Association and Principal Component Analyses of Eating Quality Traits of 141 *Japonica* Rice Cultivars in China

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Abstract: Eating quality is the important trait of rice, and rice breeders also employ eating quality in breeding selection for advanced generations. Therefore, to better understand the factors affecting the eating quality of *japonica* rice in China, the physicochemical indices [apparent amylose content (AAC), gel consistency (GC), protein content (PC), and gelatinization temperature (GT)], rapid visco analyzer parameters, and cooked rice taste values of 141 rice cultivars were analyzed. The rice cultivars were divided into low, medium, and total AAC groups. Association and principal component analyses of these indices were performed. In total AAC rice, cooked rice taste value showed a significant negative correlation with AAC, final viscosity (CPV), setback viscosity (SBV), consistence viscosity (CSV), and a positive correlation with GC, peak viscosity (PKV), holding strength (HPV), and breakdown viscosity (BDV). PC showed a significant negative correlation with cooked rice taste value in low, medium, and total AAC rice. For both low and medium AAC rice, the factor load matrix of PC and cooked rice taste value in factor 1 was remarkably higher than that of the other indices, indicating that PC was the most important factor for the eating quality of low and medium AAC rice. For total AAC rice, the factor load matrix of AAC, GC, and cooked rice taste value in factor 1 was remarkably higher than that of the other indices, indicating that AAC and GC were important factors for the eating quality of different type rice cultivars. The results showed that AAC and GC were more important for the eating quality of different type rice cultivars, while PC was more important for the eating quality of similar type rice cultivars. Our findings offer new insight into target traits in breeding rice with high eating quality.

Keywords: Japonica Rice, Eating Quality, Apparent Amylose Content, Protein Content

1. Introduction

Rice (*Oryza sativa* L.) is one of the most widely consumed foods in the world, and the subspecies *japonica* is commonly consumed in the Yangtze River Delta Region and North China. Eating quality is the most important rice quality for consumers and primarily affected by hardness, stickiness, appearance and taste [1].

Physicochemical indices, such as apparent amylose content (AAC), gel consistency (GC), protein content (PC), and gelatinization temperature (GT) have been widely studied to evaluate rice eating quality [2, 3]. Rice with low AAC and PC becomes soft and sticky after cooking [4, 5]. Recently, cooked rice taste analyzers and Rapid Visco Analyzers (RVAs) have been widely used by breeders to evaluate rice eating quality [6, 7].

The eating quality of rice is highly complex [8]. Although the relationships among the physicochemical indices, pasting properties, and eating quality have been widely studied [9, 10], their correlations have not been studied in detail as different groups by multivariate analysis. Recently, low AAC rice has been developed and is preferred in the Yangtze River Delta Region because of its high eating quality. To better understand the factors affecting the eating quality of *Japonica* rice in China, the physicochemical indices, RVA parameters, and cooked taste values of 141 *japonica* rice cultivars were

measured. The cultivars were divided into low, medium, and total AAC rice groups. Association and principal component analyses of the eating quality indices were performed in all three groups. The results will be useful for breeders to select high eating quality rice.

2. Materials and Methods

2.1. Plant Materials and Sample Preparation

Rice plants were grown in the Zhuanghang experiment field (Shanghai, China) in May 2018 and were harvested in November 2018. The rice seeds were air-dried to ~ 14% moisture content. Brown rice grains were husked, polished, milled, and then the flour was passed through 100-mesh sieves.

2.2. Measurement of Physicochemical Properties

AC and GC was determined as previously described [11]. Nitrogen was determined using an Automatic Kjeldahl Nitrogen Determination Apparatus (8400, Foss, Hillerød, Denmark). The total PC was obtained based on the nitrogen by multiplying a nitrogen protein conversion factor of 5.95. The alkali spreading value (ASV), an indicator of GT, was measured as previously described [12].

2.3. Rice Eating Quality Analysis

The taste value of cooked rice was analyzed with a rice taste meter (STA1B, SATAKE Co. Ltd., Japan).

