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Important Sensory Properties Differentiating Premium Rice Varieties

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Abstract In rice-consuming countries, specific varieties are recognized as premium, "gold standard" varieties, while others are recognized as being superior but second best, despite being identical using the current suite of tools to evaluate quality. The objectives of this study were to determine if there are distinguishable differences in sensory properties of premium and second best varieties and whether these differences are common to premium varieties. Color, an important sensory property, was determined on the raw and cooked rice using a colorimeter. As raw rice, some of the premium varieties were whiter than their second best counterparts while others were not. However, when cooked, with two exceptions, the premium varieties were of the same or greater whiteness than their counterparts. A trained sensory panel employed descriptive sensory analysis, an objective tool, to characterize and analytically measure the flavor (aromatics, taste, mouthfeel) and texture of premium and second best varieties collected from nine rice-consuming countries. Sweet taste, popcorn aroma/flavor, and water-like metallic mouthfeel showed significant differences in intensity between the premium–second best variety pairs. Slickness, roughness, and springiness were the major traits that distinguished the texture of varieties. Quality evaluation programs do not routinely measure these texture and flavor traits, but the fact that they distinguished the varieties in most pairs indicates that their measurement should be added to the suite of grain quality tests in the development of new higher-yielding, stress-tolerant varieties. The incorporation of premium quality will ensure that quality is no impediment to widespread adoption leading to enhanced productivity and food security.

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Introduction

Rice consumers, particularly from countries for which rice is the staple, have strong preferences for the sensory properties of rice. Different countries have different requirements for quality, and within countries, a range of preferences can be found.

Many of the varieties famed for their quality were selected/released many decades ago (Fitzgerald et al. 2009). In the ensuing years, rice improvement programs have significantly increased attainable yield and yield potential, but high yield has not, in many cases, been successfully combined with the high quality of the older varieties. Internationally famous examples, due to export and in part to the effects of migration on national cuisines, are the Japanese variety Koshihikari, the Thai fragrant variety Khao Dawk Mali 105, Super Basmati which is grown in the Punjab between Pakistan and India, and IR64 which is grown in many countries. However, all rice-consuming regions have their favorite varieties, and in most cases, these too have persisted for several decades.

Every rice improvement program strives to replace lower-yielding, high-quality varieties with higher-yielding versions of them. To date, rice breeders have generally failed to combine high yields with optimal quality because not all quality traits are defined (Fitzgerald et al. 2009). Quality evaluation programs have been measuring the same traits for many decades, and current tools of evaluating grain quality cannot distinguish an old variety from a potential replacement, though consumers are readily able to do so. Rapid adoption, resulting from fortuitous combination rather than planned breeding, occurs when the quality of the grain is reproduced in the new variety. An example is IR64, which was released in the 1980s. IR64 is still, 30 years later, grown on over a million hectares of land each year. The challenge that rice improvement programs face is that consumers cannot elaborate on what is considered to be good quality, so it is difficult to identify new and relevant traits.

Descriptive sensory analysis is an objective tool used to characterize and analytically measure traits of aroma, flavor, and texture of foods by a trained panel (Meilgaard et al. 2007). The technique has been used extensively for determining the effect of different growing and/or processing conditions on sensory properties of rice (Champagne et al. 1997, 2004a, b, 2007, 2009; Meullenet et al. 1999, 2000).

Using premium and second best varieties sourced from the national programs of nine rice-growing countries around the world, the first objective of this study was to determine if there are distinguishable differences in the sensory properties of premium varieties, compared with one from the same country with identical grain quality, as defined by our current suite of tools, but which does not reach the superior classification. The second objective was to determine whether identified differences are common to premium varieties. The third objective was to identify the most important descriptors of sensory quality that distinguished each premium and second best pair and to determine if there was any correlation with traits of quality that are currently measured. Premium and second best varieties were determined by each national rice institute using data on crop growth, persistence of premium varieties, adoption rates of second best varieties, and market prices of each of the premium and second best varieties.

Results and discussion

Premium and second best varieties were obtained from nine countries. The two varieties in each pair were very similar based on the current suite of quality evaluation tools. Table 1 shows the variety, the country of origin, gelatinization temperature, amylose content, and protein content. Only the pair from Pakistan differed in gelatinization temperature, which was unexpected since the standard for Basmati quality defines intermediate gelatinization temperature. Perhaps, some environmental condition during grain-filling led to the low value obtained for Basmati 385. For most pairs, there were small differences in amylose content, but in most cases, these differences did not cross the current classifications of amylose (Fitzgerald et al. 2009). Protein content ranged from 5.9% to 11.2% across the set, but in most cases, the protein content was similar for the pairs although statistical analysis of technical replicates indicates significant differences between many pairs

Color

One of the most important attributes of raw and cooked rice is degree of whiteness (Goodwin et al. 1992, Suwansri et al. 2002). The whiteness (L^*) of the raw premium rice compared to its second best counterpart was not an indicator of the relative whiteness of the cooked rice (Tables 2 and 3). However, when cooked, the only premium rice varieties that were not of the same or greater whiteness than their second best counterparts were IR64 and BR IRGA 417 (2009).

Green–red color (a^*) varied markedly across countries and between premium–second best variety pairs (Table 3). Cooking decreased the green color of all the varieties and resulted in a^* values that differed by no more than 0.1 unit.

