

# Noodle Quality as Related to Sorghum Starch Properties

Trust Beta<sup>1</sup> and Harold Corke<sup>2</sup>

## ABSTRACT

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Starch was extracted from 10 sorghum genotypes and physicochemical properties (amylose content and pasting, textural, and thermal properties) were evaluated. The amylose content was 24–30%. DC-75 starch had the highest peak viscosity (380 Rapid Visco Analyser units). Gelatinization peak temperature occurred over a narrow range (67–69°C). Genotypes Kasvikisire and SV2 produced white starches. Starches from other genotypes were different shades of pink. The starch noodles prepared were, accordingly, either white or pink. Cooking enhanced the pink coloration of noodles. Cooking loss, noodle rehydration, and elasticity were evaluated.

Cooking loss was low (mean 2.4%). Noodle elasticity was highly correlated with starch pasting properties of hot paste viscosity (HPV) ( $r = 0.81$ ,  $P < 0.01$ ) and cold paste viscosity (CPV) ( $r = 0.75$ ,  $P < 0.01$ ). Noodle rehydration was significantly correlated to the initial swelling temperature of starch ( $T_i$ ) ( $r = -0.91$ ,  $P < 0.001$ ) and gelatinization peak temperature ( $T_p$ ) ( $r = 0.69$ ,  $P < 0.05$ ). The findings suggest a potential area of food application for sorghum genotypes of different grain colors. Evaluation of starch properties could be a good starting point for selecting sorghum genotypes with superior noodle-making properties.

Sorghum proteins lack the gluten functionality found in wheat that is essential for making such products as bread and flour-based noodles. The use of sorghum in these products has largely been as a supplement to wheat in composite flours (Dendy 1992; Hugo et al 2000), with relatively small amounts of sorghum flour being added to wheat flour. This usage is common in some countries, such as in tropical Asia and Africa, with climates that are not suitable for wheat cultivation and which, therefore, rely on costly wheat imports. Noodles are widely consumed in Asia. Asian wheat noodles made from common wheat flour (hexaploid wheat [*Triticum aestivum*] bread wheat) can be distinguished from starch noodles prepared by mixing purified starch with pregelatinized starch as a binder, mixing to a “dough”, and extruding into boiling water (Corke and Bhattacharya 1999). The use of nonwheat cereals for noodle production is a topic under active investigation (Bhattacharya et al 1999; Waniska et al 1999; Suhendro et al 2000). The starch-related properties of flour are manipulated in nonwheat cereals to enhance the noodle structure. The quality of noodles made from sorghum flour is significantly affected by numerous variables including flour particle size, method of heating to produce pregelatinized starch, sequence and timing of starch gelatinization and retrogradation, and method of drying (Suhendro et al 2000).

Mung bean starch has been reported as an excellent raw material for starch noodles (Lii and Chang 1991). However, starch noodles have been prepared from various other plant sources, including red bean (Lii and Chang 1981), pigeon pea (Singh et al 1989), potato (Kim and Wiesenborn 1996), and sweet potato (Collado and Corke 1997). A potential novel use of sorghum starch is in the manufacture of noodles, given the characteristic glossy, transparent appearance of cooked starch noodles (Kim and Wiesenborn 1996), coupled with the natural pink coloration of sorghum starch (Freeman and Watson 1971; Norris 1971; Yang and Seib 1995). The objectives of this study were to 1) develop a laboratory-scale method for making sorghum starch noodles, 2) isolate starch from a range of genotypes and determine variation in physicochemical properties, and 3) relate noodle quality to the starch properties.

## MATERIALS AND METHODS

Ten sorghum genotypes grown under uniform field conditions in the 1996–97 season at Matopos, Zimbabwe (a semi-arid location with sandveld soil) were used. The genotypes differed in polyphenol

content and structural characteristics (Beta et al 1999). The genotypes Chirimaugute, Chibonda, Mutode, and DC-75 (a hybrid) were tannin-containing. Katandanzara, Kasvikisire, Mukadzuisaenda, Mukadzizoka, Tsveta, and SV2 (an improved cultivar) were tannin-free.

