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Varietal Variations in Physicochemical Characteristics and Amylopectin Structure of Grain in Glutinous Rice

Hae Chune Choi*†, Ha Cheol Hong**, Yeon Gyu Kim**, and Baek Hie Nahm***

ABSTRACT

Thirty-eight glutinous rice varieties were classified into nine groups on the scatter diagram by the upper two principal components (56% contribution to the total information) based on eleven physicochemical characteristics including the viscograms and physical properties of cooked rice. The first principal component was the factor mainly associated with the viscogram characteristics of rice flour emulsion and the second was the factor chiefly related to the physical properties of cooked rice and water absorbability of rice grain.

Indica glutinous rices were clearly distinguished from japonica ones by the first principal component score. Javanica glutinous rices were widely distributed on the intermediate zone between indica and japonica or on several japonica rice groups.

Significant positive or negative correlations were found among water absorption rates of rice grain, physical properties of cooked rice, and viscogram characteristics of rice flour. Especially in japonica glutinous rices, the breakdown and setback viscosities of rice flour were closely associated with the alkali digestion value of milled rice and the stickiness of cooked rice. The frequency ratio of short glucose chains (A-chain) to intermediate glucose chains (B-chain), the ratio of B- chains to long glucose chains (C-chain) and the relative frequency of A- or B-chain fractions representing the amylopection structure of rice starch was closely associated with the breakdown and setback viscosities of rice flour.

Keywords : glutinous rice, grain quality, physicohemical property, amylopectin.

Glutinous rice shows an opaque endosperm since those have micropores in the single starch granule and hollows on the outer surface of compound granules.

Also, the glutinous rice starch is composed of only amylopectin without amylose fractions. Accordingly, glutinous rice reveals lower hardness of rice endosperm and markedly softer and sticky texture of cooked rice as compared with the nonglutinous ones.

The softness and sticky texture of gelatinized endosperm result from its own amylopectin structure as well as the low gelatinization temperature and very soft gel consistency of waxy rice starch (Perez et al., 1979).

Perdon et al. (1975) reported that the quality of waxy rice depend upon the varietal difference in gel consistency and gelatinization temperature of rice starch. Kim et al. (1996) pointed out that the significant differences between japonica and indica waxy rices were mainly found in the water binding capacity, gel consistency and a few amylogram properties of rice flour, and the hardness of cooked rice.

This study was carried out to understand the varietal variations of glutinous rice in physicochemical properties and starch structure of rice endosperm and physical components of cooked rice, and to elucidate the interrelationship among these characters.

MATERIALS AND METHODS

Thirty-eight glutinous rices including twenty six japonica, five indica and seven javanica ones were selected randomly and evenly from each of six varietal groups classified through preliminary grain quality test of 177 waxy rice accessions in 1995. They were grown in the paddy field of National Crop Experiment Station under the standard cultural condition in 1996.

The grain size and shape of glutinous rice samples were measured by profile-magnifying projector analyzer. The alkali digestion of polished rice was carried out with the two levels of 1.0% and 1.4% potassium hydroxide (KOH) solution for twenty three hours at 30℃ in an incubator. The alkali digestion value (ADV) was evaluated according to the observational scales suggested by Little et al. (1958).

The water uptake rate of milled rice at room temperature was determined by the percentage of absorbed water amounts to dry weight of milled rice sample after soaking for twenty minutes in about 25℃ tap water. The volume expansion rate and water uptake ratio of milled rice during boiling were

*Rice Research Div., National Yeongnam Agricultural Experiment Station, R.D.A., Milyang, Republic of Korea.
** Rice Breeding Div., National Crop Experiment Station, R.D. A., Suwon, Republic of Korea, *** College of Natural Science, Myeongji Univ. Yong-in, Republic of Korea, *† Corresponding author: (E-mail) hcchoi@nyaes.go.kr (Phone)+82-527-350-1150. Received 26 June, 1999.

measured after soaking for fifteen minutes in boiling water.