Table 1 Premium (rank 1) and second best (rank 2) variety pairs with country of origin

Country	Variety	Rank	GT °C[a]	Apparent amylose[b]	Protein[b]
Thailand	KDML105	1	66	15.7a	6.9a
	PTT1	2	65	16.6b	8.0b
China	Zhongzheyou 1	1	76	15.5a	7.2a
	Guodao 6	2	76	18.5b	7.4b
Philippines	IR64	1	77	21.7a	8.2a
	IRRI-132	2	78	17.0b	8.7b
Japan	Koshihikari	1	67	18.1a	5.9a
	Koshiibuki	2	69	16.1b	5.9a
Australia	Pelde	1	74	21.2a	7.0a
	Langi	2	74	21.4a	7.4b
Pakistan	Super Basmati	1	73	23.4a	8.0a
	Basmati 385	2	67	24.9b	8.2b
India	Samba Mahsuri	1	75	24.0a	10.4a
	Swarna	2	75	24.2a	8.6b
Iran	Hashemi	1	76	21.3a	10.3a
	Khazar	2	75	22.2a	9.2b
Brazil	BR IRGA-417 (2008)	1	62	24.9a	8.7a
	BRS Jaçanã (2008)	2	62	24.6a	7.7b
Brazil	BR IRGA-417 (2009)	1	Low	25.5a	7.5a
	BRS Primavera (2009)	2	Intermediate	23.5b	11.2b

[a] High gelatinization temperature (GT) type >74°C; intermediate GT type 70–74°C; low GT <70°C

[b] Values with different letters are significantly ($P<0.05$) different between premium and second best varieties

Table 2 Rice samples prepared using rice cooker and excess water methods

		Rice cooker methods		
Variety	Wash (no. of times)	Water–rice ratio (*w*:*w*)	Soak time (min)	Mean cook time (min) to cooker shut-off
KDML105	2	1.5:1.0	0	20
PTT1	2	1.5:1.0	0	21
Zhongzheyou 1	3	1.35:1.0	15	18
Guodao 6	3	1.5:1.0	15	19
IR64[a]	3	1.4:1.0	10	20
IRRI-132[a]	3	1.4:1.0	10	20
Koshihikari	2	1.4:1.0	30	18
Koshiibuki	2	1.4:1.0	30	19
Langi	2	1.4:1.0	0	22
Pelde	2	1.4:1.0	0	22
		Pan Methods		
Variety	Wash (no. of times)	Water–rice ratio (*v*:*v*)	Soak time (min)	Mean cook time
Super Basmati	3	Excess	30	17
Basmati 385	3	Excess	30	20
Samba Mahsuri	3	Excess	30	21
Swarna	3	Excess	30	21
Hashemi[b]	5	Excess	120	11
Khazar[b]	5	Excess	120	10
BR IRGA-417 (2008)	3	Complete evaporation (2:1)	0	16
BR IRGA-417 (2009)	3	Complete evaporation (2:1)	0	15
BRS Jaçanã	3	Complete evaporation (2:1)	0	17
BRS Primavera	3	Complete evaporation (2:1)	0	15

[a] Drained in strainer 15 min after washing

[b] Rice samples were steamed on top of hot oil for 10 min following cooking

Table 3 Tristimulus L^*, a^*, and b^* values for color measured using a HunterLab MiniScan XE Plus Diffuse LAV M072096 colorimeter

Variety	Raw			Cooked		
	L^*	a^*	b^*	L^*	a^*	b^*
Zhongzheyou	79.6a	−0.58a	11.1a	77.1a	−1.8a	6.0a
Guodao 6	75.8b	−0.50a	11.3a	76.7a	−1.9b	5.6a
Koshihikari	77.1a	−0.83a	12.8a	75.9a	−2.1a	5.1a
Koshiibuki	74.7b	−0.98b	12.9a	75.6a	−2.1a	5.0a
IR 64	78.1a	−0.62a	12.3a	77.3a	−1.8a	5.2a
IRRI 1132	79.1b	0.20b	13.8b	79.3b	−1.7a	7.0b
KDML105	77.3a	−0.95a	11.6a	79.0a	−2.0a	5.0a
PTT1	71.9b	0.03b	13.4b	78.0b	−1.9b	5.2a
Pelde	75.8a	−0.57a	13.5a	77.7a	−2.0a	5.8a
Langi	77.1b	−0.77b	12.5b	77.9a	−2.1a	6.0a
IRGA 417 (2008)	76.0a	−1.02a	10.0a	76.8a	−1.8a	2.4a
Jaçanã	75.4b	−0.49b	11.5b	76.7a	−1.9b	3.2b
IRGA 417 (2009)	73.3a	−0.48a	11.7a	76.4a	−1.7a	3.3a
Primavera	73.2a	−0.95b	12.5b	78.9b	−1.8b	4.8b
Super Basmati	77.1a	−0.33a	12.9a	78.1a	−1.8a	3.9a
Basmati 385	76.8b	0.96b	15.3b	76.2b	−1.8b	2.7b
Sambha Mahsuri	76.3a	0.21a	15.3a	78.6a	−1.7a	4.8a
Swarna	78.6b	−0.40b	13.6b	76.9b	−1.7a	3.4b
Hashemi	77.7a	0.12a	15.3a	79.1a	−1.8a	5.4a
Khazar	78.1b	0.12a	15.0b	79.1a	−1.8a	5.0b

