Suitability of Different Starches for Production of *Kuanfen* (Chinese Flat Starch Noodles)

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ABSTRACT

Starches from potato, corn, sweet potato, and rice were compared with mung bean starch for their suitability for producing *kuanfen*, Chinese flat starch noodles. Significant differences were found in the chemical composition and swelling power among starches ($P < 0.05$). Maximum tensile stress and maximum tensile strain was highest for *kuanfen* made from mung bean starch and sweet potato starch, respectively. Higher work was needed to break *kuanfen* made from mung bean and sweet potato starches. *Kuanfen* made from mung bean starch was most favored by panelists, followed by those from sweet potato starch. General acceptability of *kuanfen* correlated positively and significantly with chewiness, cohesiveness, and elasticity of the noodles. For predicting sensory acceptability of *kuanfen* using instrumental methods, correlation was performed between sensory variables and tensile parameters. Results showed that work-to-break correlated significantly with chewiness, elasticity, and general acceptability while maximum tensile strain correlated significantly with sensory cohesiveness. Therefore, both of these two tensile parameters could be useful for predicting the textural properties of *kuanfen*.

Starch noodle is one of the traditional oriental foods popularly consumed both as a staple food and in cooked dishes throughout Asian countries (Kasemsuwan et al 1998; Collado et al 2001; Liu and Shen 2007). In China, mung bean starch noodles are called "glassy noodles" because of their transparent appearance. There are two types of starch noodles in China: the flat starch noodle (*kuanfen*) and the round threadlike starch noodle (*fensi*). Even though the same material (mung bean starch) is normally used for the preparation of both starch noodles, the processing of *kuanfen* is totally different from *fensi*. The preparation of *fensi* noodles is well documented. It involves basically mixing native starch with pregelatinized starch, extruding the prepared dough into boiling water, cooking, and cooling (Chang et al 2006). On the other hand, *kuanfen* is prepared by spreading starch slurry on round dishes, steaming, cooling, and cutting into long strips.

The structure continuity of *fensi* noodles is provided by the ramified three-dimensional networks of short segments strongly linked to one another by junction zones composed of amylose crystallites (Mestres et al 1988). Many studies have shown that starches exert great influence on the final quality of *fensi* noodles (Bhattacharya et al 1999; Beta and Corke 2001; Sodhi and Singh 2003). Lii and Chang (1981) noted that an ideal starch for manufacturing gluten-free starch noodle should have high amylose content. Although mung bean starch is considered the best raw material for manufacturing starch noodles, its high cost and limited availability have prompted manufacturers to search for other inexpensive replacements. For instance, starches from pigeon pea (Singh et al 1989), tapioca (Kasemsuwan et al 1998), sorghum (Beta and Corke 2001), red bean (Lii and Chang 1981), and sweet potato (Collado et al 2001) have been studied for their suitability for producing *fensi*.

Texture of cooked starch noodle is the most important criterion determining consumer acceptance of the product. Although the sensory evaluation can be used to assess noodle texture, it is impractical when sample size is limited or when large numbers of lines are to be evaluated in breeding (Edwards et al 1993). Due to the constraints of sensory evaluation, various instrumental methods that are quick, accurate, and reproducible have been developed for measuring the textural properties of starch noodles (Galvez et al 1994; Kasemsuwan et al 1998; Bhattacharya et al 1999; Collado et al 2001). However, these objective measurements do not always reflect the actual perception of consumers of the products. Hence it is necessary to relate the instrumental textural properties to the actual sensory acceptability to monitor product quality and to facilitate product development process.

In China, mung bean, potato, sweet potato, rice, and corn starches are the raw materials most commonly used in *kuanfen* production. Although *kuanfen* made from these different starches are widely available in China, the quality of the noodles and the relationship to the starches have yet to be studied systematically. In this study, we related the physicochemical properties of starches isolated from mung bean, potato, corn, sweet potato, and rice to the final quality of *kuanfen*. Sensory evaluation was also performed to decide which sensory properties are important for the good eating quality of *kuanfen.* Furthermore, the instrumental method of evaluating texture of *kuanfen* was established by correlating tensile parameters with sensory attributes.