A combination of the methods used by Perez et al (1993), Zhao and Whistler (1994), and Wu et al (1995) was used for extracting sorghum starch. Sorghum grain (100 g) was steeped in NaOH (0.25% w/v) at 5°C for 24 hr. After washing, the steeped grains were ground with an equal volume of water in a Waring blender at full speed for 5 min. The slurry was filtered through a sieve with a 75- $\mu$ m opening. The grinding and filtering process was repeated on the material that remained on the sieve. The filtrate was centrifuged at 760  $\times$  g for 10 min. The gray-colored top protein layer was removed with a spatula. The sample was resuspended in water and centrifugation was repeated for 3 min. The latter was repeated until the top starch layer was white or pink. The starch was dried in an air oven at 40°C for 24 hr. The starch color was noted. Samples were stored at 5°C before analyses.

An iodine-binding spectrophotometric method (Juliano et al 1981) was used to determine amylose-amylopectin content.

A Rapid Visco Analyser (RVA) model 3D; Newport Scientific, Warriewood, Australia) was used to determine the pasting properties of starch. Sorghum starch (3 g, 14% moisture basis) was mixed with 25 g of accurately weighed water in an aluminum canister. A controlled heating and cooling cycle was used in which the mixture was held at 50°C for 1 min, heated to 95°C in 7.5 min at the rate of 6°C/min, held at 95°C for 5 min, then cooled to 50°C in 7.5 min, and held at 50°C for 1 min (Bhattacharya et al 1997). Peak viscosity (PV), temperature at PV ( $P_{temp}$ ), initial swelling temperature ( $T_i$ ), hot paste viscosity (HPV) or holding strength, cool paste viscosity (CPV) or final viscosity, breakdown (BD) or (PV – HPV), setback (SB) or (CPV – HPV), and stability ratio (HPV/PV) were recorded. Duplicates per sample were used.

The sample, after RVA testing, was allowed to stand for 24 hr at room temperature ( $\approx 20^\circ\text{C}$ ) for gelation to take place (Bhattacharya et al 1997) inside the canister covered with parafilm wrap. A texture analyzer (SMS model TA-TX2i, Stable Micro Systems, Godalming, England), equipped with a Texture Expert software program (v. 5.16) was then used to measure the textural properties of the sorghum starch gels.

A standard two-cycle program was used to compress the gels for a distance of 10 mm at a crosshead speed of 30 mm/min using a 7-mm cylindrical probe with a flat end. The hardness (maximum force required to break the gel in cycle 1 of starch gels was recorded in grams. Four repeat measurements were taken of each of the duplicate gels per sample.

A differential scanning calorimeter (DSC-20, Mettler-Toledo AG Instruments, Naenikon-Uster, Switzerland) was used to determine the thermal properties of sorghum starches. Starch (2 mg, dwb)

<sup>1</sup> Department of Food Science and Human Nutrition, Iowa State University, 2312 Food Sciences Building, Ames, IA 50011.

<sup>2</sup> Corresponding author. Department of Botany, University of Hong Kong, Pokfulam Road, Hong Kong. Fax: +852 2858 3477. E-mail: hcorke@yahoo.com

was weighed directly into a 40- $\mu$ L aluminum standard pan and water added to give a final weight of 6.5 mg. The pan was covered with the lid and hermetically sealed. After equilibration to room temperature for at least 1 hr, the sample was heated from 30 to 120°C at 10°C/min. The gelatinization peak temperature ( $T_p$ , °C) and gelatinization enthalpy ( $\Delta H$ , J/g) were determined. Duplicates per sample were used.

### Starch Noodles

Noodles were prepared using starch (30 g) and water (22 mL), following a modification of the methods used by Kim and Wiesenborn (1996) and Collado and Corke (1997). Raw and gelatinized starch (90:10) were used. Gelatinized starch was obtained by heating starch (3 g) and hot water (15 mL) while stirring constantly. Raw starch (27 g) and cold water (7 mL) were added to the slurry in increments. The mass was thoroughly mixed to obtain a smooth dough. The starch dough was placed in a custom-made metal extruder fitted with a die (35-mm diameter) with four pores (3-mm diameter), and slowly extruded into boiling water by applying steady pressure with a piston. Noodles were cut to  $\approx$ 20 cm during extruding and then boiled for 3 min before transferring to cold water. Noodle strands were hung separately for 4 hr to partially dry, placed in plastic bags, then kept overnight at 5°C. Noodles were dried at 40°C to a moisture content of 8–9%. Color of noodles was noted.