The viscogram components were evaluated by the changing pattern of gelatinization and viscosity of 12% rice flour emulsion using Rapid Viso-Analyzer (RVA-3D). The physical properties of cooked rice samples were checked by Texture Analyzer TA-XT2.

The structure of amylopectin was characterized by the frequency ratio of short (A) and intermediate (B) glucose chains to long (C) one or that of A to B chains. The gelatinization and debranching of rice starch was carried out by weak alkali solutions and isoamylase treatments and it was flowed and separated by gel filteration chromatography.

The classification of tested glutinous rices was carried out by the projected clustering of scattered rice materials on the plane of 1st and 2nd principal component scores based on selected eleven quality properties through principal component analysis.

RESULTS AND DISCUSSION

Thirty-eight glutinous rice varieties showed relatively larger varietal variation in grain shape (length/width ratio), water uptake rate at room temperature and volume expansion rate of cooked milled rice than in other quality properties (Table 1). Average water-uptake rate of milled rice after soaking for 20 min. at room temperature was 30.6%. On the other hand, water-uptake and volume-expansion rate of cooked milled rice were 137% and 206% on the average with great varietal variation, respectively.

There were considerably large varietal variations in all viscogram components of rice flour and physical properties of cooked rice except the initiation temperature of gelatinization with above 21% coefficients of variation (Table 2). Four glutinous rice varieties showed the quite different changing pattern of paste viscosity along with heating time and condition from 50℃ to 95℃ using Rapid Visco-Analyzer (RVA-3D) (Fig. 1). Especially, indica glutinous rices revealed remarkably higher peak, break down, hot, cool and setback viscosities as compared with both japonica and javanica ones (Table 4). Kim et al. (1996) also reported that there were significant differences in peak, break down and setback viscosities among amylogram characteristics between indica and japonica glutinous rices. The setback viscosity of viscogram and the adhesiveness of cooked rice showed the highest coefficient of variation, suggesting that those were the most important components for characterizing varietal quality of glutinous rice (Table 2).

The glutinous rices showed considerably large va

Table 1. Vatrietal variation of grain size, shape, hardness of brown rice and water uptake characteristics of milled rice in tested glutinous rices.

Trait	Mean	Standard deviation	Coefficients of variation (%)	Range
L/W	1.97	0.365	18.5	1.56~2.97
HDG (kg)	11.38	0.612	5.4	9.21~12.19
WAN (%)	30.6	4.74	15.5	19.5~39.6
WAB (%)	137	10.4	7.6	118~158
GVE (%)	206	2.72	13.2	104~266
ADV (1-7)	6.2	0.18	3.0	5.9~6.7

Refer to Table 4 for abbreviations.

Table 2. Varietal variation of viscogram characteristics of rice flour and physical properties of cooked rice in tested glutinous rices.

Trait	Mean	Standard deviation	Coefficients of variation(%)	Range
GIT (℃)	68.5	2.06	3.0	62.5~74.8
Peak (RVU)	177	37.8	21.4	115~258
Hot (RVU)	85	19.7	23.1	36~120
Cool (RVU)	111	25.0	22.5	51~160
Breakdown (RVU)	92	23.4	25.5	53~148
Consistency (RVU)	26	5.8	22.2	15~41
Setback (RVU)	-66	20.7	31.5	-120~-30
Hardness (g)♪	998	249	25.0	671~2,131
Adhesiveness (g)	118	67	57.1	42~376
Balance (-H/H)	0.114	0.047	41.6	0.046~0.251

♪Hardness, adhesiveness and balance of cooked rice measured by Texture analyzer.
GIT(℃) : Initial temperature of gelatinization

rietal variation in distribution of glucose-chain fractions indicating the structural difference in amylopectin (Fig. 2, Table 3). Among the frequency ratios between short(Fr.Ⅳ), intermediate (Fr.Ⅲ) and long (Fr.Ⅱ) glucose-chain fractions, Fr.Ⅳ/Fr.Ⅲ ratio was the most important one revealing the structural specificity of amylopectin related to varietal variation of viscograms and physical properties of cooked rice (Table 3). Kang and Choi (1993) pointed out that the harder the gel consistency was, the less the frequency of short glucose- chain fractions in amylopectin of diverse nonglutinous rice materials.

