its interactions during dough development and baking. However, 'Ilphumbyeo' contains a higher amount of protein than 'IR-36' (Table 1, 2). Although the rice cookie produced

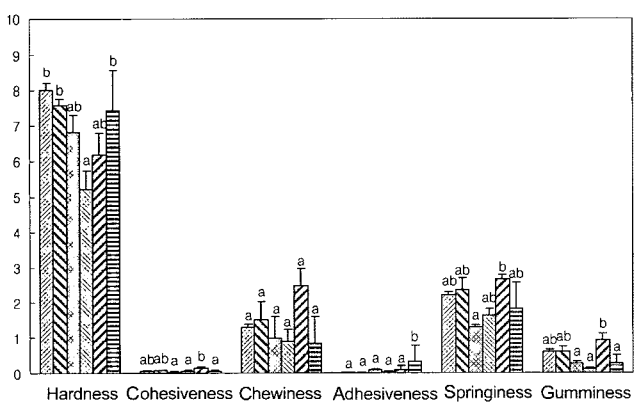

Fig. 2. Textural properties of rice cakes made from non-glutinous rice cultivars. ▨ 'IR-50'; ▧ 'IR-36'; ▩ 'Chucheong'; ▧ 'Ilphumbyeo'; ▨ 'Junambyeo'; ▤ 'Saechucheong'. Values with similar letters (a-b) do not differ significantly ($p<0.05$).

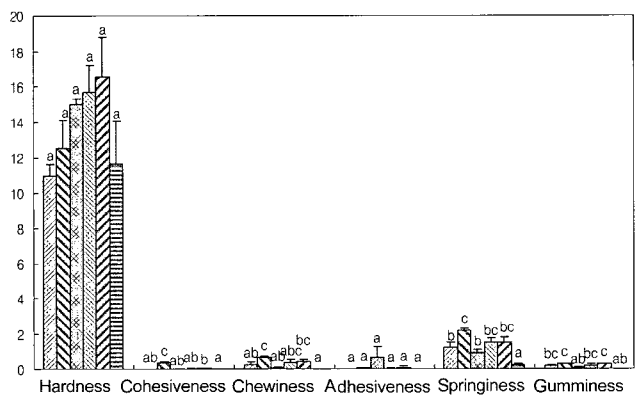

Fig. 3. Textural properties of rice cookies made from non-glutinous rice cultivars. ▨ 'IR-50'; ▧ 'IR-36'; ▩ 'Chucheong'; ▧ 'Ilphumbyeo'; ▨ 'Junambyeo'; ▤ 'Saechucheong'. Values with similar letters (a-c) do not differ significantly ($p<0.05$).

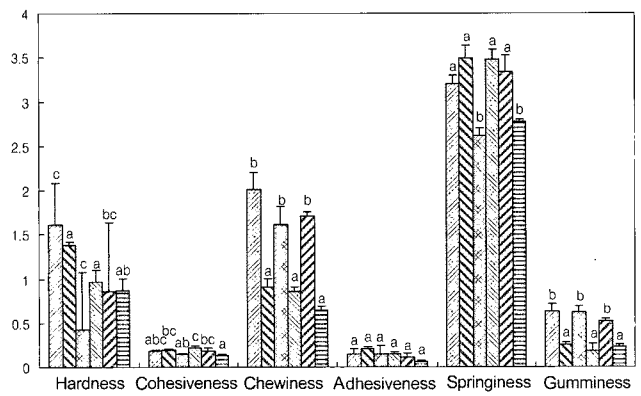

Fig. 4. Textural properties of rice breads made from non-glutinous rice cultivars. ▨ 'IR-50'; ▧ 'IR-36'; ▩ 'Chucheong'; ▧ 'Ilphumbyeo'; ▨ 'Junambyeo'; ▤ 'Saechucheong'. Values with similar letters (a-c) do not differ significantly ($p<0.05$).

from 'Junambyeo' had a slightly hard texture, it was easily broken due to its high protein amount and low cohesiveness and adhesiveness. As a result, textural properties such as the aforementioned are the preferred for cookies. Among the newly developed cultivars, 'Ilphumbyeo' was therefore considered to be a proper choice for cookie making.

Textural properties of rice bread Rice breads were produced with the newly developed rice cultivars, and their textural properties are described in Fig. 4. Hardness and chewiness were high in the rice bread made from 'IR-50', whereas low hardness and chewiness were observed in the rice breads made from 'Chucheong' and 'Saechucheong', respectively. The springiness of the rice bread was higher than the springiness of the other processed foods. Kang *et al.* (29) found that high-amylose rice was suitable for bread-making. In addition, the amylose content of milled rice was found to be negatively related to gel consistency, but positively related to the springiness of rice bread (16). Therefore, 'Ilphumbyeo' was considered to be the best choice for bread-making due to its high amylose content, moderate hardness and low consistency, and adhesiveness and chewiness (Table 4, Fig. 4). The adhesiveness values of the rice breads prepared from the 6 cultivars were not significantly different.