Noodles (5 g) were presoaked for 30 min and cooked until the white core disappeared ( $\approx$ 5–6 min), as determined by squeezing the noodle between two Plexiglas pieces. The cooked noodles were placed in cold water, drained, wiped using paper towels, and kept covered in petri dishes until further analysis. The gain in noodle weight after cooking was recorded as percentage rehydration. Cooking loss was determined using the Approved Method 16-50 (AACC 2000), as modified by Kim and Wiesenborn (1996). The texture analyzer, equipped with a spaghetti tensile using a 5-kg load cell, was used to measure noodle elasticity. The cooked noodle strand was wound two to three times around parallel rollers of a spaghetti-noodle tensile grip analyzer using adhesive tape for anchorage. The maximum force required to break the noodle strand, an indication of sample resistance to breakdown (Smewing 1997) or tension, was recorded as elasticity. The noodles were evaluated in duplicate.

### Statistical Analysis

The general linear model procedure of the Statistical Analysis System (v. 6.12; SAS Institute, Cary, NC) was used for data analysis. Means were compared at the 5% significance level using Fisher's least square difference (LSD). Pearson correlation coefficients ( $r$ ) were calculated among starch properties and noodle quality using SAS Proc Corr (v. 6.12).

### Starch Properties

Starches from two genotypes (Kasvikisire and SV2) were white in color. Other genotypes gave starches with different shades of pink. Sorghum starch color could influence acceptability in sensory tests as found with noodles made from pigeon pea dhal starch (Singh et al 1989). The genotypes were nonwaxy with amylose content of 23.8–30.8% for DC-75 and Mukadzidzoka, respectively (mean 29.0%) (Table I). The importance of amylose on the structure of starch noodles has been established (Mestres et al 1988; Jin et al 1994). The hardness of the starch gels was 28.0–63.3 g for DC-75 and Chirimaugute, respectively (mean 51.9 g).

The pasting properties of starch from sorghum genotypes are shown in Table I and Fig. 1. Lii and Chang (1981) defined an ideal type of starch for noodle production as one with restricted swelling (due to high amylose) and a Type C Brabender viscosity curve, exhibiting no paste peak but rather a very high viscosity that remains constant or continues to increase during the constant temperature, constant shear cooking phase. The pasting profiles of sorghum starches would be regarded as Type A, high swelling starch characterized by high pasting peak followed by a high degree of shear thinning (Schoch and Maywald 1968). The  $T_i$  of sorghum starches was 68.1–69.9°C (mean 68.9°C). The PV was reached at 79.2–89.2°C (mean 84.9°C). DC-75 starch had the lowest  $P_{temp}$  (79.2°C), and starches from genotypes Kasvikisire and Mukadzidzoka had the highest  $P_{temp}$  (89.2°C). PV indicates water-binding capacity of the starch and is often correlated with final product quality and occurs at the equilibrium between swelling and polymer leaching (Newport Scientific 1998). The mean PV was 325 RVU. DC-75 starch had the highest PV (380 RVU), and Chirimaugute starch had the lowest PV (292 RVU). HPV was high (>124 RVU) in Chirimaugute and Mukadzidzoka starches. The mean HPV of sorghum starches was 115 RVU. Starches from DC-75 and Mukadzidzoka showed a low HPV (<104 RVU). A high HPV generally represents low cooking loss and superior eating quality in noodles, whereas high final viscosity relates to high resistance to shear (Jin et al 1994). Final viscosity (CPV) was high in SV2 (258 RVU) and low in DC-75 (200 RVU) starch. The mean CPV was 237 RVU. The mean BD, indicating the shear thinning property of starch, was 209 RVU, ranging from 163 to 286 RVU for Chirimaugute and DC-75, respectively. A low BD suggests that those starches are stable under hot conditions. BD is a measure of susceptibility of cooked starch granules to disintegration, whereas SB is a measure of recrystallization of gelatinized starch during cooling. The mean SB for sorghum starch pastes was 121 RVU. DC-75 starch had low SB (106 RVU). SV2 starch had high SB (141 RVU). The viscosity changes during cooling of the

TABLE I  
Pasting and Swelling Properties of Starches Isolated from Zimbabwean Sorghum Genotypes<sup>a</sup>