2.4. Rice Pasting Property Analysis of Starch

Rice pasting properties were determined using a RVA (Newport Science, Warriewood, Australia) and the values were analyzed by Thermocline for Windows v3 [13]. RVA profile was expressed by pasting temperature (Pat), peak viscosity (PKV); final viscosity (CPV), holding strength (HPV), breakdown viscosity (BDV), setback viscosity (SBV), consistence viscosity (CSV). The unit used was "Rapid Visco Units" (RVU).

2.5. Statistical Analysis

All samples were analyzed in three technical replicates. Association and principal component analysis were performed using SPSS 18. Pearson's correlation coefficient was calculated to analyze the interrelationship among the parameters of rice eating quality. The results were analyzed using Tukey's tests at $p < 0.05$ significance level.

3. Results and Discussion

3.1. Distribution of Physicochemical Indices, RVA Parameters, and Taste Values

The physicochemical indices, rapid visco analyzer parameters, and cooked taste values of 141 rice cultivars were analyzed and the rice cultivars were divided into low, medium, and total (low and medium) AAC groups to compare the factors affecting the eating quality within similar and different type rice cultivars. The range distribution of the physicochemical indices, RVA parameters, and cooked rice taste values of low and medium AAC rice is listed in Tables 1-2. The AAC range of low AAC rice was 4.7%–10.7%, and that of medium AAC rice was 13.1%–18.5%. The average GC of low and medium AAC rice was 82.7 and 70.6 mm, respectively. The average PC of both low and medium AAC rice was ~8.0%. The average ASV of low and medium AAC rice was 5.1 and 5.5 grade. For the RVA parameters, the HPV, CPV, SBV, and CSV of low AAC rice was considerably lower than those of medium AAC rice, and the BDV of low AAC rice was remarkably higher than that of medium AAC rice. The average Pat of both low and medium AAC rice was ~71°C. The average cooked rice taste values of low and medium AAC rice were 77.5 and 68.3 points, respectively. The kurtosis of Pat, AAC, and GC was high in low AAC rice, and that of SBV, CSV, and Pat was high in medium AAC rice. The skewness of Pat and ASV was high in low AAC rice, and that of SBV, Pat, and ASV was high in medium AAC rice. The coefficient of variation for SBV in the groups was high, indicating that variation was considerable between different cultivars within each group, especially in medium AAC rice.

Table 1. Distribution of physicochemical indices, RVA parameters, and cooked taste values of low AAC rice cultivars.

	Average value	Standard deviation	Kurtosis	Skewness	Minimal value	Maximum value	Coefficient of variation
AAC (%)	8.48	1.03	2.74	-0.91	4.70	10.70	0.12
GC (mm)	82.67	8.23	1.71	0.58	63.50	109.00	0.10
PC (%)	8.00	0.50	−0.33	−0.32	6.68	8.95	0.06
ASV (grade)	5.08	1.04	0.68	−1.15	2.00	6.92	0.20
Pat (°C)	70.51	2.31	4.00	2.00	67.45	78.65	0.03
PKV (RVU)	261.87	36.47	0.17	0.72	194.08	349.83	0.14
HPV (RVU)	126.25	24.12	0.21	0.05	59.25	186.17	0.19
CPV (RVU)	177.88	26.63	1.07	−0.30	90.67	240.67	0.15
BDV (RVU)	135.62	25.29	0.26	0.76	94.08	201.67	0.19
SBV (RVU)	−83.99	27.75	−0.26	−0.54	−149.08	−37.50	−0.33
CSV (RVU)	51.63	5.84	1.13	−0.87	31.42	60.08	0.11
Taste value (points)	77.46	4.43	−0.57	0.04	68.67	87.67	0.06

Note: n = 70.

3.2. Correlation Coefficient of Physicochemical Indices

AAC, GC, PC, and ASV were the important physicochemical indices of the rice eating quality, and their correlation coefficient is analyzed (Tables 3-5). For both low and medium AAC rice, the correlation between all indices was not significant. For the total AAC rice, AAC was significantly negatively correlated with GC.

AAC is considered to be the most crucial factor affecting eating quality [14, 15], but rice varieties with similar AAC often have different eating qualities [16, 17]. Herein, AAC showed a significant negative correlation with GC in total AAC rice but not in low or medium AAC rice, indicating that GC may evidently vary between different rice types.