L^* is the measure of brightness from black (0) to white (100); a^* describes red–green color with positive a^* values redness and negative a^* values greenness; b^* describes yellow–blue color with positive b^* values yellowness and negative b^* values blueness. Values with different letters are significantly ($P<0.05$) different between premium and second best variety pairs

In the raw rice, yellow color (b^*) was significantly lower in the premium varieties IR64, KDML-105, BR IRGA-417 (2008 and 2009), and Super Basmati when compared to their second best counterparts. The converse relationship was observed for the Pelde–Langi, Sambha Mahsuri–Swarna, and Hashemi–Khazar pairs. No significant differences in b^* were observed for the pairs from Japan (Koshihikari–Koshiibuki) or China (Zhongzheyou 1–Guodao 6). Upon cooking, varieties became less yellow (b^*=2.4–7.0 versus 10.0–15.3) and the significant differences in b^* observed for the raw varieties were still seen for most variety pairs. No parameter of color provided a consistent explanation of differences in quality.

Comparison of flavor of premium and second best varieties

No significant ($P<0.1$) flavor (aromatics, taste, mouthfeel) differences were observed between the premium and second best variety pairs from Japan, India, and one set from Brazil. The other second best variety from Brazil, BRS Jaçanã, only differed from BR IRGA-417 (also harvested in 2008) by having a lower level of sour/silage (Table 4). Sour/silage is an off-flavor note that increases with increase in harvest moisture content of paddy and length of storage prior to drying (Champagne et al. 2004a) and, thus, was not inherently higher in BR IRGA-417.

The flavor of the other premium–second best variety pairs differed in intensity for only a few attributes, as shown in Table 4. The premium varieties from China and the Philippines were distinguished from their second best counterparts by having significantly higher levels of sweet taste (desirable attribute) and lower level of water-like metallic (undesirable attribute). A lower level of water-like metallic also distinguished the premium Super Basmati from Pakistan from its second best counterpart Basmati 385. Water-like metallic has been shown to decrease with storage time of rough rice (Meullenet et al. 2000), so the difference in intensities between the Super Basmati and the longer-stored Basmati-385 can be attributed to differences between varieties and not storage duration. The intensity of water-like metallic was also numerically but not significantly lower in the premium varieties KDML105, Pelde, IRGA-417 (2008), and Sambha Mahsuri compared to their second best counterparts. A comparison of the combined premium varieties with the combined second best varieties showed water-like metallic to be significantly lower (P=0.02) in the premium varieties. No other flavor attribute was significantly different between combined premium and second best varieties.

The compound 2-acetyl-1-pyrroline (2-AP) imparts a popcorn flavor to fragrant rice varieties (Buttery et al. 1983; Schieberle 1991). Premium KDML105 was significantly

Table 4 Flavor attributes that differed significantly ($P<0.1$) in intensity between premium and second best variety pairs

Flavor attribute	Country	Premium variety	Second best variety	Significant *P*
	China	Zhongzheyou 1	Guodao6	
Dairy		0.8	0.7	0.04
Water-like metallic		0.5	0.7	0.10
Sweet taste		1.3	1.0	0.07
	Philippines	IR64	IRRI-132	
Corn		0.6	0.2	0.01
Sweet aromatic		0.6	0.2	0.03
Water-like Metallic		0.7	1.3	0.10
Sweet taste		1.1	0.5	<0.01
Astringent		1.1	1.5	0.02
	Thailand	KDML105	PTT1	
Popcorn		1.5	1.1	0.08
	Australia	Pelde	Langi	
Sewer/animal		0.2	0.7	0.09
Grain/starchy		1.8	2.2	0.02
Sweet aromatic		0.3	0.6	0.07
Sweet taste		1.0	1.4	0.04
	Brazil	BR IRGA-417 (2008)	Jaçanã (2008)	
Sour/silage		1.2	0.6	0.06
	Pakistan	Super Basmati	Basmati 385	
Hay-like musty		1.4	0.8	0.07
Grassy/green bean		0.7	0.3	0.03
Water-like metallic		0.9	2.0	<0.01
	Iran	Hashemi	Khazar	
Dairy		0.4	0.8	0.09
Sweet Taste		0.6	1.1	0.04

higher in popcorn aroma/flavor than second best PTT1 (1.5 and 1.1, respectively; $P=0.08$). Quantification of 2-AP by GC-MS showed about twice as much 2-AP in KDML-105 (1,358 ppb) than in PTT-1 (637 ppb). Super Basmati, Basmati-385, and Hashemi are also aromatic. The panel found that premium Super Basmati and second best Basmati-385 had the same popcorn intensity as non-aromatic varieties (mean=0.7). GC-MS analysis, however, found 553 ppb of 2-AP in the Super Basmati and none in the Basmati-385. The Basmati-385 was stored as rough rice for about a year prior to milling; whereas, the Super Basmati had not been stored. The 2-AP content of rough rice decreases during storage (Wongpornchai et al. 2004). Although the Super Basmati had approximately the same 2-AP content as PTT1, the panelists perceived the popcorn aroma/flavor to be lower in the Super Basmati, consistent with differences in aroma/flavor between jasmine styles and basmati styles and suggesting that compounds other than 2-AP contribute to their aromatic character, perhaps masking the 2-AP flavor. The popcorn aroma/flavor of Hashemi was not significantly higher than that of the non-aromatic variety Khazar (1.2 and 0.8, respectively). The 2-AP content of Hashemi was 1,045 ppb, but none was detected in Khazar, further suggesting a role for volatile compounds other than 2-AP in determining popcorn aroma/flavor.