Textural properties of the slender rice cake sticks The

Table 5. Sensory properties of rice products[1)]

	'IR-50'	'IR-36'	'Chucheong'	'Ilphumbyeo'	'Junambyeo'	'Saechucheong'
Cooked rice						
Appearance	2.33^{a}	2.40^{a}	3.00^{a}	3.93^{b}	2.47^{a}	2.33^{a}
Color	2.60^{a}	2.47^{a}	2.93^{a}	3.73^{b}	2.47^{a}	2.60^{a}
Taste	2.27^{a}	2.33^{ab}	2.60^{abc}	3.20^{c}	3.00^{c}	2.93^{bc}
Texture	2.33^{a}	2.20^{a}	2.60^{ab}	3.53^{b}	2.80^{ab}	2.53^{ab}
Rice cake						
Appearance	2.13^{a}	2.06^{a}	3.07^{b}	3.87^{c}	2.40^{a}	2.27^{a}
Color	2.07^{a}	1.80^{a}	3.13^{b}	4.00^{c}	2.40^{a}	2.33^{a}
Taste	2.20^{a}	2.13^{a}	2.27^{a}	3.00^{b}	2.53^{ab}	2.47^{ab}
Texture	2.40^{a}	2.27^{a}	2.73^{ab}	3.27^{b}	2.27^{a}	2.13^{a}
Rice cookie						
Appearance	2.40^{ab}	2.33^{ab}	2.33^{ab}	3.07^{b}	2.06^{a}	2.47^{ab}
Color	2.40^{a}	2.47^{a}	2.60^{a}	2.87^{a}	2.60^{a}	3.07^{a}
Taste	2.13^{a}	2.46^{ab}	2.87^{ab}	3.20^{b}	2.80^{ab}	2.27^{a}
Texture	3.40^{a}	3.53^{a}	3.27^{a}	3.86^{a}	3.26^{a}	3.46^{a}
Rice bread						
Appearance	2.80^{ab}	2.40^{a}	3.60^{bc}	3.13^{c}	2.13^{a}	2.27^{a}
Color	2.67^{ab}	2.53^{ab}	3.47^{c}	2.93^{bc}	2.20^{a}	2.47^{ab}
Taste	2.33^{a}	2.47^{ab}	3.07^{bc}	3.40^{c}	2.73^{abc}	2.80^{abc}
Texture	2.27^{a}	2.47^{a}	3.40^{bc}	3.67^{c}	2.93^{ab}	2.73^{ab}
Slender rice cake sticks						
Appearance	-	-	3.47^{b}	4.07^{c}	2.80^{a}	2.80^{a}
Color	-	-	3.47^{b}	4.20^{c}	2.80^{a}	2.87^{a}
Taste	-	-	2.67^{a}	3.27^{a}	2.93^{a}	3.00^{a}
Texture	-	-	3.07^{ab}	3.53^{b}	2.67^{a}	2.67^{a}

[1)]Values with similar letters (a-c) in a column do not differ significantly ($p<0.05$).

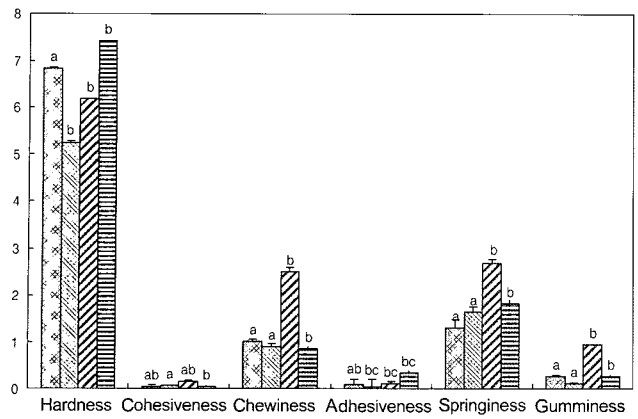

Fig. 5. Textural properties of the slender rice cake sticks made from non-glutinous rice cultivars. ▨'Chucheong'; ▧ 'Ilphumbyeo'; ▨ 'Junambyeo'; ▤ 'Saechucheong'. Values with similar letters (a-c) do not differ significantly ($p<0.05$).

slender rice cake sticks were also produced with the newly developed rice cultivars, and their textural properties are described in Fig. 5. The 'IR-50' and 'IR-36' cultivars were excluded from the rice cake stick production because their tremendous setback led to excessive hardness in the rice cakes, thus creating an interruption of extrusion for the slender rice cake sticks in the study. The hardness of the processed rice products was positively correlated with breakdown, paste viscosity, and setback, but it was negatively correlated with stickiness (29). The slender rice cake sticks made from 'Ilphumbyeo' had low hardness, and moderate breakdown, paste viscosity, and setback, implying that 'Ilphumbyeo' is the proper choice for producing the slender rice cake sticks.

Sensory properties Following the sensory evaluation, among the 6 newly developed cultivars, we determined that 'Ilphumbyeo' was the best cultivar for making processed rice food products because its sensory attributes and acceptability scored significantly higher in all the processed foods than the other cultivars, with the exception of the rice cake (Table 5 and 6). The results of the sensory property tests were not in exact accordance with those of acceptability tests. The appearance, color, taste, and texture of the rice cake prepared with 'Ilphumbyeo' scored significantly higher than those for the rice cake prepared with 'Chucheong' (Table 5). However, the acceptability for the rice cake prepared with 'Chucheong' was higher (Table 6). Complicated results such as these imply that consumer acceptance of a food product is influenced not only by the sensory properties, but also by familiarity.

Acknowledgments

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Table 6. Overall acceptabilities of rice products[1)]

	'IR-50'	'IR-36'	'Chucheong'	'Ilphumbyeo'	'Junambyeo'	'Saechucheong'
Cooked rice	2.13^{a}	2.20^{a}	2.67^{a}	3.13^{b}	2.67^{a}	2.80^{a}
Rice cake	2.47^{ab}	2.47^{ab}	4.07^{b}	3.67^{ab}	2.20^{a}	2.20^{a}
Rice cookie	2.53^{a}	3.40^{b}	3.47^{b}	3.47^{b}	3.20^{ab}	3.00^{ab}
Rice bread	2.40^{a}	2.33^{a}	3.27^{bc}	3.53^{c}	2.73^{ab}	2.67^{ab}
Slender rice cake stick			4.47^{a}	4.63^{a}	2.60^{a}	2.73^{a}

[1)]Values with similar letters (a-c) in a column do not differ significantly ($p<0.05$).

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