MATERIALS AND METHODS

Starch Samples

Corn starch (*nongda 108,* harvested in Neimenggu, China, in 2005) was isolated using the method of Sandhu et al (2005). Mung bean starch was isolated from whole mung bean seed (*zhonglv 2*, harvested in Shanxi, China, in 2004) using the method of Schoch and Maywald (1968) modified by Singh et al (1989). Rice starch (*zhongzao 22*, Indica rice, harvested in Fuyang, Zhejiang, China, in 2005) was isolated by the alkali extraction method of Sodhi and Singh (2003). These isolated starches were dried in an air oven at 40°C for ≈12 hr, then ground with a mortar and pestle, passed through a 100-mesh screen, and stored at 4°C until used. Sweet potato and potato starches were purchased from a supermarket in Beijing and used directly without further treatment.

Preparation of *Kuanfen*

Starch slurry (30 g) (35.5%, db) was prepared with distilled water. The slurry was homogenized completely with a mixer (Ika T25 Basic, Ika-Werke Gmbh & Co. KG, Staufen, Germany). After vacuum degassing (600 mmHg, 10 min), the slurry was spread on six aluminum dishes (47 mm diameter, 10 mm height) with 4.5 g of slurry each, then steamed for 10 min in an electric cooker preheated to 100°C. The cooked sheets were cooled in an air-conditioned room for 10 min and then cut into strips (43 × 15 mm for tensile determination, and 30 × 5 mm for sensory evaluation). *Kuanfen* noodles were kept at 4°C to retrograde for 24 hr while covered with plastic film. After retrogradation, they were cooked

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in boiling distilled water until the white core disappeared (≈30 sec) and cooled in tap water. Then they were used for tensile measurement and sensory evaluation.

Chemical Analysis

Moisture, ash, lipid, and protein contents (N × 6.25 for sweet potato, mung bean, and potato starch; N × 6.24 for corn starch; N × 5.95 for rice starch) of starches were determined according to Official Method 922.06 (AOAC International 2000) (Table I). Apparent amylose content of starches was determined by the colorimetric method of McGrance et al (1998). For total amylose content, starches were first defatted before being subjected to the same colorimetric measurement.

Swelling Power and Solubility

Swelling power and solubility of starches were determined at 30, 45, 60, 75, and 95°C according to Lii et al (1996). Samples of starch (2 g) were used for each measurement (Fig. 1 A and B).

Tensile Measurements

The tensile properties of *kuanfen* were measured according to Lu et al (2003) using a rheometer (Fudoh RT-2002DD, Tokyo, Japan). The ends of *kuanfen* were mounted and clamped with grips on the rheometer. The *kuanfen* was stretched with a table speed (V_T) of 60 mm/min and force range set to 2 kg. The testing temperature was controlled at 25°C. The mechanical properties we report are maximum tensile stress σ (maximum tensile force for *kuanfen* breaking/initial area of *kuanfen*, kPa); maximum tensile strain ε (maximum extension/original length of the *kuanfen*, %); apparent elasticity modulus *E* (σ/ε, kPa); and work-to-break *W* (the work applied to *kuanfen* until it is broken, kg × mm). Each measurement was replicated six times.

Sensory Evaluation of *Kuanfen*

Sensory evaluation was conducted in the Sensory Evaluation Center of the Sino-Japanese Food Research Center, China Agricultural University. Products were evaluated by 10 trained panelists who were members of a permanent descriptive analysis panel for *kuanfen*. Six members of the group were female and four were male panelists ranging in age from 22 to 35.

Two 20-min training sessions were devoted to texture of *kuanfen*. In the first session, texture terminology was discussed and related to *kuanfen* texture. Panelists were also told how the ballot procedure worked and told the procedures for evaluating each parameter. Unstructured line scales anchored 1 cm from each end represented extremes of the parameters. In the second session, panelists practiced using the ballot with five types of *kuanfen*. They discussed evaluations and reviewed any definitions and procedures that caused problems.

Samples were evaluated after cooking and cooling. Panelists were given five plastic dishes with each dish containing six strands of one type of *kuanfen*. Samples were evaluated using the procedures described on the ballot. Purified drinking water (purchased in the supermarket) was used to cleanse the mouth between samples.