Ward's cluster analysis, using selected aromatic (Table 5) and taste/mouthfeel (Table 6) attributes, was used to determine whether the premium and second best varieties grouped into the same or different clusters. The varieties are listed in the Tables in the order they appear in the cluster analysis tree charts. The varieties did not cluster based on premium–second best classification (Tables 5 and 6). Apart from China, India, and the Philippines, varieties from each country fell in the same cluster, suggesting that flavor is specific to the country of origin. Premium Zhongzheyou1 clustered with varieties high in popcorn, corn, hay-like musty, grain/starchy, and sweet aromatic (Table 5). Its counterpart Guodao 6 clustered with ones lower in these attributes. Premium IR64 clustered with varieties high in sweet taste and low in water-like metallic, while its counterpart IRRI-132 grouped with those high in sewer animal, water-like metallic, astringent, and sour/silage and low in sweet taste (Tables 5 and 6). IRRI-132 yields very well in upland and water-scarce areas, but it has not been

Table 5 Ward's cluster analysis using select aroma/flavor attributes to categorize varieties

Variety	Country	Type	Cluster A–B (r^2=0.58)	Cluster A1–A2 (r^2=0.21)	Common characteristics[a]
IRGA-417 (2008)	Brazil	Premium	A	A1	
BRS Jaçanã (2008)	Brazil	2nd best	A	A1	
Khazar	Iran	2nd best	A	A1	
IR64	Philippines	Premium	A	A1	
Pelde	Australia	Premium	A	A1	
Langi	Australia	2nd best	A	A1	
Koshihikari	Japan	Premium	A	A1	
Sambha Mahsuri	India	Premium	A	A1	
Guodao 6	China	2nd best	A	A1	
Koshiibuki	Japan	2nd best	A	A1	
Hashemi	Iran	Premium	A	A1	
Swarna	India	2nd best	A	A2	High sewer animal
IRRI-132	Philippines	2nd best	A	A2	
IRGA-417 (2009)	Brazil	Premium	B		High popcorn
PTT1	Thailand	2nd best	B		High corn
BRS Primavera	Brazil	2nd best	B		High hay-like musty
Zhongzheyou 1	China	Premium	B		High grain/starchy
KDML105	Thailand	Premium	B		High sweet aromatic

The varieties listed in the table in the order they appear in the cluster analysis tree chart

[a] Cluster B means were significantly higher ($P<0.01$) than cluster A means for popcorn (1.2 versus 0.7), corn (0.9 versus 0.6), hay-like musty (1.3 versus 0.9), grain/starchy (2.3 versus 1.9), and sweet aromatic (0.7 versus 0.4)

Table 6 Ward's cluster analysis using taste and mouthfeel attributes to categorize varieties

Variety	Country	Type	Cluster A–B (r^2=0.75)	Cluster A1–A2 (r^2=0.14)	Common characteristics[a]
IRGA-417 (2008)	Brazil	Premium	A	A1	
Guodao 6	China	2nd best	A	A1	
BRS Jaçanã (2008)	Brazil	2nd best	A	A1	
IRGA-417 (2009)	Brazil	Premium	A	A1	
Koshihikari	Japan	Premium	A	A1	
Hashemi	Iran	Premium	A	A1	
BRS Primavera (2009)	Brazil	2nd best	A	A2	
Pelde	Australia	Premium	A	A2	
Khazar	Iran	2nd best	A	A2	
PTT1	Thailand	2nd best	A	A2	
IR64	Philippines	Premium	A	A2	High sweet taste
Zhongzheyou 1	China	Premium	A	A2	
KDML105	Thailand	Premium	A	A2	
Langi	Australia	2nd best	A	A2	
Koshiibuki	Japan	2nd best	A	A2	
Sambha Mahsuri	India	Premium	B		High water-like metallic
Swarna	India	2nd best	B		High astringent
IRRI-132	Philippines	2nd best	B		High sour/silage
					Low sweet taste

The varieties listed in the table in the order they appear in the cluster analysis tree chart

[a] Cluster A means were significantly higher ($P<0.01$) than cluster B means for sweet taste (1.1 versus 0.5) and significantly lower ($P<0.01$) for sour/silage (0.7 versus 1.4), water-like metallic (0.8 versus 1.3), and astringent (1.1 versus 1.6). Cluster A2 means for sweet taste (1.2 versus 0.9) and water-like metallic (0.7 versus 0.9) were significantly higher ($P<0.01$) and lower ($P<0.02$), respectively, than means for cluster A1

widely accepted by consumers, even though current tools for measuring grain quality show that it is similar in quality to the highly popular IR64. If its flavor profile explains its non-adoption, quality evaluation programs need to add flavor evaluations to their repertoire. A high score for sewer animal differentiated second best Swarna from premium Sambha Mahsuri in the cluster analysis (Table 5). Analysis of variance (ANOVA), however, showed no significant differences (P=0.16) in sewer animal between the two varieties. Sambha Mahsuri and Swarna clustered for the other aromatic and mouthfeel/taste attributes, and as noted above, in a comparison of the two varieties, none of these attributes were significantly different. Thus, flavor differences do not appear to explain why Sambha Mahsuri commands much higher prices in the market than Swarna.

