Physicochemical Characterization and Consumer Acceptance by Asian Consumers of Aromatic Jasmine Rice

S. SUWANSRI AND J.-F. MEULLENET

ABSTRACT: Physicochemical properties and acceptance by Asian consumers in the United States of 3 commercially U.S.-grown and 12 imported jasmine rice samples were evaluated. Rice kernels, flour, and starch were characterized for physical, chemical, pasting, and thermal properties. Amylose content, gel type, hardness-to-stickiness ratio, surface fat, protein, and pasting properties significantly affected the eating and cooking qualities and physical appearances of the rice samples; these variables were key to distinguishing the major quality differences and to differentiating U.S.-grown from imported jasmine rice. Data collected from this study could be useful to rice producers, importers, or rice breeders for understanding the physicochemical characteristics of aromatic jasmine rice and its acceptance by Asian consumers.

Keywords: jasmine rice, consumer acceptance, Asian

Introduction

Jasmine rice is popular and is reported to be consumed primarily in the United Stated among the Asian-Americans emigrating from Southeast Asia (Pinson 1994). The acceptance of cooked rice has been described in the literature among the Asian population living in Asian countries (Juliano 1990) and by those living in the United States (Meullenet and others 2001; Suwansri and others 2001). Juliano (1990) indicated that Asian consumers preferred rice with high milling quality and high cooking quality (that is, few broken, more polish, and intermediate amylose content), whereas Meullenet and others (2001) found that appearance and aroma were the most important factors in determining the Asian consumer acceptance of cooked nonaromatic and aromatic varieties. Suwansri and others (2001) also showed that appearance, aroma, flavor, and texture strongly impacted Asian consumers' acceptance of cooked jasmine rice. Very few studies have reporting on the physicochemical properties of jasmine rice.

The physicochemical properties of the rice kernels, flour, and starch have been studied and reviewed previously by a number of researchers (Russell and Juliano 1983; Nakazawa and others 1984). Starch is the major component of the rice kernels. Its properties are important to rice flour characteristics. Isono and others (1994) established standard methods for evaluating the physicochemical factors affecting the eating quality of Japanese and other imported rice. Hettiarachchy and others (1997) investigated the physicochemical properties of the U.S.-grown rice varieties. Limited physicochemical characterization work has been carried out on commercially milled rice, especially jasmine rice (U.S.-grown and imported).

The objectives of this study were to investigate the physicochemical properties of commercially grown U.S. and imported jasmine rice in the United States and identify possible parameters indicative of jasmine rice quality.

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Materials and Methods

Samples

In February 2000, 15 domestic and imported jasmine rice samples were purchased from either local specialty stores or producers in Arkansas (Fayetteville, Fort Smith, and Springdale) and Houston, Texas. A list of jasmine rice samples evaluated is given in Table 1. Three-digit random numbers were generated according to Cochran and Cox (1957) and assigned randomly for all 15 jasmine rice samples. Each sample was premeasured in 3-lb plastic bags (Glad, Ziploc™ bags), coded and sealed, and then placed in plastic airtight storage buckets and stored at 4 °C in a commercial walk-in refrigerator until testing.

Consumer testing

Home-use testing was conducted using 105 Asian families recruited on the basis of consumption of jasmine rice. A complete description of the test can be found in Suwansri and others (2002). This consumer group was represented by 15% islanders (Filipinos and Indonesian), 13% Laotian, 12% Malaysian, 23% Thai, 12% continental (Sri Lanka, Bangladesh, and Burma), and 25% Chinese (mainland China and Taiwan). A jasmine rice sample was delivered weekly to the respondents' homes for 7 consecutive weeks. A 9-point verbal hedonic scale (Meilgaard and others 1999) anchored from "dislike extremely" to "like extremely" was used to assess the acceptance of various aspects (such as overall acceptance, appearance, aroma, flavor, and texture) of the products. However, only overall acceptance will be considered here.

Sample preparation for physicochemical analysis

For analyses requiring flour, the milled jasmine rice kernels were reduced in particle size to 0.5 mm or less with a laboratory mill (Foss Cyclotec, model 1093, Hoganas, Sweden). A modified alkali

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steeping method was then used to isolate rice starch from the flour (Yang and others 1984). The resulting starch was reduced in particle size to approximately a 75 mesh.

Physical characterization of milled jasmine rice

Whiteness of the 15 samples was measured with a milling meter (Satake Model MM-1B, Satake Engineering Corp., Tokyo, Japan). The whiteness was recorded as the percentage of light reflected from the sample, and the instrumental range for whiteness was between 15% and 60%.

The surface reflectance of uncooked milled jasmine rice was also evaluated with a colorimeter (model CR-300, Minolta Chromameter, Tokyo, Japan) using the standard CIELAB color system (*L* = lightness, black to white; *a* = red to green; *b* = yellow to blue). To make the measurement, 50 g of milled rice was placed in a glass container.

The kernel physical attributes (kernel length and kernel length-to-width ratio) were measured using a rice image analyzer equipped with a NaiS image checker 30R (Satake Engineering Corp., Tokyo, Japan). For 1 measurement, 100 uniform rice kernels were randomly selected, and each rice sample was analyzed in duplicate.