Genotype	$T_i$ (°C)	$P_{temp}$ (°C)	PV (RVU)	HPV (RVU)	CPV (RVU)	BD (RVU)	SB (RVU)	STABR	AC (%)	Hard (g)	$T_p$ (°C)	$\Delta H$ (J/g)
Katandanzara	69.1	84.9	319	116	237	203	121	0.364	29.9	59.3	68.0	9.3
Mutode	69.1	83.4	339	119	242	220	123	0.351	28.2	60.6	67.5	7.7
Chibonda	69.1	82.9	332	120	229	212	109	0.361	30.5	54.6	67.0	9.5
Chirimaugute	69.1	85.3	292	129	257	163	128	0.442	28.9	63.3	67.3	9.1
Kasvikisire	69.4	89.2	314	117	247	197	130	0.373	28.6	61.5	67.3	9.1
Mukadzidzoka	69.2	84.9	327	125	254	202	130	0.381	29.8	44.4	68.5	9.5
Mukadzidzoka	69.9	89.2	307	103	221	204	118	0.334	30.8	38.9	68.8	9.5
Tsveta	67.7	82.3	324	114	224	211	111	0.350	30.0	54.8	66.8	9.2
SV2	68.5	88.0	315	117	258	198	141	0.372	29.0	54.0	67.3	8.4
DC-75	68.1	79.2	380	94	200	286	106	0.247	23.8	28.0	68.0	9.0
Mean	68.9	84.9	325	115	237	209	121	0.358	29.0	51.9	67.6	9.0
LSD <sup>b</sup>	0.43	1.09	5.27	5.25	5.3	5.53	7.29	0.015	0.75	2.63	0.52	0.67

<sup>a</sup>  $T_i$  = initial swelling temperature,  $P_{temp}$  = temperature at peak viscosity, PV = peak viscosity, RVU = Rapid Visco Analyser units, HPV = hot peak viscosity, CPV = cool paste viscosity, BD = breakdown (PV - HPV), SB = setback (CPV - HPV), STABR = stability ratio (HPV/PV), AC = amylose content, Hard = gel hardness,  $T_p$  = peak gelatinization temperature,  $\Delta H$  = gelatinization enthalpy.

<sup>b</sup> Least significant difference ( $P < 0.05$ ).

starch paste are considered to be mainly due to amylose molecular reassociation (Newport Scientific 1998). The variation in pasting properties among sorghum genotypes is quite low compared with some other sets of material such as rice flour (Bhattacharya et al 1999) or sweet potato starch (Collado and Corke 1997) previously used to make noodles.

Gelatinization temperatures are associated with the loss of birefringence characteristics of starch. Gelatinization peak temperature ( $T_p$ ) occurred over a narrow range of 66.8–68.8°C for Tsveta and Mukadzidzoka starch, respectively (mean 67.6°C) (Table I). Mung bean and pigeon pea starches that are used to prepare noodles had gelatinization temperature of 61–72 and 65–76°C, respectively (Mestres et al 1988). Those values were similar to those of sorghum starches. The energy required for gelatinization ( $\Delta H$ ) ranged from 7.7 J/g (Mutode starch) to 9.5 J/g (Chibonda, Mukadziusaenda, and Mukadzidzoka starches) (mean 9.0 J/g). In gluten-free, pasta-like products, native starch structures disappear and new crystalline organizations are found; amylose-based structures are more useful in noodle cooking quality (Mestres et al 1988).

### Noodle Properties

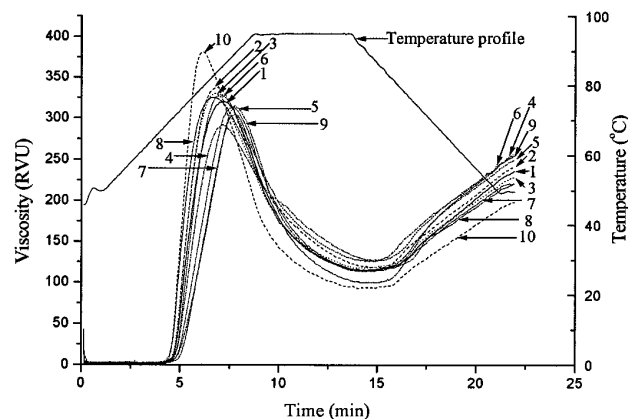
All noodles appeared glossy despite the differences in physico-chemical properties among sorghum starches. Noodles were either white (from SV2 and Kasvikisire starches) or different shades of pink (from starches of other genotypes). Presoaking for 30 min before cooking was essential; otherwise, noodles disintegrated before they were fully cooked. In starch noodles starch, rather than gluten, functions as the network that maintains structure during cooking (Mestres et al 1988). Complete degradation of this network probably occurred after the release of the amylose. Sorghum starch noodles