Comparison of texture of premium and second best varieties

Roughness was a distinguishing trait between most pairs (Table 7). The premium variety from Southeast Asia and Northern Asian countries was always less rough than the second best, but for South and Central Asia, the cooked surface of the premium variety was rougher. The cuisine of South and Central Asia is predominantly thick curries and consumers like the curry sauce to stick to the rice. A sauce is more likely to stick to a rough surface than a smooth one, which could explain the preference for surface roughness in the varieties of that region.

An association between roughness and protein content (r^2=0.58) was observed and concurs with earlier observations (Champagne et al. 2004b, 2009). However, the present paper indicates that other factors also contribute to roughness. The 0.2% difference in protein content between Zhongzheyou 1 and Guodao 6 would be too low to result in a detectable difference in roughness by the trained panel (Champagne et al. 2009). Moreover, IRRI-132 had the highest roughness score (6.6) of all the varieties with a protein content of 8.7%, and with identical protein content, IRGA-417 (2008) scored a significantly lower value for roughness, further indicating the contribution of other factors. Given that roughness was a distinguishing feature in almost all pairs, and appears to be market-specific, it is important to understand further the biology and structures that lead to a rough surface when the grain is cooked.

Slickness was a distinguishing textural feature for five of the pairs, and in all but one case, slickness was higher in the premium variety (Table 7). In this study, slickness was negatively correlated with both protein (r^2=0.60) and apparent amylose (r^2=0.39) contents. These parameters could indicate differences in slickness when large differences in protein and/or amylose are present. However, in the present paper, the small differences in protein and amylose contents between the premium and second best of each country are not likely to be a sufficient predictor of differences in slickness (Champagne et al. 2009).

For the varietal pairs from South and Central Asia, a number of textural attributes distinguished the premium from the second best, but common to all was springiness, which was higher in the premium variety. Springiness was not a distinguishing feature of the pairs from North and Southeast Asia, Australia, and Brazil. A weak negative correlation (r^2=0.31) was found between springiness and amylose content, but there was no significant difference between the amylose content of each variety in each pair from South and Central Asia, suggesting that amylose is not the primary basis of springiness.

Ward's cluster analysis was used to categorize the rice based on texture characteristics described in Table 10. Analysis using phase I texture attributes resulted in two clusters with the varieties from Iran, India, Brazil, and IRRI-132 from the Philippines comprising cluster A and cluster B composed of varieties from Japan, China, Thailand, Australia, and IR64 from the Philippines (Table 8). Cluster A contained varieties with high roughness scores. Interestingly, all varieties in cluster A, with the exception of IRRI-132, were boiled in a pan (Table 2). Excess cooking water was used for all but the Brazilian samples. This suggests that the cooking method could contribute to roughness. Cluster B was characterized by varieties that scored high for slickness, stickiness to lips, initial starchy coating, and stickiness between grains. Koshihikari and Koshiibuki had the highest scores for initial starchy coating, slickness, stickiness to lips, and stickiness between grains. All varieties in cluster B were cooked by the absorption method in rice cookers, and there is a relatively good association between the order of varieties within cluster B (Table 8) and the length of soaking time before cooking (Table 2), strengthening the need to understand the effect of cooking method on sensory properties.

Conclusions

This preliminary research has taken a snapshot approach to identifying sensory characteristics that may differentiate varieties considered by consumers to be premium and those considered to be second best in their respective countries. The major positive flavor attribute that distinguished varieties grown and traded to and within Southeast Asia was sweet taste. The major off-flavor note was water-like metallic followed by sewer/animal. The major textural attributes that distinguished cooked rice of each pair were roughness and slickness of the surface of the grain.

Table 7 Texture attributes that differed significantly ($P<0.1$) in intensity between premium and second best variety pairs

Texture attribute	Country/region	Premium cultivar	Second best cultivar	Significant *P*
	China/N. Asia	Zhongzheyou 1	Guodao 6	
Slickness		5.7	4.8	0.08
Roughness		4.2	5.1	0.05
Moisture absorption		5.9	6.8	0.03
	Japan/S.E. Asia	Koshihikari	Koshiibuki	
Slickness		6.3	7.3	0.03
	Philippines/S.E. Asia	IR64	IRRI-132	
Slickness		4.9	3.8	0.02
Roughness		5.4	6.6	0.03
Stickiness to lips		5.8	4.8	0.04
	Thailand/S.E. Asia	KDML105	PTT1	
Roughness		4.6	5.4	0.07
Cohesiveness		5.5	5.0	0.07
	Australia	Pelde	Langi	
Moisture absorption		5.0	5.9	0.04
	Brazil	BR IRGA-417 (2008)	Jaçanã (2008)	
Initial starchy coating		2.5	1.8	0.01
Roughness		5.3	4.1	0.01
Stickiness between grains		4.1	3.1	0.01
Uniformity of bite		8.4	7.3	<0.01
	Brazil	BR IRGA-417 (2009)	Primavera (2009)	
Slickness		4.1	3.3	0.05
Roughness		4.7	5.7	0.02
Stickiness to lips		2.8	3.6	0.03
	Pakistan/Central Asia	Super Basmati	Basmati 385	
Roughness		5.2	4.3	0.05
Stickiness to lips		4.2	2.4	<0.01
Springiness		2.1	1.4	0.02
Number of chews		23.4	18.7	<0.01
	India/S. Asia	Sambha Mahsuri	Swarna	
Slickness		3.5	3.0	0.06
Springiness		3.2	2.5	0.02
Number of chews		25.6	22.9	0.04
	Iran/S. Asia	Hashemi	Khazar	
Initial starchy coating		1.5	2.2	<0.01
Roughness		6.1	5.3	0.08
Stickiness between grains		3.0	3.9	0.03
Springiness		3.5	2.8	0.03
Hardness		3.9	3.0	<0.01
Moisture absorption		6.8	5.9	0.04