Statistical Analysis

All tests were performed in triplicate except tensile measurement which was repeated six times. The data collected from this

TABLE I
Chemical Composition (%, db) of Various Starches[a]

Starch Source	Lipid	Ash	Crude Protein	Amylose		Amylose-Lipid Complex[b]
				Apparent	Total	
Mung bean	0.49d (0.05)	0.08c (0.02)	0.08d (0.02)	40.35a (0.49)	45.18a (0.58)	10.68c (1.14)
Corn	0.82ab (0.07)	0.13ab (0.03)	0.26b (0.02)	26.81b (0.72)	35.90b (0.87)	25.33b (1.88)
Rice	0.93a (0.06)	0.10bc (0.02)	0.43a (0.03)	23.85d (0.57)	32.06c (0.81)	25.61b (0.10)
Sweet potato	0.66c (0.05)	0.14ab (0.03)	0.12d (0.03)	25.39c (0.09)	27.35d (0.35)	7.16d (0.86)
Potato	0.73bc (0.04)	0.16a (0.03)	0.17c (0.02)	22.11e (0.78)	32.14c (0.97)	31.25a (0.35)

[a] Data in parentheses are standard deviations. Values followed by the same letter in each column are not significantly different ($P < 0.05$).
[b] [(Total amylose – Apparent amylose)/Total amylose] × 100.

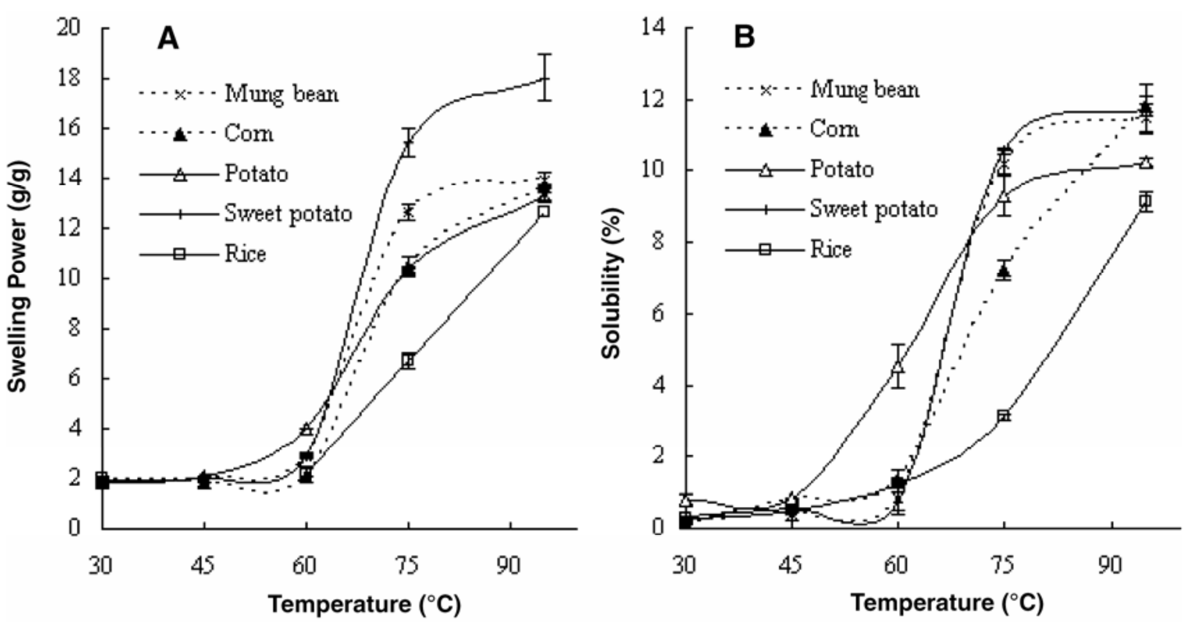

Fig. 1. Swelling power (**A**) and solubility (**B**) of various starches.

study were analyzed by analysis of variance using SAS software (v.8.2, SAS Institute, Cary, NC). Comparison of means was performed using the Duncan's multiple range test with the *F*-value significant at $P < 0.05$.