Table 2. *Distribution of physicochemical indices, RVA parameters, and taste values of medium AAC rice cultivars.*

	Average value	Standard deviation	Kurtosis	Skewness	Minimal value	Maximum value	Coefficient of variation
AAC (%)	16.02	1.05	1.22	−0.64	13.05	18.50	0.07
GC (mm)	70.59	7.87	0.56	−0.67	49.50	87.50	0.11
PC (%)	8.02	0.63	0.38	−0.10	6.62	9.65	0.08
ASV (grade)	5.52	0.99	1.19	−1.13	2.33	6.92	0.18
Pat (°C)	71.12	1.56	1.71	1.14	68.75	76.55	0.02
PKV (RVU)	235.73	21.78	0.70	0.13	173.58	297.83	0.09
HPV (RVU)	157.10	19.99	−0.39	0.40	115.83	202.75	0.13
CPV (RVU)	247.11	20.12	0.29	−0.14	190.33	293.92	0.08
BDV (RVU)	78.63	18.76	1.09	0.49	41.42	145.50	0.24
SBV (RVU)	11.38	20.56	6.71	−1.86	−87.17	44.50	1.81
CSV (RVU)	90.01	8.23	3.15	−1.00	58.33	109.92	0.09
Taste value (points)	68.25	6.05	1.52	0.61	56.33	90.00	0.09

Note: n = 71.

Table 3. *Correlation coefficient of physicochemical indices of low AAC rice.*

	AAC	GC	PC
GC	−0.213		
PC	−0.118	−0.077	
ASV	−0.283*	0.156	−0.202

Note: n = 70. **, significantly correlated at 0.01 level; *, significantly correlated at 0.05 level.

Table 4. *Correlation coefficient of physicochemical indices of medium AAC rice.*

	AAC	GC	PC
GC	0.029		
PC	−0.199	0.113	
ASV	−0.033	−0.245*	0.076

Note: n = 71. **, significantly correlated at 0.01 level; *, significantly correlated at 0.05 level.

Table 5. *Correlation coefficient of physicochemical indices of total AAC rice.*

	AAC	GC	PC
GC	−0.604**		
PC	−0.053	0.032	
ASV	0.165	−0.159	−0.042

Note: n = 141. **, significantly correlated at 0.01 level; *, significantly correlated at 0.05 level.

3.3. Correlation Among Physicochemical Indices, RVA Parameters, and Cooked Rice Taste Values

The correlations among cooked rice taste values, physicochemical indices, and RVA parameters were analyzed (Table 6). RVA characteristics are controlled mostly by *Wx* gene [18], which determines the eating quality by affecting AAC and GC [15]. In total AAC rice, cooked rice taste value showed a significant negative correlation with AAC, CPV, SBV, and CSV, and a positive correlation with GC, PKV, HPV, and BDV; no such correlation was observed in low or medium AAC rice groups, indicating that these parameters may be important reference indices for different type rice cultivars. ASV and Pat are indicators of GT. The two indices were not correlated with cooked rice taste value in low, medium, and total AAC rice.

PC also affects eating quality [19]. PC showed a significant negative correlation with cooked rice taste value in low, medium, and total AAC rice, indicating that PC can be an essential index for evaluating eating quality in similar or different type rice cultivars. For different type rice cultivars, AAC, GC, and RVA parameters can be important indices for evaluating eating quality.

Table 6. *Correlation coefficient between physicochemical indices and cooked rice taste value.*

AAC	GC	PC	ASV	Pat	PKV	HPV	CPV	BDV	SBV	CSV
Low AAC rice										
0.107	0.203	−0.373**	0.022	−0.071	−0.028	−0.221	−0.248*	0.170	−0.200	−0.215
Medium AAC rice										
0.086	−0.128	−0.395**	−0.070	−0.178	0.096	0.278*	0.060	0.196	0.086	−0.128
Total AAC rice										
−0.614**	0.402**	−0.297**	−0.158	−0.126	0.346**	0.367**	−0.563**	0.584**	−0.649**	−0.669**