were therefore allowed to hydrate slowly in cold water because rapid swelling, solubilizing, and rupturing of starch granules led to higher cooking losses in sweet potato starch noodles (Lii and Chang 1991). The cooking time (5–6 min) after presoaking of starch noodles was comparable to that of sorghum flour (Suhendro et al 2000) and rice flour noodles (Bhattacharya et al 1999). The mean cooked weight of the noodles was 14.1 g (Table II). Tsveta noodles had a high cooked weight (15.0 g). Rehydration calculated from cooked weight was high (>289%) in DC-75 and Tsveta starch noodles. The mean rehydration was higher for sorghum (282%) compared to sweet potato (226%) starch noodles (Collado and Corke 1997). Sorghum flour noodles prepared by microwave gelatinization and a two-stage drying technique had a lower rehydration (193%) (Suhendro et al 2000). Rehydration after cooking was high (248–296%), indicating that the rice flour noodles had good cooking tolerance (Bhattacharya et al 1999). The mean cooking loss was 2.37% but potato (Kim and Wiesenborn 1996) and sweet potato (Collado and Corke 1997) starch noodles had even lower cooking losses (mean <1.6%) than sorghum starch noodles. A high cooking loss is undesirable because it represents high solubility of starch, resulting in turbid cooking water, low cooking tolerance, and sticky mouthfeel (Jin et al 1994). Cooking losses were lowest (<1.9 g) in Kasvikisire, but relatively high (>3.0 g) in Mukadzidzoka and Tsveta noodles. Elasticity was similar to firmness in potato starch noodles, with a high firmness score being more desirable (Kim and Wiesenborn 1996). Elasticity (mean 31.6 g) was high (>40.7 g) in Mutode and Mukadziusaenda sorghum starch noodles (Table II). DC-75

**TABLE II**  
Cooking Quality and Elasticity of Sorghum Starch Noodles

Genotype	Cooked Wt (g)	Cooking Loss (%)	Elasticity (g)	Rehydration (%)
Katandanzara	14.0	2.0	32.7	280
Mutode	14.0	2.2	40.8	279
Chibonda	14.1	1.9	34.5	281
Chirimaugute	14.3	2.0	32.6	286
Kasvikisire	13.9	1.8	29.4	278
Mukadziusaenda	13.5	2.6	44.5	271
Mukadzidzoka	13.6	3.3	24.9	271
Tsveta	15.0	3.1	26.1	300
SV2	14.3	2.1	32.9	286
DC-75	14.5	2.6	17.3	290
Mean	14.1	2.4	31.6	282
LSD <sup>a</sup>	0.69	0.77	1.88	18.7

<sup>a</sup> Least significant difference ( $P < 0.05$ ).



**Fig. 1.** Rapid Visco Analyser pasting profiles of starch from 10 genotypes: 1 = Katandanzara, 2 = Mutode, 3 = Chibonda, 4 = Chirimaugute, 5 = Kasikisire, 6 = Mukadziusaenda, 7 = Mukadzidzoka, 8 = Tsveta, 9 = SV2, and 10 = DC-75.

**TABLE III**  
Pearson Correlation Coefficients ( $r$  values) of Sorghum Starch Properties and Noodle Quality Parameters<sup>a</sup>