To classify the selected thirty-eight glutinous rice varieties, the principal component analysis was adopted using eleven physicochemical and structural characteristics including the viscograms of rice flour, physical properties of cooked rice and frequency ratios among three different glucose-chain fractions of rice starch. The upper four principal component scores contributed about 83% to the total variation, and the upper two principal components about 56%(Table 5). The first principal component was the factor mainly associated with the viscogram characteristics of rice flour, while the second was chiefly related to the physical properties of cooked rice and water absorbability of milled rice grain. The third and fourth principal components were the factors mainly contracted from the hardness of brown rice, water absorbability and volume expansion rate of milled rice grain during boiling, and hardness of cooked rice (Table 6).

Thirty-eight glutinous rices could be clustered into nine varietal groups by the scattered diagram of the rice materials on the plane of the upper two principal components (Fig. 3). Indica glutinous rices were clearly distinguished from japonica ones by the first principal component score. Javanica glutinous rices were widely distributed on the intermediate zone between indica and japonica or on several japonica glutinous rice groups. Among japonica glutinous rices, an upland glutinous rice variety, Rikuto- Norinmochi 24, was the only one that was included in an indica glutinous rice group of Hangangchalbyeo. The corresponding glutinous rice varieties of nine varietal groups were shown in Table 7. Korean local glutinous rices belonged to five different varietal groups (Ⅰ, Ⅲ, Ⅳ,

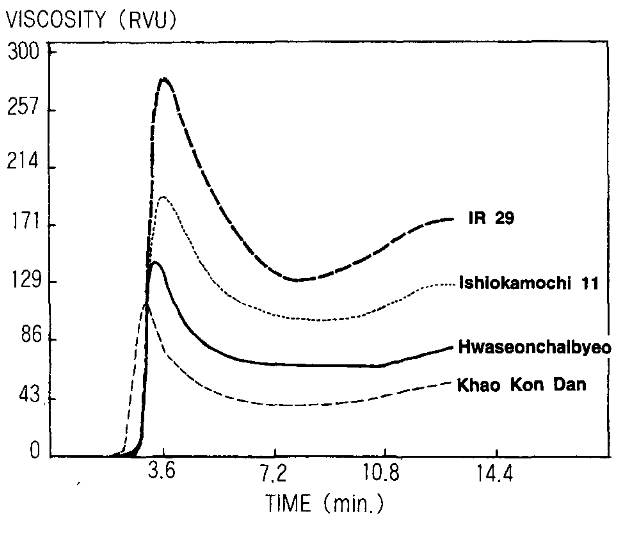

Fig. 1. Varietal difference in viscograms of glutinous rice flour using Rapid Visco-Analyzer (RVA-3D).

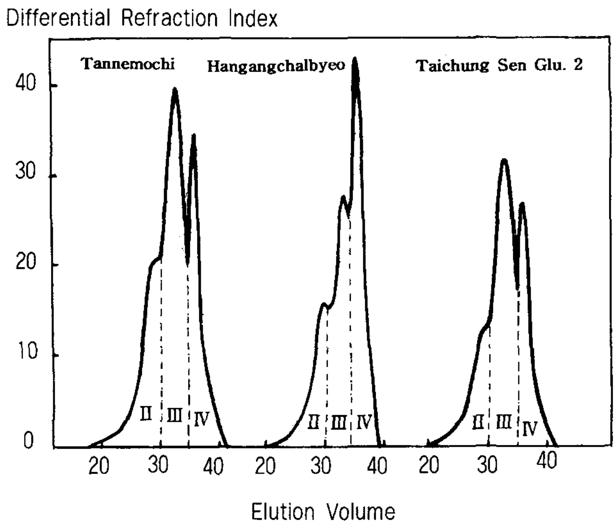

Fig. 2. Variental difference of glutinous rices in distribution of glucose-chain fractions debranched by isoamylase from gelatinized starch and separated by HPLC.