Springiness was important for varieties of South and Central Asia. This work has revealed a number of sensory traits of quality that are important in different markets. By understanding the structural and genetic basis of these traits, quality evaluation programs could build upon their current capacity and develop tools to enable evaluation of these traits.

Experimental

Materials

Premium and second best varieties were obtained from nine countries. Koshihikari and Koshiibuki were cultivated in the experimental field of the Niigata Prefectural Agricul-

Table 8 Ward's cluster analysis using phase 1 texture attributes to categorize varieties

Variety	Country	Type	Cluster A–B (r^2=0.64)	Cluster B1–B2 (r^2=0.11)	Common characteristics[a]
IRGA-417 (2008)	Brazil	Premium	A		
Khazar	Iran	2nd best	A		
IRRI-132	Philippines	2nd best	A		
BRS Jaçanã (2008)	Brazil	2nd best	A		
IRGA-417 (2009)	Brazil	Premium	A		High Roughness
BRS Primavera I2009)	Brazil	2nd best	A		
Sambha Mahsuri	India	Premium	A		
Hashemi	Iran	Premium	A		
Swarna	India	2nd best	A		
Langi	Australia	2nd best	B	B1	
Pelde	Australia	Premium	B	B1	High Initial Starchy Coating
KDML105	Thailand	Premium	B	B1	High Slickness
Guodao 6	China	2nd best	B	B1	High Stickiness to Lips
PTT1	Thailand	2nd best	B	B1	High Stickiness Between Grains
IR64	Philippines	Premium	B	B1	
Zhongzheyou 1	China	Premium	B	B2	High Stickiness to Lips
Koshihikari	Japan	Premium	B	B2	Higher Slickness
Koshiibuki	Japan	2nd best	B	B2	Higher Initial Starchy Coating
					Higher Stickiness Between Grains

The varieties listed in the table in the order they appear in the cluster analysis tree chart

[a] Cluster A mean was significantly higher ($P<0.01$) than cluster B mean for roughness (5.4 versus 4.7). Cluster B means were significantly higher ($P<0.01$) than cluster A means for initial starchy coating (2.6 versus 2.0), slickness (5.4 versus 4.0), stickiness to lips (6.0 versus 3.4), and stickiness between grains (4.3 versus 3.1). Cluster B2 means were significantly higher ($P<0.01$) than cluster B1 means for initial starchy coating (3.5 versus 2.3), slickness (6.4 versus 5.1), and stickiness between grains (4.8 versus 4.2). Cluster B1 mean was significantly higher ($P<0.01$) than cluster B2 mean for roughness (4.9 versus 3.8) in cluster B2

tural Institute, Niigata, Japan in 2007. They were stored as rough rice for 6 months and milled identically using an experimental rice mill (Yamamoto Co., Ltd). The milled rice was stored under refrigeration for 2 months and shipped to the International Rice Research Institute (IRRI), Los Baños, Philippines. Khao Dawk Mali105 (KDML105) and Pathumthani 1 (PTT1) were grown at the Ubon Rice Research Center and Pathumthani Rice Research Center, respectively, in Thailand in 2007. The rice was stored as rough rice for 3–4 months, and both were milled identically on the same date at Ubon Rice Research Center using a mill similar to a McGill (Sintawee Co.). The milled rice was stored for 1 week at room temperature and shipped to IRRI. Zhongzheyou 1 and Guodao 6 were grown at the experimental farm of the China National Rice Research Institute, Hangzhou, China in 2007. They were stored for 5 months as rough rice and milled identically using a McGill No. 2 mill. After 15 days of storage at room temperature, they were shipped to IRRI. Super Basmati was collected from a farmer's field in the Punjab Province of Pakistan in October 2008 and milled within a week. Basmati-385 was from the 2007 crop and was obtained from the Kaku Rice Research Institute in the Punjab Province of Pakistan. It was stored as rough rice for about a year prior to milling. Both samples were milled identically at the same time using a Satake Rice Mill No. 2. The rice was stored at room temperature for 10 days and shipped to IRRI. Hashemi and Khazar obtained from Iran were from the 2008 crop and were stored as rough rice for about 3 months prior to being commercially milled following which they were shipped within a week to IRRI. IR64, IRRI-132, Sambha Mahsuri, and Swarna were grown at IRRI in 2007. After harvest and 11 months of storage at cool temperature, the rough rice was dehulled (Otake FCY4 Dehusker), and the variety pairs were milled identically using the Grainman 65-220-60-3PH. Pelde and Langi, which are usually exported to markets in Hong Kong and Singapore, were harvested during April 2008 from plots grown at the Leeton Field Station of NSW Industry and Investment's Yanco Agricultural Institute, Yanco, NSW, Australia. They were stored for 4–5 weeks as rough rice before milling. The samples were milled identically using a "flow-through" mill (Satake Rice Whitener MCM-250) and were stored for approximately 1 month at room temperature before shipping to IRRI. BR IRGA-417 and BRS Jaçanã were harvested in 2008 at the Palmital farm of Embrapa