Gel consistency of the rice flour was determined in duplicate according to a rapid method described by Cagampang and others (1973).

Water absorption and volume expansion ratio were measured according to the method developed by Bhattacharya and Sowbhagya (1971). Water absorption was calculated from the increase in the mass of the cooked rice divided by the mass of the uncooked milled rice. The volume expansion ratio was calculated from the ratio of the height of cooked rice to the height of uncooked rice.

Instrumental texture measurement

A steaming procedure (Sesmat and Meullenet 2001) was selected to prepare the cooked rice for the instrumental measurement because it required smaller samples and would be better adapted to quality evaluation in a laboratory. In a 150-mL beaker, 20 g of milled rice was combined with 30 g of water and was then cooked in a household-electronic rice cooker (Rice-O-Mat, Natl. Brand, Osaka, Japan) model nr SR-w10F-5 quart capacity) under steam condition for 30 min. Ten intact uniform rice kernels were randomly selected from the center portion of the beaker and placed under the plate for testing. Six replicated measures were made for each rice sample from the same beaker within 10 min after cooking.

Instrumental evaluation was carried out using a texture analyzer (model TA-XT2i, Texture Technologies, Scarsdale, N.Y., U.S.A.) in combination with a 25-kg load cell. A 100-mm dia compression plate (SMS P/20, Texture Technologies) was used as the upper fixture, whereas a heavy-duty platform was used as the bottom fixture. The crosshead speed was set at 0.5 mm/s and the travel distance at 90% of the sample's original height. The clearance between the plate and base was set at 30 mm and the contact force (test trigger) was set at 60 g. Force in grams required to compress the sample was recorded as a function of time. Maximum positive force of the first compression cycle when kernels are compressed to 90% of their original height (hardness) and maximum negative force during the upward movement of the probe (stickiness) were extracted from each curve using macro commands from the Texture Expert software (Version 1.22, Stable Microsystems, Surrey, England).

Pasting properties of jasmine rice flour

Flour gelatinization, pasting, and setback curves were determined in duplicate according to AACC method 61-02 (AACC 1995a) using a Rapid Visco Analyzer (RVA, model RVA-3C, Newport Scientific, Australia). Before the analysis, the moisture content after drying at 135 °C for 1 h (AACC 1995b) was determined. The viscosities measured included the maximum viscosity during heating at 95 °C (peak viscosity), minimum viscosity after the peak, breakdown viscosity (the decrease in viscosity during heating at 95 °C relative to the peak viscosity), final viscosity at 50 °C, and setback viscosity (final viscosity at 50 °C minus minimum viscosity) after 12.5 min.

Chemical analysis

Moisture content analysis was conducted following the method recommended by ASAE (1995). Jasmine rice samples of 10 g were dried in a conventional convection oven at a temperature of 130 °C for 24 h.

Surface fat of the rice kernels was determined in duplicate using a Soxtec system (Soxtec Avanti model 2050, Foss). Apparent amylose content of the defatted rice starch was determined using an iodine colorimetric method as described by Juliano (1971). Total nitrogen was determined according to AACC method nr 22-60 (AACC 1983). Crude protein was then calculated by multiplying the nitrogen level by 5.95. Each rice sample was analyzed in duplicate.

Thermal properties of Jasmine rice starch

The gelatinization properties of jasmine rice starches were determined using a differential scanning calorimeter (Pyris-1 DSC, Perkin-Elmer, Norwalk, Conn. U.S.A.) equipped with an intercooling system. Previous research showed that fully cooked rice flour or starch is obtained when the cooked sample absorbed approximately 70% moisture (Juliano and others 1981a). To obtain fully gelatinized rice starch, each sample was accurately weighed (for example, 4.0 mg dry basis), transferred to an aluminum DSC sample pan (Perkin-Elmer), and then 8 μL distilled water was added using a micro-syringe, hermetically sealed. This sample was then allowed to stand at room temperature for at least 1 h before analysis. Samples were heated at the rate of 10 °C/min over the temperature range of 25 °C to 100 °C. An empty pan was used as the reference cell. Gelatinization onset temperature (T_0), peak temperature (T_p), and gelatinization enthalpy (ΔH, the integral of the specific heat over the specified temperature range) were automatically computed. The enthalpy of gelatinization, expressed as joules per unit weight of dry starch (J/g), was calculated by integrating the area between the thermogram and the baseline under the peak. Each rice sample was analyzed in duplicate. The thermogram characteristic of jasmine rice starch is presented in Figure 1.

Statistical analysis

Physicochemical analytical data were analyzed according to a 2-way ANOVA by using PROC GLM of SAS® (SAS Version 8.1, SAS Inst. Inc., Cary, N.C., U.S.A.) with samples and replications as main effects. Fisher's least significant difference (LSD) test was used to conduct a series of *t*-tests between pairs of mean attributes if significant effects were reported in the ANOVA. Differences between 2 means exceeding LSD values ($\alpha = 0.05$) for each attribute indicated a significant difference between the samples ($\alpha = 0.05$).