Table 3. Varietal variation in frequency ratios among short, intermediate and long glucose chains composing amylopectin structure of glutinous rice endosperms.

Trait	Mean	Standard deviation	Coefficients of variation(%)	Range
Fr.Ⅱ(%)	18.6	2.684	14.4	14.7~25.2
(Fr.Ⅲ+Ⅳ)/Fr.Ⅱ	4.47	0.729	16.3	2.97~5.79
Fr.Ⅳ/Fr.Ⅱ	1.78	0.460	25.9	1.09~2.72
Fr.Ⅲ/Fr.Ⅱ	2.70	0.505	18.7	1.42~3.59
Fr.Ⅳ/Fr.Ⅲ	0.68	0.234	34.3	0.41~1.31

Fr.Ⅱ, Ⅲ and Ⅳ are the long, intermediate and short glucose chains of amlyopectin, respectively.

Table 4. Comparison of physicochemical characteristics of rice grain among three ecotypes of glutinous rice.

Ecotype	HDG	WAN (%)	WAB (%)	GVE (folds)	GIT (℃)	P	H	C	BD
						....	....	RVU	....
Japonica(A)	11.402	31.3	138.6	2.09	68.5	163.7	80.1	104.2	84.0
Javanica(B)	11.277	30.2	131.1	1.80	68.6	172.4	85.1	110.7	87.6
Indica (C)	11.434	27.6	139.0	2.25	68.3	250.0	112.4	147.4	137.8
S.D. (A-B)	0.125	1.1	7.5	0.29	-0.1	-8.7	-5.0	-6.5	-3.6
S.D. (A-C)	-0.032	3.7	-1.3	-0.16	0.2	-86.3**	-32.3**	-43.2**	-53.8**
S.D. (B-C)	-0.157	2.5	-8.8	-0.45	0.3	-77.6**	-27.3**	-36.7**	-50.2**

Ecotype	CO	SB	HD (g)	ST (-g)	BA (-)	L/W	ADV(1-7)		GE
	--- RVU ---						1.0%	1.4%	
Japonica(A)	24.5	-59.7	1004	125	0.121	1.81	3.35	6.22	1.23
Javanica(B)	25.6	-62.1	1078	108	0.097	2.18	3.36	6.20	1.23
Indica(C)	35.6	-102.8	853	94	0.103	2.55	3.2	6.46	1.11
S.D. (A-B)	-1.1	2.4	-74	17	0.024	-0.37**	-0.01	0.02	0.0
S.D. (A-C)	-11.1**	43.1**	151	31	0.018	-0.74**	0.15	-0.24**	0.12
S.D. (B-C)	-10.0**	40.7**	225	14	-0.006	-0.37	0.16	-0.26	0.12

HDG : Hardness of brown rice. WAN : Water absorption rate of milled rice at room temperature. WAB : Water absorption rate of milled rice after 15 minutes soaking in boiling water, GVE : Volume expansion rate of milled rice after 15 minutes soaking in boiling water, GIT, P, H, C, BD, CO, SB : Initial temperature of gelatinization, Peak, Hot, Cool, Breakdown, Consistency and Setback viscosities of rice flour, respectively checked by Rapid Visco-Analyzer. HD, ST, BA : Hardness, Stickiness and the Balance of stickiness/hardness of cooked rice, respectively checked by Texture analyzer. L/W : Length/Width ratio of brown rice, ADV : Alkali digestion value, GE : Grain elongation after cooking expressed by the ratio between length/width ratio of cooked rice and that of milled rice.

S.D. : Significancy of difference between means of three different ecotypes of glutinous rice.

*, ** : Significant at 5% and 1% levels, respectively by t-test.

Table 5. Eigen value, contribution, and cumulative contribution of the upper four principal components to total variation of eleven quality properties.

Item	Z_1	Z_2	Z_3	Z_4
Eigen value	3.343	2.823	1.80	1.170
Contribution(%)	30.4	25.7	16.4	10.6
Cumulative contribution(%)	30.4	56.1	72.4	83.1

Table 6. Correlation coefficients between the upper four principal components and eleven quality properties.