Rice and Beans (Goias State, Brazil) (irrigated system) and stored for 3 months as rough rice before milling. Another sample of BR IRGA-417 (irrigated) and BRS Primavera (upland system) were harvested in 2009 at the Palmital and Capivara farms of Embrapa Rice and Beans (Goias State, Brazil), respectively, and milled without storage. All of the Brazilian varieties were milled identically using a Suzuki mill and shipped directly to the USDA ARS Southern Regional Research Center (SRRC), New Orleans, Louisiana, via expedited shipping. The other samples in the study were sealed and stored under refrigeration (4°C) at IRRI, fumigated for 72 h with Phostoxin, and shipped to the USDA ARS SRRC via courier where the samples were refrigerated until analyzed. Samples reached the USDA 3 days after shipping from IRRI.

Methods

Chemical analyses

Apparent amylose content was determined on the samples in duplicate by the simplified iodine assay method (Juliano 1971). Protein contents (N×5.95) were determined in duplicate by the combustion method (FP-428, LECO, St. Joseph, MI). Gelatinization temperature was measured in triplicate using a differential scanning calorimeter in modulating mode (TA Instruments, DSC Q100). Flour (4 mg) was mixed with water (8 µL) in an aluminum hermetic pan which was then hermetically sealed. The temperature was raised from 35°C to 140°C at 4°C/min, with modulation of ±0.5°C every 40 s. Thermal transitions were recorded and analyzed using Universal Analysis 2000 software. The gelatinization temperature is reported as the peak of the gelatinization endotherm.

Sample preparation for sensory analyses

The cooking protocol for each rice was typical of how the rice variety is cooked in its country of origin. *Samples prepared in rice cookers*: Portions (600 g) of milled rice were washed by covering the rice two or three times with cold water followed by straining to remove excess water. After washing, the samples were transferred to pre-weighed rice cooker insert bowls, and water was added to give the appropriate water to rice ratio, as given in Table 2. The rice was cooked with or without prior soaking (Table 2) in a ten-cup rice cooker-steamer (randomly selected from five used) (Breville RC19XL) to completion, followed by a 10-min holding period in the warm mode. Samples were taken from the rice cookers as described by (Champagne et al. 1999). *Samples prepared using pan methods with excess water*: Portions (600 g) were washed three to five times (Table 2). The rice was added to three times as much water (*w*/*w*), soaked (Table 2), and boiled until the grains had no opaque center when pressed between two pieces of glass. The excess water was drained off. The drained samples from Iran (Hashemi and Khazar) were mounded on top of hot Crisco vegetable oil (2T), the pan was covered, and the rice steamed for 10 min. *Samples prepared using pan methods with complete evaporation*: Portions [three cups (~ 600 g)] were washed three times and then pan-fried in Crisco vegetable oil for 5 min. Six cups of boiling water were added, and after it reached a boil again, the rice was allowed to simmer until the water evaporated. After cooking, pan-prepared rice was held in the pan off the burner for 10 min prior to presentation. Cooking of all samples, irrespective of preparation method, was staggered, so they were analyzed at 20-min intervals by the panel.

Sensory evaluation protocol

Eight panelists trained in the principles and concepts of descriptive sensory analysis (Meilgaard et al. 2007) participated in the study. The rice flavor lexicon included 13 unique flavor attributes which were determined by smelling and evaluation in the mouth (Goodwin et al. 1996) (Table 9). The intensities were scored based on a universal scale for all foods (Meilgaard et al. 2007); the maximum rating for rice flavor attributes is generally about 5. The lexicon for rice texture used by the panel was based on a previously developed method (Lyon et al. 1999; Goodwin et al. 1996) and is described in Table 10. The sensory texture profile used by the panelists included ten attributes that described rice texture at different phases of sensory evaluation, beginning with the feel of the rice when it was first placed in the mouth and ending with the rice being ready to swallow. Paired country samples were randomly chosen for a given session with two country sets presented at each session. Two replicates were evaluated for each variety/country, for a total of ten sessions. The details of the procedure followed for presenting samples and standard (warm-up sample of commercial long grain) to panelists at each session are as previously described (Champagne et al. 1999).

Color

Color was recorded as tristimulus L^*, a^*, and b^* values using a HunterLab MiniScan XE Plus Diffuse LAV "M072096" colorimeter (Reston, VA) with a 1-in.-diameter specimen port. The standard observer was 10°, and the illuminant was D65 (afternoon daylight). The system was standardized using the white and black tiles provided by HunterLab for this instrument. Color was measured on the raw rice and on the cooked rice each of the two times it was prepared in triplicate.