**, significantly correlated at 0.01 level; *, significantly correlated at 0.05 level.

3.4. Principal Component Analysis of Rice-eating Quality Traits

To analyze the role of physiochemical indices in eating quality, AAC, GC, PC, ASV, and cooked rice taste value were selected for principal component analyses (Tables 7-9). For both low and medium AAC rice, the factor load matrix of PC and cooked rice taste value in factor 1 was remarkably higher than that of the other indices, indicating that PC was the most important factor for the eating quality of low and medium AAC rice. Factor 1 contributed to more than 30% of the factors for eating quality in both low and medium AAC rice. For total AAC rice, the factor load matrix of AAC, GC, and cooked rice taste value in factor 1 was remarkably higher than that of the other indices, indicating that AAC and GC were important factors for the eating quality of different type rice cultivars, contributing more than 43% to the rice-eating quality traits. The factor load matrix of PC in factor 2 was much higher than that of other indices, indicating the importance of PC in the eating quality of different type rice cultivars, contributing more than 22% to the rice eating quality traits.

Table 7. Factor load matrix of the eating quality of low AAC rice.

Variable	Factor 1	Factor 2
AAC	−0.242	0.798
GC	0.578	−0.286
PC	−0.665	−0.445
ASV	0.556	−0.457
Taste value	0.638	0.496
Eigenvalue	1.551	1.371
Percentage contribution (%)	31.023	27.410
Cumulative contribution (%)	31.023	58.433

Table 8. Factor load matrix of the eating quality of medium AAC rice.

Variable	Factor 1	Factor 2
AAC	−0.425	0.227
GC	0.286	0.766
PC	0.815	−0.053
ASV	0.112	−0.783
Taste value	−0.766	−0.011
Eigenvalue	1.526	1.254
Percentage contribution (%)	30.512	25.074
Cumulative contribution (%)	30.512	55.586

Table 9. Factor load matrix of the eating quality traits of total AAC rice.

Variable	Factor 1	Factor 2
AAC	−0.875	−0.148
GC	0.778	0.216
PC	−0.134	0.926
ASV	−0.336	−0.311
Taste value	0.812	−0.343
Eigenvalue	2.161	1.140
Percentage contribution (%)	43.227	22.802
Cumulative contribution (%)	43.227	66.029

Association analysis of these indices and principal component analyses were performed to identify the important indices affecting the rice eating quality, which will assist in varietal selection in rice breeding. The principal component analysis was performed to identify the important factors of rice eating quality, and the results showed that AAC, GC, and cooked rice taste value were the most important factors affecting the eating quality of different type rice cultivars. Our results showed that for different *japonica* rice cultivars, the eating quality was largely determined by AAC and GC.

For low and medium AAC rice, the results of principal component analyses showed that PC and cooked rice taste value can be classified into one category; factor 1, indicating that PC was the most important index for evaluating the eating quality of similar type rice cultivars. Furthermore, for total AAC rice, PC showed a significant negative correlation with cooked rice taste value, and its load matrix in factor 2 was high, indicating the importance of PC in different type rice cultivars. Thus, PC could be an essential indicator of eating quality in rice, especially for similar rice types.

Rice varieties with low GT save water and cooking time and tend to be selected by breeders [20]. The factor load matrix of ASV was not high in low and total AAC rice. Taken together, the results indicated GT may not be as important as AAC or PC for evaluating rice eating quality.

4. Conclusion

In total AAC rice, cooked rice taste value showed a significant negative correlation with AAC, CPV, SBV, and CSV, and a positive correlation with GC, PKV, HPV, and BDV. PC showed a significant negative correlation with cooked rice taste value in low, medium, and total AAC rice. For both low and medium AAC rice, the factor load matrix of PC and cooked rice taste value in factor 1 was remarkably higher than that of the other indices, indicating that PC was the most important factor for the eating quality of low and medium AAC rice. For total AAC rice, the factor load matrix of AAC, GC, and cooked rice taste value in factor 1 was remarkably higher than that of the other indices, indicating that AAC and GC were important factors for the eating quality of different type rice cultivars. Taken together, AAC and GC were more important for the eating quality of different type rice cultivars; however, for similar type rice cultivars, PC was more important. It offers new insight into target traits in breeding rice with high eating quality. These findings and correlations of the present study will be useful for breeders during rice breeding selection for advanced generations.

Acknowledgements

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