Relevant components	Correlation coefficients			
	Z_1	Z_2	Z_3	Z_4
HDG	-0.173	0.396*	0.174	0.687**
WAN	0.009	-0.650**	-0.439*	-0.286
WAB	0.258	-0.175	-0.708**	0.299
GVE	0.271	-0.175	-0.615**	0.537**
Peak	0.947**	0.194	0.159	0.006
Breakdown	0.966**	-0.077	0.145	-0.085
Consistency	0.699**	0.466**	0.130	0.211
Setback	-0.897**	0.214	-0.123	0.158
HD	-0.171	-0.486**	0.697**	0.311
ST	0.04	-0.891**	0.364	0.237
BA	0.135	-0.920**	-0.025	0.097

Refer to Table 4 for abbreviations. *,** : Significant at 5% and 1% levels, respectively.

V and Ⅵ).

The water absorbability of milled rice was negatively correlated with the balance (stickiness/hardness ratio) of cooked rice, and the water absorption rate of milled rice during boiling was closely associated with the volume expansion ratio of boiled rice. The lower alkali digestion value (ADV) was closely associated with the higher temperature of gelatinization initiation, the lower breakdown and the higher setback viscosities of glutinous rice flour. The length/width ratio of brown rice was closely associated with all viscogram properties of rice flour and grain

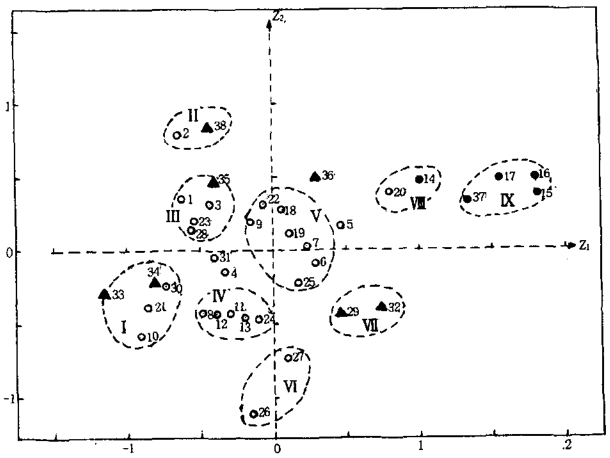

Fig. 3. Scatter diagram of tested glutinous rice cultivars on the plane of lst(Z_1) and 2nd (Z_2) principal components contracted from eleven qulity properties, (○: Japonica, ●: Indica, ▲: Javanica).

elongation rate after cooking since it is a major character distinguishing two rice ecotypes and the two different ecotypes of glutinous rice showed quite different viscogram characteristics and elongation of cooked rice grain. Especially in japonica glutinous rice, the higher breakdown and lower setback viscosities of rice flour were closely associated with the lower stickiness and balance of cooked rice and the higher ADV of milled rice (Table 8).

The frequency ratio of short(A-chain) to inter mediate (B-chain) or intermediate to long (C-chain) glucose-chain fractions and the relative frequency of A- or B-chain fractions representing the fine structure of glutinous starch (amylopectin) were closely associated with the breakdown and setback viscosities of rice flour and the stickiness of cooked rice (Table 9). These interrelationships between some physicochemical properties of milled rice or the physical characteristics of cooked rice were attributable to ecotypical difference between indica and japonica glutinous rices (Kim et al. 1996).

Perdon & Juliano (1975) and Perez et al. (1997) also pointed out that the quality of glutinous rice mainly depend on the gelatinization temperature and gel consistency. Asaoka et al. (1984, '85) reported that the A- to B-chain ratio of amylopectin in both glutinous and nonglutinous rice was reduced by high temperature during ripening but there was no significant varietal difference in A/B-chain ratio. The relationship between the fine structure of amylopectin and other physical or processing characteristics of glutinous rice should be elucidated by more advanced study.