	$P_{temp}$	PV	HPV	CPV	BD	SB	$T_i$	AC	$T_p$	$\Delta H$	Hard	CL	Elast	Rehyd
PV	-0.76**													
HPV	0.26	-0.62												
CPV	0.56	-0.68*	0.87***											
BD	-0.67*	0.97***	-0.80**	-0.81**										
SB	0.70*	-0.57	0.55	0.89***	-0.62									
$T_i$	0.66*	-0.48	0.24	0.32	-0.45	0.30								
AC	0.54	-0.75**	0.54	0.43	-0.75**	0.23	0.44							
$T_p$	0.21	0.08	-0.36	-0.18	0.18	0.04	0.52	-0.02						
$\Delta H$	0.07	-0.19	-0.06	-0.23	-0.12	0.32	0.19	0.34	0.28					
Hard	0.32	-0.63	0.78**	0.69*	-0.73*	0.44	0.15	0.47	0.61	-0.28				
CL	-0.07	0.10	-0.52	-0.51	0.25	0.36	-0.15	0.09	0.45	0.25	-0.61			
Elast	0.19	-0.31	0.81**	0.75**	-0.51	0.52	0.37	0.47	0.0004	-0.23	0.51	-0.37		
Rehyd	-0.54	0.23	0.16	-0.29	0.24	0.33	-0.91***	-0.33	0.69*	-0.16	0.06	0.08	-0.48	
STABR	0.48	-0.85**	0.93***	0.87***	-0.95***	0.61	0.33	0.61	-0.29	0.042	0.78**	-0.41	0.62	-0.16

<sup>a</sup> PV = peak viscosity,  $P_{temp}$  = temperature at PV, HPV = hot paste viscosity, CPV = cool-paste viscosity, BD = breakdown (PV - HPV), SB = setback (CPV - HPV),  $T_i$  = initial swelling temperature, STABR = stability ratio (HPV/PV), Hard = gel hardness, AC = amylose,  $T_p$  = peak gelatinization temperature,  $\Delta H$  = gelatinization enthalpy, CL = cooking loss, Elast = noodle elasticity, Rehyd = rehydration. \*\*\*, \*\*, and \* =  $P < 0.001$ , 0.01, and 0.05, respectively;  $n = 10$ .

starch gave noodles that had low elasticity (17.3 g). Noodle elasticity was also low in Tsveta and Mukadzidzoka samples.

### Correlations Among Starch and Noodle Properties

Correlations among starch properties and noodle quality parameters are shown in Table III. Starch pasting properties were significantly correlated among themselves, as observed in other studies using sweet potato starch (Collado et al 1999), coix starch (Li and Corke 1999), and rice flour (Bhattacharya et al 1999). Starch amylose content was highly correlated with PV ( $r = -0.75$ ,  $P < 0.01$ ), as previously found with sweet potato starch (Collado and Corke 1997). Amylose content was also negatively correlated to BD ( $r = -0.75$ ,  $P < 0.01$ ). Starch gel hardness was positively correlated to HPV ( $r = 0.78$ ,  $P < 0.01$ ) and CPV ( $r = 0.69$ ,  $P < 0.05$ ) but negatively correlated to BD ( $r = -0.73$ ,  $P < 0.05$ ). Noodle elasticity was highly correlated with HPV ( $r = 0.81$ ,  $P < 0.01$ ) and CPV ( $r = 0.75$ ,  $P < 0.01$ ). PV was not correlated to textural, thermal, or noodle quality parameters and therefore could not be used to predict end-use related functionality in starch properties as previously observed in other studies using wheat flour (Bhattacharya et al 1997). Stability ratio (HPV/PV) was also not correlated to any of the noodle quality parameters, including rehydration, in contrast with results with sweet potato noodles (Collado and Corke 1997). Rehydration was highly correlated with  $T_i$  ( $r = -0.91$ ,  $P < 0.001$ ) and  $T_p$  ( $r = 0.69$ ,  $P < 0.05$ ).

The correlations between noodle elasticity and rehydration and sorghum starch pasting properties of HPV, CPV, and  $T_i$ , respectively, provide further evidence that pasting characteristics could provide information on the quality of noodles produced (Collado and Corke 1997; Bhattacharya et al 1999). However, differences are expected on specific pasting characteristics that could be used to predict noodle quality depending on the starch source. For example, according to Jin et al (1994), a high HPV generally represents low cooking loss. In sorghum starch noodles, cooking loss was low and not significantly correlated to starch properties.

### CONCLUSIONS

Sorghum starch has potential for use in noodle preparation. The variation in properties of starch from different sorghum genotypes results in differences in noodle-making quality and indicates the need to optimize the noodle-making procedure for each genotype. Depending on consumer preferences for texture, different genotypes may be optimal. This study, conducted on a limited number of sorghum genotypes, showed that noodle elasticity varied considerably among starches and was apparently correlated to pasting HPV and CPV. These pasting properties can be useful in predicting noodle quality.

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