RESULTS AND DISCUSSION

Chemical Composition of Various Starches

Amounts of lipid, protein, amylose (apparent and total), and amylose-lipid complex differed between starches ($P < 0.05$). Rice starch showed the highest lipid and protein contents, while mung bean starch showed the lowest ($P < 0.05$). The ash content range was 0.08–0.16%, with mung bean starch being the lowest, and potato starch being the highest. The apparent and total amylose content of mung bean starch were the highest among the five starches, and total amylose content was higher than that reported by Chang et al (2006) (30.9–31.1%). Although potato starch had the lowest apparent amylose content, this starch demonstrated the highest amylose-lipid complex content (31.25%). Mung bean starch and sweet potato starch possessed the lowest amylose-lipid complex content.

Swelling Power and Solubility

Swelling power and solubility of all the starches increased with increasing temperature. At low temperatures (<60°C), no significant difference in swelling power was found among the five starches. At high temperatures (≥75°C), however, highest swelling power was observed in sweet potato starch, followed by mung bean starch, corn starch, potato starch, and rice starch. Rice starch showed a drastic increment in swelling power during heating, even though swelling power was significantly lower than that of mung bean starch, corn starch, and potato starch at 75°C. Rice starch swelling power was comparable to those starches when the temperature rose to 95°C. The swelling behavior of a starch relies primarily on the property of amylopectin, while amylose acts as a diluent and an inhibitor for swelling, especially in the presence of lipid (Tester and Morrison 1990; Tester et al 1993). Hence, the low levels of amylose, lipid, and lipid-amylose complex in sweet potato starch may result in high swelling power. Similarly, the relatively low swelling power of corn, potato, and rice starches may be partially attributed to high lipid and amylose-lipid complex contents. In another study on wheat starch, however, the swelling power correlated negatively with amylose content but not with lipid content (Sasaki and Matsuki 1998). Mung bean starch possessed the highest amylose content and, at the same time, high swelling power. The unique molecular structure of amylopectin and low lipid content might be the reason for the high swelling power of mung bean starch (Tester and Morrison 1990; Tester et al 1993; Wang and Seib 1996). Changes in solubility of various starches showed a trend similar to those of swelling power, except that the solubility of corn and mung bean starches at 95°C was comparable to that of sweet potato starch.

Tensile Properties of *Kuanfen*

The tensile properties of *kuanfen* are summarized in Table II. The maximum tensile stress (σ) for *kuanfen* made from mung bean starch was about threefold that of the σ value of other *kuanfen*, indicating *kuanfen* made from mung bean starch was harder than those made from other starches. The σ value of *kuanfen* seems to be highly dependent on the amylose content of starch. Pearson's correlation showed that σ value was correlated positively and significantly with apparent amylose content ($r = 0.97$, $P < 0.01$) and total amylose content ($r = 0.94$, $P < 0.05$) of the starches (Table III). Like *fensi* noodles (Mestres et al 1988), structure of *kuanfen* is maintained as a ramified three-dimensional network interlinked by amylose-based crystallites. The higher the amylose content is, the more rigid gels will form, leading to the harder *kuanfen* texture. The correlation between amylose content and noodle hardness in this study was consistent with the results of Toyokawa et al (1989) on wheat noodles but different from the result of Young et al (1996) on bean and potato starch noodle in which no significant correlation was observed between the two variables.

The highest maximum tensile strain (ε) was observed in *kuanfen* made from sweet potato starch. The ε value was correlated positively and significantly with swelling power of starches at 95°C ($r = 0.92$, $P < 0.05$) (Table III).

Miles et al (1985) defines starch gel as a composite material with swollen starch granules (mainly composed of amylopectin) filling the amylose gel matrix. High swelling of granules increases the softness of the amylose gel dramatically (Ring 1985), and the gels formed are easily deformable.