Table 7. Classification of tested glutinous rice cultivars based on scattering positions on the plane of two upper principal component scores contracted from eleven quality components of glutinous endosperm.

Varietal group	Corresponding rice cultivars
Ⅰ	Jinbuchalbyeo, Mokjeom 3, Hwanghaedo, Khao A, Khao Kon Dan
Ⅱ	Onnemochi, TD 46
Ⅲ	Kamuimochi, Tannemochi, Pyodo, Gujungdo, Malagkitsinaguing
Ⅳ	Shinseonchalbyeo, Hwaseonchalbyeo, Mangetsumochi, Tatsumimochi, Baekgokna, Ishiokamochi 7, Josugpochajochun
Ⅴ	Ishiokamochi 15, Ishiokamochi 20, Wonsanchalbyeo, Calmochi, Rikuto-Norinmochi 1, Monajo, Byeongok, Ishiokamochi 11, Pinaopa
Ⅵ	Daejodo, Gangwonna
Ⅶ	Hung-Tsan, Khamu
Ⅷ	Hangangchalbyeo, Rikuto-Norinmochi 24
Ⅸ	IR 29, Taichung Sen glutinous 1, Taichung Sen glutinous 2, RD 1

The cultivars underlined are indica and those dot-underlined are javanica. The others are japonica.

Table 8. Correlation coefficients among various quality components of tested glutinous rice materials.

Relevant characters	HDG	WAN	WAB	GVE	GIT	P	H	C	BD
HDG		-0.334	-0.091	0.202	0.330	0.115	0.360	0.359	-0.177
WAN	-0.354*		0.138	0.065	-0.143	0.102	-0.120	-0.169	0.269
WAB	-0.108	0.225		0.344	0.065	0.113	-0.003	0.021	0.174
GVE	0.027	0.193	0.516**		0.257	-0.140	-0.031	-0.036	-0.184
GIT	0.129	-0.119	-0.173	0.082		-0.205	0.391*	0.407*	-0.713**
P	-0.031	-0.112	0.071	0.120	0.141		0.762**	0.746**	0.756**
H	0.169	-0.218	-0.037	0.065	0.486**	0.853**		0.995**	0.152
C	0.160	-0.243	-0.014	0.079	0.460**	0.858**	0.995**		0.132
BD	-0.185	-0.003	0.142	0.135	-0.180	0.900**	0.541**	0.553**	
CO	0.140	-0.321	0.056	0.129	0.331*	0.819**	0.909**	0.946**	0.563**
SB	0.253	-0.083	-0.146	-0.119	0.291	-0.788**	-0.356*	-0.360*	-0.972**
HD	0.032	-0.098	-0.260	-0.194	-0.172	-0.145	-0.199	-0.188	-0.067
ST	0.163	-0.333*	0.009	-0.063	0.312	0.073	0.293	0.287	-0.126
BA	0.240	-0.580**	-0.187	-0.217	0.310	0.051	0.319	0.318	-0.184
L/W	-0.075	-0.372*	-0.010	0.134	0.186	0.518**	0.432**	0.453**	0.471**
ADV1.0	-0.108	0.305	0.026	-0.076	-0.411*	-0.131	-0.351*	-0.363*	0.085
ADV1.4	-0.147	0.176	0.095	-0.029	-0.620**	0.289	-0.060	-0.040	0.516**
GE	-0.037	0.164	-0.069	-0.128	-0.149	-0.262	-0.290	-0.297	-0.179