Principal component analysis (PCA) (Unscrambler®, version 7.5, Camo, Norway) was used so that all complex multidimensional data sets (that is, analytical variables) were visualized. The PCA can be translated as the linear combination of the initial variables that contributed most to making the samples different from each other (Camo 1999). The analytical variables were standardized to unit variance before the analysis so that variables that are thought to be more important than other variables could be given larger weights than those variables of lesser importance. For interpretation of the results, the optimal number of the principal components was determined to be those that explained most of the information in the data (that is, the model with a total residual variance close to 0 or a large total explained variance).

Consumer overall acceptance was predicted from physicochemical properties using Partial Least Squares (PLS) regression (The Unscrambler®, version 7.5, Camo, Norway). Data were centered before PLS regression so that all results were interpreted in terms of variation around the mean. Predictive variables were standardized by weighting with the standard deviation, so that all variables were given the same chance to influence the prediction of the consumer data, regardless of differences in variable magnitude. The full cross-validation method was used to validate the model. The predictive models were optimized using the Jack-knifing method available as an option of the Unscrambler. Jack-knifing is a procedure that is designed to test the significance of the model parameters and is performed during cross-validation. In this method, the approximate uncertainty variance of the regression coefficients can then be estimated and a *t*-test performed for each element relative to its estimated uncertainty variance, giving a significant level for each parameter. All parameters for which $P < 0.05$ were kept in the model.

Table 1—Jasmine rice samples

Product type	Code	Product name	Manufacturer or brand	Origin
Domestic	dJ	Jasmine 85	Lowell Farm	Texas
	dS	Jasmine	Specialty Rice Marketing	Arkansas
	dT	Jasmati		Rice Tec
Texas				
Imported	iA	Jasmine	Angel Rice	Thailand
	iB	Jasmine	Bell & Flowers	Thailand
	iK	Jasmine	B.K.M.	Thailand
	iC	Jasmine	C.T.F.	Thailand
	iS	Jasmine	Dynasty	Thailand
	iG	Jasmine	Golden Boy	Thailand
	iM	Jasmine	Golden Camel	Thailand
	iD	Jasmine	Golden Cobra	Thailand
	iI	Jasmine	I.T.C.	Thailand
	iR	Jasmine	Riviana	Thailand
	iR1	Jasmine	Rose Rice	Thailand
	iR2	Jasmine	Rose Rice	Thailand

Results and Discussion

Physical characterization

Physicochemical properties of domestic and imported jasmine rice are summarized in Table 2. The whiteness results indicated that 2 domestic jasmine rice samples (dS and dJ) were significantly lower in whiteness than all imported samples. The other domestic sample (dT) was similar to the imported products. The lab results indicated that the domestic jasmine rice sample (dS) exhibited the lowest whiteness and L^* value and the highest a^* and b^* values. A visual examination result revealed that this sample looked dull and off-white in color. The other 2 domestic samples (dJ and dT) and all imported jasmine rice sample exhibited a whiter appearance and were found to have significantly higher L^* and lower a^* and b^* values than dS. One significant finding was that the b^* value, for domestic products, was higher than that for many of the imported products, confirming that domestic samples were more yellow than imported jasmine rices.

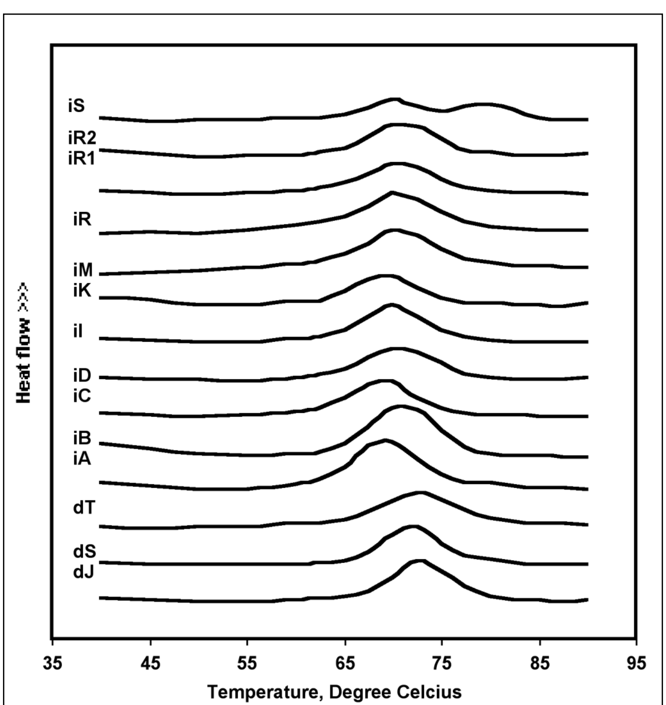

Figure 1—Gelanization properties of jasmine rice samples using differential scanning calorimetry (DSC). Sample abbreviations can be found in Table 1.