Apparent elasticity modulus (*E*) was highly correlated with total amylose content of the starches ($r = 0.98$, $P < 0.01$) (Table III). The work needed to break a noodle strip (*W*) was highest for noodles made from mung bean starch, followed by sweet potato starch, and lowest for those made from corn starch ($P < 0.05$). This tensile parameter was negatively correlated with lipid content ($r = –0.91$, $P < 0.05$) of the starches, but it was positively correlated with apparent amylose content ($r = 0.88$, $P < 0.05$) of starches (Table III). Lipid could form complexes with amylose (Nierle and

TABLE II
Tensile Properties of Cooked *Kuanfen* Noodles[a,b]

Noodle	σ (kPa)	ε (%)	*E* (kPa)	*W* (kg × mm)
Corn	48.29 ± 0.82b	26.94 ± 1.07c	179.48 ± 9.27b	0.96 ± 0.02d
Mung bean	126.77 ± 8.04a	44.21 ± 2.28b	287.37 ± 26.50a	3.50 ± 0.07a
Rice	39.40 ± 1.35cd	38.62 ± 1.58b	102.17 ± 5.97c	1.20 ± 0.07cd
Sweet potato	34.09 ± 2.18d	79.54 ± 6.84a	43.09 ± 4.57d	2.05 ± 0.24b
Potato	41.86 ± 3.27c	41.07 ± 2.42b	102.05 ± 8.59c	1.38 ± 0.23c

[a] Values followed by the same letter in each column are not significantly different ($P < 0.05$).
[b] σ = Maximum tensile stress; ε = maximum tensile strain; *E* = apparent elasticity modulus; *W* = work-to-break.

TABLE III
Pearson's Correlation Coefficients Between Tensile Variables and Physicochemical Properties[a,b]

	Lipid	Protein	Apparent Amylose	Total Amylose	Swelling Power at 95°C
σ	–0.75	–0.61	0.97**	0.94*	–0.18
ε	–0.39	0.72	–0.05	–0.48	0.92*
E	–0.53	–0.84	0.82	0.98**	–0.49
W	–0.91*	–0.24	0.88*	0.64	0.26

[a] σ = Maximum tensile stress; ε = maximum tensile strain; *E* = apparent elasticity modulus; *W* = work-to-break.
[b] *,** Indicate significance at $P = 0.05$ and $P = 0.01$, respectively.

El Baya 1990). The higher the lipid content of a starch, the more amylose-lipid complex would form in the gel, which would inhibit the leaching of amylose and affect the formation of continuous amylose matrix. Thus, the starch gel formed will be weaker and less work will be needed to break the *kuanfen*.

Sensory Properties of *Kuanfen*

Sensory attribute definitions, ballot instructions for evaluating parameters, and the scales used are shown in Table IV; mean values for various sensory variables are listed in Table V.

Results for general acceptability showed that noodles from mung bean starch were most favored by the panelists, followed by those from sweet potato starch. By contrast, *kuanfen* noodles made from corn starch received the lowest score for general acceptability. Chewiness, cohesiveness, and elasticity of *kuanfen* made from mung bean starch and sweet potato starch were quite similar. Hence, the general acceptability rating of noodles seems to be governed by chewiness, cohesiveness, and elasticity ratings of the noodles. Pearson's correlations showed that general acceptability was correlated positively with chewiness ($r = 0.98$, $P < 0.05$), cohesiveness ($r = 0.89$, $P < 0.05$) and elasticity ($r = 0.99$, $P < 0.01$) of noodles (Table VI).

These results showed that, like *fensi* noodles, consumers perceived chewiness and elasticity as the essential textural properties for good eating quality of *kuanfen* (Young et al 1996; Shiau and Yeh 2001). However, unlike *fensi* (Young et al 1996) and wheat noodles (Crosbie et al 1999), hardness, adhesiveness, and slickness did not greatly affect general acceptability of *kuanfen*.

TABLE IV
Sensory Analyses Attributes and Definitions Used to Evaluate Cooked *Kuanfen* Noodle Texture[a]

Sensory Attributes	Score	Definition
Hardness	–3 = soft; 3 = hard	Force required to bite through the sample with the molars.
Chewiness	–3 = not chewy; 3 = very chewy	Amount of work to chew the sample until ready to swallow.
Cohesiveness	–3 = ruptures easily; 3 = compresses a lot before rupture	Degree to which the noodles deform rather than crumble, crack, or break when biting with molars.
Elasticity	–3 = stays compressed; 3 = quickly returns to size and shape	Degree to which the noodles return to original shape after compressing force of molar teeth is removed.
Adhesiveness	–3 = very adhesive; 3 = not adhesive	Force of which the noodle adheres to teeth when masticating.
Slickness	–3 = not slick; 3 = very slick	Maximum ease of passing tongue over the noodle surface when saliva starts to mix with sample.
General acceptability	–3 = very bad; 3 = very good	

[a] Definitions of hardness, chewiness, cohesiveness, and slickness from Champagne et al (1999).