Relevant characters	CO	SB	HD	ST	BA	L/W	ADV		GE
							1.0%	1.4%	
HDG	0.362	0.282	0.005	0.189	0.249	-0.029	-0.076	-0.323	-0.188
WAN	-0.350	-0.357	-0.115	-0.326	-0.589**	-0.278	0.401*	0.457*	0.017
WAB	0.083	-0.146	-0.106	0.026	-0.109	0.175	0.049	0.010	0.038
GVE	-0.064	0.161	0.024	-0.152	-0.225	0.407*	0.184	0.253	-0.395*
GIT	0.435*	0.810**	-0.265	0.395*	0.401*	0.124	-0.575**	-0.492*	-0.453*
P	0.626**	-0.561**	0.205	-0.141	-0.052	-0.066	-0.009	0.280	0.010
H	0.909**	0.103	-0.029	0.253	0.363	-0.013	-0.345	-0.096	-0.222
C	0.944**	0.132	-0.022	0.268	0.391*	0.006	-0.370	-0.123	-0.225
BD	0.034	-0.962**	0.341	-0.466*	-0.443*	-0.094	0.340	0.522**	0.246
CO		0.240	-0.013	0.317	0.471*	0.069	-0.448*	-0.232	-0.213
SB	-0.355*		-0.333	0.540**	0.562**	0.107	-0.448*	-0.570**	-0.296
HD	-0.159	0.038		-0.770**	-0.326	0.023	0.101	-0.088	0.019
ST	0.257	0.210	-0.747**		0.843**	0.023	-0.262	-0.039	-0.022
BA	0.296	0.228	-0.313	0.851**		0.035	-0.418*	-0.158	-0.011
L/W	0.491**	-0.402*	-0.134	0.220	0.228		-0.129	-0.289	-0.735**
ADV1.0	-0.385*	-0.201	0.108	-0.220	-0.327*	-0.161		0.386	0.214
ADV1.4	0.031	-0.573**	-0.082	-0.055	-0.136	0.026	0.348*		0.363
GE	-0.307	0.120	0.141	-0.069	-0.010	- 0.613**	0.146	0.123	

Refer to Table 4 for abbreviations. Correlation coefficients on upper and lower parts from diagonal indicate those in japonica glutinous rices and those in total tested glutinous materials including japonica, javanica and indicas, respectively.

Table 9. Correlation coefficients between some indicators of amylopectin structure and other physico-chemical properties of glutinous rice.

Relevant characters	Fr.Ⅱ(%)	Fr.Ⅲ(%)	Fr.Ⅳ(%)	(Fr.Ⅳ+Ⅲ)/Fr.Ⅱ	Fr.Ⅳ/Fr.Ⅱ	Fr.Ⅲ/Fr.Ⅱ	Fr.Ⅳ/Fr.Ⅲ
WBA	0.492*	0.054	-0.270	-0.476*	-0.441*	-0.284	-0.151
GVE	0.467*	0.009	-0.197	-0.453*	-0.381	-0.307	-0.105
BD	-0.339	0.657**	-0.498*	0.340	-0.216	0.687**	-0.541*
SB	0.376	-0.683**	0.509*	-0.369	0.206	-0.719**	0.568**
ST	-0.234	0.430*	-0.322	0.208	-0.153	0.439*	-0.372
BA	-0.275	0.543*	-0.417	0.246	-0.206	0.541*	-0.473*

Refer to Table 3 & 4 for abbreviations.

Table 10. Identification of useful glutinous germplasms for special utility of food processing.

Major characteristics	Corresponding cultivars
Rapid retrogradation of cooked rice	IR 29, Taichung Sen glutinous 1 & 2, Pinaopa, Rikuto-Norinmochi 24, Hangangchalbyeo, RD 1
Slow retrogradation of cooked rice	Daejodo, Khao A, Jinbuchalbyeo, Shinseonchalbyeo, Hwaseonchalbyeo
High volume expansion of boiled rice	Taichung Sen glutinous 1, IR 29, Mokjeom 3, Hangangchalbyeo, Hwaseonchalbyeo, Khao Kon Dan
High gelatinization temperature	Malagkitsinaguing, Pinaopa

Useful glutinous germplasms for special utility of food processing were listed up with typical quality characteristics in Table 10. Generally, indica glutinous rices (Ⅷ, Ⅸ) showed slightly more rapid retrogradation of cooked rice compared with japonica ones. However, there are some large varietal difference in retrogradation and volume expansion of boiled rice among respective japonica and indica glutinous rice varieties. Some adaptability to food processing should be examined under the desirable combination of relevant quality components related to respective processing utility.

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