Significant differences in the gel length separated the jasmine rice samples into 2 types: soft gel and medium gel types. One domestic (dT) and 1 imported sample (iS) were classified as medium gels. All other samples, including jasmine 85 (dJ), were classified as soft gels. According to the grain length classification, 3 jasmine rice samples from this study were categorized as the medium grain type (dS, dT, iD) (Table 2). These 3 samples were found to be significantly shorter than the other 12 samples, which were categorized as the long grain type. However, the length/width ratio of the grains for all samples was greater than 3.0, indicating that the grain shape was slender (Khush and others 1979). Bhattacharya and Sowbhagya (1971) reported that grain size and shape inversely affected the water uptake of rice. Larger grains show lower water uptake at constant cooking time. The results from this study showed that the water absorption ratio of the cooked rice correlated positively with the volume expansion ratio and correlated negatively with grain dimensions, except in 1 of the domestic jasmine rice samples (dJ), only partially confirming observations by Bhattacharya and Sowbhagya (1971). This sample (dJ) also exhibited the largest grain length and the smallest ratio of grain length to grain width (3.08).

Results obtained from this study did not fully explain the relationship between the grain physical dimensions and the water uptake ratio. However, it should be noted that the samples evaluated were commercial samples that were probably not pure cultivars. Other factors such as the composition (physical and chemical), and postharvest conditions, including harvest moisture content, drying temperature, milling process, and storage (aging) conditions and durations, would affect the water-uptake ratio, the appearance, and gel character of these samples.

Instrumental texture measurement

Instrumental measurement of the cooked rice hardness and stickiness were also reported in Table 2. The results showed that hardest cooked rice samples (dT and iS) were also those that were of the medium gel types with high water absorption and high volume expansion ratios. Instrumental stickiness values (the force

Table 2—Physicochemical properties of milled jasmine rice

Sample codes[a]	White (%)	CIELAB L*[b]	a*[c]	b*[d]	Gel consistency[e] (mm)	Water absorption ratio	Volume expansion ratio	Grain dimension Length[f] (mm)	Length/ width[g]	Cooked rice texture Hardness (g)	Stickiness (g)	Chemical properties Moisture content (%)	Surface fat content (%)	Protein content (%)	Apparent amylose[h] (%)
Domestic															
dJ	36.93	96.15	–0.14	1.27	79.00	1.75	2.38	7.09	3.08	4231.3	643.7	12.28	0.55	7.71	12.35
dS	31.50	91.38	0.45	6.12	61.33	2.29	3.33	6.40	3.13	5038.8	303.1	12.04	0.52	8.67	13.20
dT	43.50	100.35	–0.82	3.32	47.33	2.08	3.16	6.32	3.23	9456.1	483.6	12.06	0.29	7.08	15.86
Imported															
iA	41.23	96.93	–0.45	0.63	75.33	1.97	2.70	6.76	3.26	5120.0	850.9	14.20	0.24	6.40	13.05
iB	42.70	99.32	–0.39	–1.91	63.67	1.89	2.87	6.75	3.42	5147.3	837.1	13.02	0.27	6.02	10.67
iC	41.97	93.05	–0.14	–3.67	76.77	2.03	2.84	6.76	3.36	6177.6	1048.9	14.14	0.27	6.75	12.92
iD	41.83	99.54	–0.58	–1.70	78.00	1.96	2.92	6.55	3.15	5887.8	876.1	13.65	0.30	6.46	11.14
iG	43.27	99.53	–0.67	0.00	82.33	1.75	2.51	6.82	3.48	4401.0	852.2	12.34	0.21	6.10	13.09
iI	41.83	97.69	–0.22	–3.31	76.00	1.83	2.78	6.95	3.44	5003.0	748.5	13.52	0.25	6.50	13.28
iK	42.33	97.29	–0.18	–2.76	78.67	1.80	2.55	6.80	3.36	5670.3	920.2	13.78	0.25	6.40	12.30
iM	42.30	98.94	–0.39	–3.68	88.00	1.88	2.80	6.82	3.40	3658.8	481.6	14.76	0.21	6.16	11.92
iR	43.83	97.62	–0.44	–0.83	65.00	1.81	2.51	6.92	3.45	6031.9	737.2	13.59	0.20	7.05	13.28
iR1	42.63	97.96	–0.58	–0.87	75.33	1.88	2.58	6.70	3.35	5412.4	935.5	12.99	0.26	6.12	12.90
iR2	42.93	100.48	–0.63	0.67	62.33	1.87	2.70	6.77	3.38	5188.3	918.4	13.32	0.28	6.30	13.01
iS	43.07	97.93	–0.83	0.24	55.00	2.23	3.28	6.75	3.30	8185.2	643.3	13.47	0.15	6.21	17.54
LSD[i]	0.50	4.72	0.23	2.35	15.53	0.19	0.41	0.23	0.11	831.56	205.3	0.12	0.02	0.38	0.09

[a]Sample name abbreviation can be found in Table 1.
[b]*L**: 0 = black and 100 = white.
[c]*a**: –60 = green and +60 = red.
[d]*b**: –60 = blue and +60 = yellow.
[e]Hard gel = gel length 28 to 40 mm; medium gel = gel length of 41 to 60 mm; soft gel = gel length of more than 60 mm (Cagampang and others 1973).
[f]Extra long grain = grain length of more than 7.50 mm; long grain = 6.61 to 7.50 mm; medium grain = 5.51 to 6.60 mm; short grain = grain length of less than 5.50 mm (Khush and others 1979).
[g]Slender shape = the ratio over 3.0; medium shape = 2.1 to 3.0; bold shape = 1.1 to 2.0; round shape = less than 1.0 (Khush and others 1979).
[h]Waxy rice = 1.4% to 4.4%; low amylose rice = less than 20%; intermediate amylose rice = 20% to 25%; high amylose rice = more than 25% (Juliano 1979; Kongseree 1979).
[i]Least significant difference (/alpha/ = 0.05).