Table 9 Descriptive sensory analysis attributes and definitions used to evaluate cooked rice flavor (aromatics, taste, mouthfeel)

Sewer animal	An immediate and distinct pungent aromatic in the flavor characterized as sulfur-like and generic animal. The animal aromatic in the flavor can sometimes be identified as "piggy."
Floral	Aromatics associated with dried flowers, such as lilac and/or lavender. This aromatic is characterized as spicy floral as in an "old fashioned sachet."
Grain starchy	A general term used to describe the aromatics in the flavor associated with grains such as corn, oats and wheat. It is an overall grainy impression characterized as sweet, brown, sometimes dusty, and sometimes generic nutty or starchy.
Hay-like musty	A dry, dusty, slightly brown aroma/flavor with a possible trace of musty.
Popcorn	A dry, dusty, slightly toasted and slightly sweet aromatic in the flavor that can be specifically identified as popcorn.
Corn	The sweet aromatics of the combination of corn kernels, corn milk, and corn germ found in canned yellow creamed-style corn.
Alfalfa/grassy/green beans	A dried, green, slightly earthy, slightly sweet aroma/flavor including grassy and fresh green bean aroma/flavor.
Dairy	A general term associated with the aromatics of pasteurized cow's milk. Most apparent just before swallowing.
Sweet aromatic	A sweet impression such as cotton candy, caramel, or sweet fruity that may appear in the aroma and or aromatics.
Water-like metallic	Aromatics and mouthfeel of the minerals and metals commonly associated with tap water. This excludes any chlorine aromatics that may be perceived.
Sweet taste	Basic sweet taste associated with sugar
Sour/silage	A sour fermented vegetation aroma/flavor, not decaying vegetation.
Astringent	The chemical feeling factor on the tongue, described as puckering/dry and associated with tannins or aluminum.

2-Acetyl-1-pyrroline analysis

The method of Bergman et al. (2000) was employed for the quantification of 2-acetyl-1-pyrroline (2-AP). In brief, 0.3 g of rice flour was placed in a 2-ml vial. A solution of 0.5 ml of MeCl2 containing 2,4,6-trimethylpyridine (TMP) (Sigma-Aldrich, St Louis, MO) at a concentration of 485 ppb was added to the vial and capped with a steel cap. The vials were heated at 85°C for 2.5 h to ensure complete gelatinization of the rice samples. An Agilent 7890 GC (Agilent Technologies, Folsom, CA) equipped with a 30-m × 0.25-mm DB-WAX capillary column (J & W Scientific, St. Joseph, MO) was used for analysis. Aliquots of 2 μl were injected into an injection port operated in splitless mode at 155°C. The oven was initially held for 1 min at 40°C then increased at a rate of 9°C/min to 120°C and then at

Table 10 Sensory descriptive texture attributes and their definitions used to evaluate cooked rice texture

Phases/attributes	Definition
Phase I	Place 6–7 grains of rice in mouth behind front teeth. Press tongue over surface and evaluate.
Initial starchy coating	Amount of paste-like thickness perceived on the product before mixing with saliva (3 passes).
Slickness	Maximum ease of passing tongue over the rice surface when saliva starts to mix with sample.
Roughness	Amount of irregularities in the surface of the product.
Stickiness to lips	Degree to which kernels adhere to lips.
Stickiness between grains	Degree to which the kernels adhere to each other.
Phase II	Place 1/2 teaspoon of rice in mouth. Evaluate before or at first bite.
Springiness	Degree grains return to original shape after partial compression.
Cohesiveness	Degree to which the grains deform rather than crumble, crack, or break when biting with molars.
Hardness	Force required to bite through the sample with the molars.
Phase III	Evaluate during chew.
Cohesiveness of mass	Maximum degree to which the sample holds together in a mass while chewing.
Chewiness	Amount of work to chew the sample.
Uniformity of bite	Evenness of force throughout bites to chew.
Moisture absorption	Amount of saliva absorbed by sample during chewing.
Phase IV	Evaluate after swallow.
Residual loose particles	Amount of loose particles in mouth.
Toothpack	Amount of product adhering in/on the teeth.

a rate of 25°C/min to 250°C and held for 5 min. Samples were run in triplicate, and concentration of 2-AP was calculated on the relative peak areas of the 2-AP peak and the TMP peak.

Statistical analyses

Analysis of variance (ANOVA) was used to compare the varieties for all countries combined and within each country for flavor and texture attributes. Ward's cluster analysis was also performed using standardized data to determine if rice varieties could be grouped based on similarities in flavor and texture characteristics. Three sets of variables were used in the cluster analyses: (1) aromas/flavors (sewer animal, grain/starchy, hay-like musty, popcorn, corn, and sweet aromatic), (2) taste (sour/silage and sweet taste) and mouthfeel (astringent and water-like metallic) attributes, and (3) texture at phase I of sensory evaluation (Table 10). Cluster means were compared using Tukey–Kramer honestly significant difference tests. The combined data comparisons were performed both with and without the Super Basmati–Basmati-385 pair because the samples were stored for different lengths of time prior to milling. Storage time of rough rice has been shown to affect the flavor and texture of milled rice (Meullenet et al. 2000), so the Super Basmati–Basmati-385 pair was excluded from the cluster analysis. All statistical analyses were performed using SAS® software, version 9.2; Enterprise Guide, version 4.1; and JMP® software, version 8.0.1 (SAS Institute Inc., Cary, NC). Results were considered significant at the 0.10 level for the sensory analyses; other data were reported significant at $P<0.05$.

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