TABLE V
Sensory Scores for Various *Kuanfen* Noodles[a,b]

Noodle	HD	CW	CO	EL	AD	SK	GA
Corn	0.8b	0.4c	0.6d	–0.3d	0.6d	–1.0d	–0.2c
Mung bean	2.3a	2.3a	1.8b	2.7a	2.4a	2.3a	2.5a
Rice	0.5c	0.8b	1.3c	1.0c	1.9b	1.7b	0.8b
Sweet potato	–0.3d	2.2a	2.4a	2.1b	1.4c	1.9b	2.2a
Potato	0.6c	1.0b	1.6c	1.1c	1.1c	–0.1c	1.0b

[a] Each value is a mean of 10 scores. Values followed by the same letter in each column are not significantly different ($P < 0.05$).
[b] HD = hardness; CW = chewiness; CO = cohesiveness; EL = elasticity; AD = adhesiveness; SK = slickness; GA = general acceptability.

TABLE VI
Pearson's Correlation Coefficients Between Sensory Variables[a,b]

	HD	CW	CO	EL	AD	SK	GA
HD	1						
CW	0.22	1					
CO	–0.20	0.87	1				
EL	0.16	0.95*	0.86	1			
AD	0.54	0.64	0.47	0.80	1		
SK	0.18	0.79	0.73	0.87	0.90*	1	
GA	0.24	0.98*	0.89*	0.99**	0.74	0.85	1

[a] HD = hardness; CW = chewiness; CO = cohesiveness; EL = elasticity; AD = adhesiveness; SK = slickness; GA = general acceptability.
[b] *,** Indicate significance at $P = 0.05$ and $P = 0.01$, respectively.

TABLE VII
Pearson's Correlation Coefficients Between Tensile Variables and Sensory Results[a,b]

	HD	CW	CO	EL	AD	SK	GA
σ	0.94*	0.53	0.10	0.57	0.67	0.42	0.53
ε	–0.48	0.74	0.91*	0.64	0.20	0.58	0.71
E	0.97*	0.17	–0.30	0.20	0.41	0.08	0.15
W	0.66	0.88*	0.58	0.89*	0.77	0.71	0.88*

[a] HD = hardness; CW = chewiness; CO = cohesiveness; EL = elasticity; AD = adhesiveness; SK = slickness; GA = general acceptability; σ = maximum tensile stress; ε = maximum tensile strain; E = apparent elasticity modulus; W = work-to-break.
[b] *Indicates significance at $P = 0.05$.

Correlation Between Sensory Attributes and Tensile Parameters of *Kuanfen*

Texture of cooked starch noodles is the most important characteristic that determines consumer acceptance of the product. The direct and ultimate method for assessing texture of noodles is by sensory evaluation. Kim et al (1996) found that cohesiveness as measured by instrumental methods is useful in rapid screening of *fensi* noodles before subjecting them to a more laborious sensory evaluation. Earlier analysis in this study showed that chewiness, cohesiveness, and elasticity were important in determining the general acceptability of *kuanfen* noodles. Hence, Pearson's correlation was performed to establish the relationship of these sensory attributes with tensile measurements (Table VII).

Results showed that work-to-break was correlated positively and significantly with chewiness ($r = 0.88$, $P < 0.05$), elasticity ($r = 0.89$, $P < 0.05$), and general acceptability ($r = 0.88$, $P < 0.05$). Maximum tensile strain was correlated positively and highly with sensory cohesiveness ($r = 0.91$, $P < 0.05$). Hence both of these tensile parameters could be useful for predicting sensory acceptability of *kuanfen* noodles.

CONCLUSIONS

Our results show that not all starches are suitable for the preparation of *kuanfen* noodles. Sweet potato starch is economical and easily available and could be used as a substitute for mung bean starch in *kuanfen* production. Chewiness, cohesiveness, and elasticity are the most crucial properties for the good eating quality of *kuanfen* and these properties could be easily predicted by instrument measurement of the maximum tensile strain and work-to-break of the noodles.

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