required to pull the compression platen away from the sample) ranged from 303.1 to 1048.9 g. The values appeared to be independent of the gel type. This is an interesting result because stickiness was found, in a previous study on the same set of samples (Suwansri and others 2001), to be an important driver of acceptance by Asian consumers. However, stickiness values were significantly negatively correlated ($r = –0.59$, $\alpha = 0.05$, data not shown) with instrumental hardness. These findings were in agreement with Juliano and others (1981b) who reported that instrumentally assessed stickiness was significantly negative correlated to hardness. However, 2 samples (dT and iM) that were greatly different in hardness exhibited similar instrumental stickiness values (negative force of about 480 g) (Table 2). The inconsistency in the results indicated that some other intrinsic factors and their interactions significantly affected the cooked jasmine rice texture (for example, amylose-amylopectin content and starch-oryzenin interaction.

The ratio of instrumental hardness and stickiness has been used to clearly assess texture differences between rice samples (Okadome and others 1995). In the present study, the ratios between these 2 factors tended to better statistically discriminate between the jasmine rice samples. The highest values of the hardness-to-stickiness ratio were exhibited in 2 domestic samples (dS = 16.92 and dT = 19.55) and 1 imported sample (iS = 12.72). In most of the imported jasmine rice and in 1 domestic sample (dJ) that exhibited a soft texture, the ratio of the hardness and stickiness ranged from 5.16 to 8.18. The ratio of these 2 instrumental parameters will later be subjected, along with the other analytical variables, to further analysis (PCA).

Chemical properties

Chemical properties of jasmine rice are presented in Table 2. There were significant differences in the moisture contents of domestic and imported jasmine rices. The domestic samples were found to have lower moisture contents (12.04% to 12.28%) than most of imported samples (12.34% to 14.76%). This was probably a result of differences in postharvest handling techniques (drying, storage, and milling) between the domestic and imported rice samples (Goodwin and others 1992). Some of the results observed for the instrumental texture test might have been a result of the differences in milled rice moisture content. Under the same cooking conditions and a fixed water-to-rice ratio (1 to 1.5), it has been shown that samples with lower starting moisture content will yield a harder texture than a sample starting from a higher moisture content (Meullenet and others 1999). The higher moisture content of some imported products (for example, iM) could have contributed to yielding a softer texture than other domestic products (for example, dT), which were cooked from a lower starting moisture content.

Other chemical constituents of milled jasmine rice ranged from 0.15% to 0.55% wt/wt (dry weight basis) for surface fat content, 6.02% to 8.67% wt/wt (dry weight basis) for protein content, and 10.67% to 17.54% wt/wt (dry weight basis) for apparent amylose content (Table 2). The amount of surface fat found in 2 domestic jasmine rice samples (dJ and dS) was higher than that found in imported samples. These 2 samples also exhibited very low whiteness values measured from the milling meter. This result was similar to that reported by Siebenmorgen and Sun (1994). Siebenmorgen and Sun (1994) reported that surface fat content was inversely related to the degree of milling. This result could have impacted some of the consumer acceptability reported in Suwansri and others (2001). As surface fat oxidized, it tends to give off-flavors to rice. Therefore, in future studies, the degree of milling should be kept constant, so that a fairer comparison can be made between products.

Similarly to the fat content, the protein content in all domestic samples was significantly higher than the protein content in most of the imported samples, except for Riviana jasmine rice (iR). The amount of protein contained in iR (7.05% wt/wt) was not statistically different ($\alpha = 0.05$) from Rice Tec Jasmati (dT), 1 sample of the domestic jasmine rice.

The amylose content in samples from this study ranged from 10.67% to 17.54% wt/wt (dry weight basis), which classifies the samples as low amylose rice (Juliano 1979; Kongseree 1979). However, the amylose content of Rice Tec Jasmati (dT) and Dynasty Jasmine rice (iS) was significantly higher (15.9% and 17.5%) than that of other samples. These results were also in agreement with previous research by Juliano (1979). Juliano (1979) found that the volume expansion ratio was positively correlated to the amylose content and the gel type. According to his findings, medium and hard gel type rice that contained high amylose content (such as dT and iS) would expand more than those with lower amylose content during cooking.

Pasting properties of jasmine rice flour

The viscosity profile results of domestic and imported jasmine rice obtained from a Rapid Visco Analyzer are presented in Figure 2. As reported by Halick and Kelly (1959), the gelatinization temperature was recorded as the point of initial increase in viscosity. In this study, the pasting temperatures were between 72 °C and 76 °C for most samples. Most of these results were in agreement with previous studies by Juliano (1972). Juliano (1972) confirmed that the endpoint of the starch gelatinization temperature varied from 55 °C to 79 °C for most rice. Two exceptions were found in dS and iS. These 2 samples exhibited very high pasting temperature of 86.6 °C and 83.5 °C, respectively.

The low pasting temperatures observed (<77 °C) were associated with high peak viscosity (>3500 cPs) (Figure 1a and 1b). These results indicated that starch granules hydrated and swelled rapidly. Some intrinsic factors from different rice origins may affect the pasting characteristics of flour. For example, Nikuni and others (1969) reported that the ripening temperature of the rice grains from different origins was a major factor affecting the pasting temperature of Japanese rice. The rice starch granules formed at higher temperatures exhibited lower pasting temperatures and higher peak viscosity. However, because the samples selected were commercial samples and probably not pure varieties, it would be difficult to make inferences on the causes of the differences observed.

The significantly higher fat and protein contents of 2 domestic samples (dS and dT, Table 2) might also explain some of the pasting properties observed. Starch-lipid or starch-protein interactions that can occur during heating may have resulted in lowering the pasting viscosity. The pasting curves for dS and dT (Figure 1a) and iS (Figure 1b) showed small values of breakdown viscosity (the difference between peak viscosity and minimum viscosity, approximately 1000 cPs). These curves also showed a large increase in viscosity during the cooling stage. These findings indicated that retrogradation occurred rapidly in these 3 samples. In the home use consumer study conducted with the same sample set (Suwansri and Meullenet 2001), consumers reported that these 3 cooked samples (dS, dT, and iS) became very crumbly and hard in texture after cooling down, rendering the samples less acceptable. This could be because Asian-American consumers prepare rice in large quantities for future meals, and reheat rice as needed for specific dishes.

Most of the imported jasmine rice and 1 domestic sample (dJ) exhibited low setback viscosity (<1300 cPs), whereas dS, dT, and iS exhibited high setback viscosity (1500 to 1900 cPs) (Figure 1a and 1b). The setback viscosity is related to the gel network formation and is correlated to the amount of the amylose present in the rice starch (Jane and others 1999). This is consistent with our findings because most of the imported jasmine rice samples, which exhibited low amylose contents, exhibited low setback viscosities.

Thermal properties of jasmine rice starch

The DSC thermograms of the 15 samples of jasmine rice starch are given in Figure 2. There were significant differences in the gelatinization temperature (that is, onset temperature, peak temperature, and end temperature) between domestic jasmine rice and imported types. The domestic samples were found to be significantly higher in their onset (65.9 °C to 67.1 °C), peak (72.2 °C to 72.6 °C), and end (79 °C to 85.1 °C) temperatures than imported samples. However, most of the samples exhibited a similar profile, except for 1 imported sample (iS). Besides the 1 gelatinization endotherm, this sample showed a second distinct higher temperature endotherm from 76 °C to 87 °C. This rice sample exhibited high amounts of amylose, but very small amounts of surface fat and protein. Although it is difficult to speculate on the character of the higher temperature endotherm, this distinct peak probably does not represent

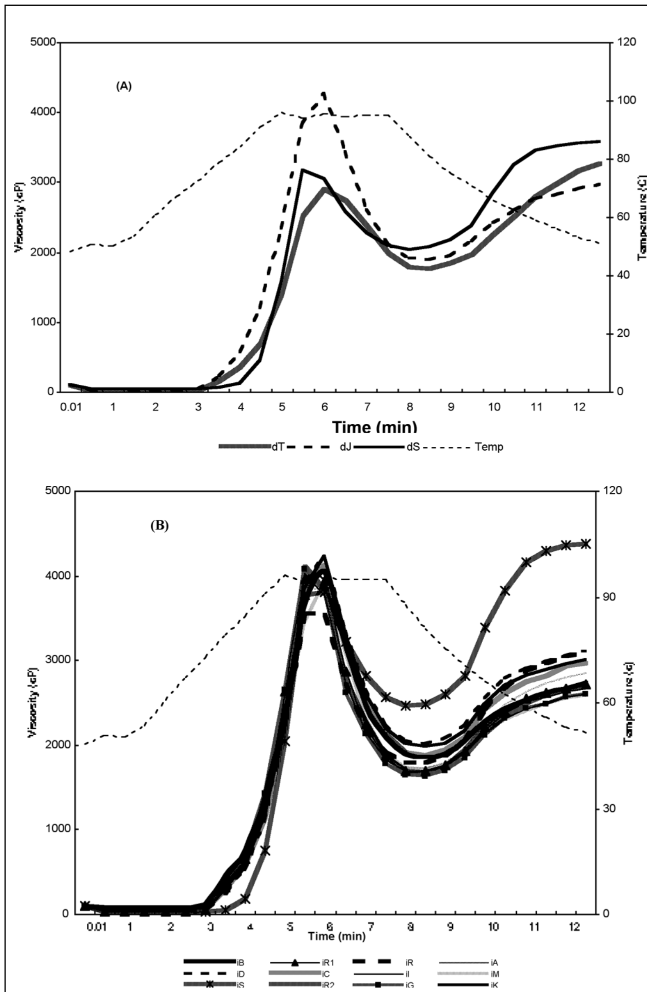

Figure 2—Viscosity profiles of domestic (a) and imported (b) jasmine rice flours. Sample abbreviations can be found in Table 1.

the melting of the amylose-lipid complex as reported by Normand and Marshall (1989). A possible explanation is that this sample may be a mixture of different rice varieties with 2 different sets of thermal properties. The small amount of enthalpy change reported for iA, iC, and iK (9.4 to 9.8 J/g) indicated that the starches were gelatinized rapidly at low temperature.

Correlations between physicochemical properties

Principal component analysis plots are presented in Figure 3. The plots allow for visualization of the relationship among physicochemical properties, viscosity profile, and thermal properties of the 15 jasmine rice samples. Two components explained a total of 64% of the variation. The map of jasmine rice samples (score plot) and analytical properties (loading plot) for the first 2 components is shown in Figure 3. Principal component 1 (PC1) was found to account for 43% of the variation in the data, whereas principal component 2 (PC2) accounted for 21% of the variation.

The biplot showed that most of the imported samples except Dynasty (iS) laid close to each other along the X-axis (PC1) and had similar properties (Figure 3). The high gel consistency values (soft gel) exhibited by most of the imported samples (except iS) were closely related to the flour pasting profile (the large breakdown viscosity and high peak viscosity) and the stickiness of cooked rice measured instrumentally. It was found that replicated samples (Rose Rice, iR1, and iR2) were almost identical in their physical, chemical, pasting, and thermal properties indicating the reliability of the analytical procedures. Fisher's LSD tests at $\alpha = 0.05$ (data not shown) indicated that the chemical properties of these 2 samples (iR1 and iR2) were different only for moisture content (12.99% and 13.32 %, LSD = 0.12). The variables, which loaded in the upper right corner of the plot, were related to what many researchers have called "eating/cooking quality factors."

Amylose content, instrumental hardness, and the hardness-to-stickiness ratio all loaded negatively on PC1, illustrating the positive correlation between these variables. Accordingly, samples for which the amylose content was high (such as Dynasty [iS] and Rice Tec [dT]) loaded in the same quadrant of the PCA map (for example, the lower left quadrant). The variables previously described also were positively correlated to cooking and pasting properties such as setback, minimum, and final viscosities. This shows that as amylose content increased, so did the pasting temperature, the minimum viscosity, the magnitude of the setback viscosity, and the final viscosity. It should also be noted that the breakdown viscosity loaded in the opposite quadrant, which shows that this variable was negatively correlated to the aforementioned variables. This result was expected because a small breakdown viscosity and significant increase in final viscosity indicate that starch retrogradation occurs rapidly (true for iS and dT). Variables that loaded in the lower left quadrant were also related to eating/cooking quality factors. As a result, eating/cooking quality was defined as the axis going from the lower left to the upper right quadrants. In a similar analysis previously reported (Suwansri and others 2001) on the same sample set for sensory descriptive analysis of rice texture, the samples were arranged in a very similar pattern, bringing some validity to the definition of the eating quality vector defined here.

These findings were in agreement with those reported in the literature (Bhattacharya and Sowbhagya 1971; Juliano 1979; Sowbhagya and others 1994). Under given cooking conditions (that is, 100 °C/20 min), water absorption of milled rice was positively correlated to amylose content and grain surface per unit weight (Bhattacharya and Sowbhagya 1971; Juliano 1979; Sowbhagya and others 1994). Juliano (1979) reported that water absorption, amylose content, and kernel dimensions are quality parameters related to absorption behavior of rice. However, the results from the present study revealed that the kernel dimensions—for example, length and length-to-width ratio—play a small role in determining jasmine rice quality characteristics.

Protein, fat, and thermal properties loaded similarly in the upper left quadrant of Figure 3. These variables were negatively correlated to moisture, length-to-width ratio, stickiness, whiteness, and L^*. The significant amount of surface fat and protein content found in dJ and dS seemed to affect the appearance quality (high a^* and b^*value), and the thermal properties of the rice starch (that is, increase in onset temperature, peak temperature, and end temperature). Even though the protein content was high for iR (Table 2), the sample PCA scores indicated that this sample also exhibited a high degree of whiteness, showing that protein and fat are not the only

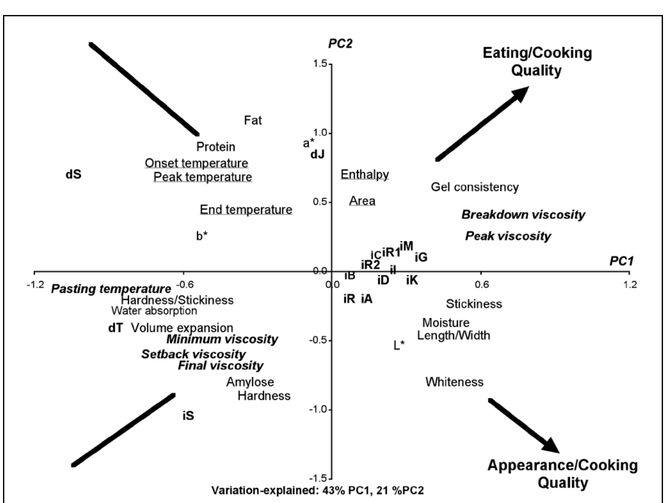

Figure 3—Sample scores and variable loadings for the principal components analysis (PCA) of the physicochemical characteristics: PC1 compared with PC2. Scores and loading obtained from physicochemical and instrumental texture analysis, pasting properties (italicized), and thermal properties (underlined) using PCA model. The variation of the data described was 43% and 21% for PC1 and PC2, respectively. Sample name abbreviations can be found in Table 1.

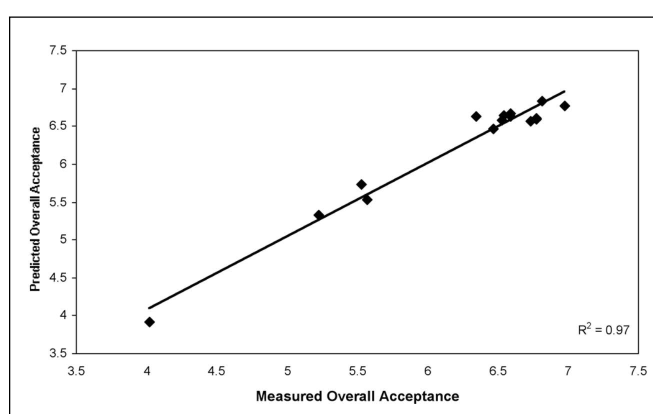

Figure 4—Predicted compared with measured overall acceptance of cooked jasmine rice by Asian consumers living in the United States. Predictive variables included all physicochemical properties measured by those variables not found significant by the Jack-knifing procedure. Sample name abbreviations can be found in Table 1.

determinants of rice color. The top left and bottom right quadrants involved variables related to rice appearance and the corresponding axis was named "appearance quality."

Prediction of overall consumer acceptance from physicochemical properties

Overall consumer acceptance was predicted from physicochemical properties measured on the 15 jasmine rice samples. Consumer acceptance means were reported by Suwansri and others (2002) and will not be discussed here, except to say that imported jasmine rice samples were for the most part more acceptable than domestic products. Overall acceptance was adequately predicted from physicochemical properties (r^2 = 0.97, Figure 4 and 5) using 2 factors. The prediction of overall acceptance was found to be even better than that reported from descriptive analysis data (r^2 = 0.95; Suwansri and others 2002). Of the 16 physicochemical properties measured, 12 predictive variables were retained in the model. The variables that were positively correlated with acceptance by Asian consumers included L*(lightness), stickiness, and breakdown viscosity. This confirmed consumer preference for rice with a white appearance and a slightly sticky texture. All other variables were negatively correlated with overall acceptance. Among these were protein and surface fat contents and the hardness-to-stickiness ratio. This shows that consumers disliked rice with high surface fat content (imparting a yellow color or potentially off flavors) and high protein content, which is a usual characteristic of rice of firmer texture. These results show that it is possible to predict jasmine rice acceptance from instrumental measurements such as those described in this manuscript.

Conclusions

Physicochemical properties of the 15 milled, commercial jasmine rice samples, their flours, and their starches were documented. The gel consistency, pasting profile, and the instrumental texture determined the eating quality factors of cooked jasmine rice. The amylose content significantly affected jasmine rice cooking quality in terms of physical properties (such as water absorption and volume expansion ratio), instrumental hardness, hardness-to-stickiness ratio, and pasting characteristics, whereas the surface fat and the protein content significantly affected the cooking quality of jasmine rice in terms of the thermal properties. As determined through the measurements of whiteness and L*, a*, b* values, surface fat and protein content significantly influenced the appearance of jasmine rice. The documentation of jasmine rice physicochemical characteristics has illustrated the differences between domestic and imported products and pointed out the weaknesses of the domestic jasmine rice currently grown in the United States. In contrast to imported samples, some domestic products were high amylose, medium gel type, resulting in the relatively harder texture of cooked rice. Domestic samples exhibited high surface fat and protein contents, which correlated positively with appearance (dark color) and thermal properties (high gelatinization temperatures). Our conclusion is that domestically grown jasmine-like rice could be improved by the development of cultivars with lower amylose content or cultivars exhibiting slightly less firm texture. To optimize the appearance of existing jasmine-like cultivars, whiteness should be enhanced by lowering the protein content and/or adapt milling processes to decrease residual surface oil content. The maps and model developed from this study could be used as a guide for rice breeders to identify important physicochemical properties of jasmine rice and breed these characteristics into improved varieties.

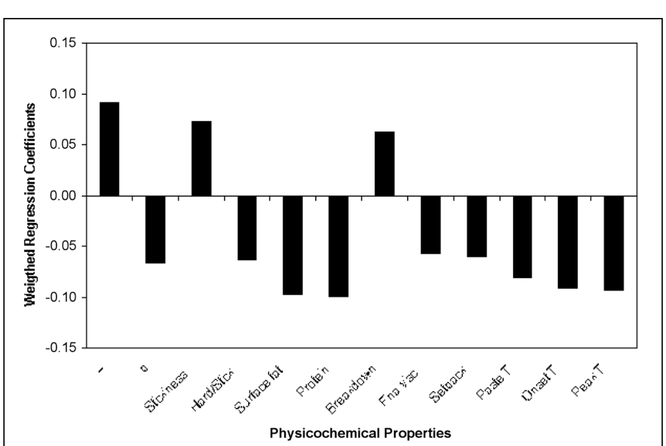

Figure 5—Weighted regression coefficients for physicochemical variables predictive of overall consumer acceptance of cooked jasmine rice by Asian consumers living in the United States.

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