Genetic Diversity in Properties of Starch from Zimbabwean Sorghum Landraces

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ABSTRACT

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Starch was isolated from 95 sorghum landraces from Zimbabwe using an alkali steep and wet-milling procedure. The physicochemical properties of sorghum starch were examined for potential use in Southern Africa. All the landraces evaluated had a normal endosperm indicated by the amylose content of the starches. Starch properties were not correlated to most of the physical grain quality traits evaluated. Grain hardness was weakly correlated to starch gel adhesiveness ($r = 0.36$) and amylose content ($r = 0.38$) ($P < 0.001$). The mean peak viscosity (PV) of the sorghum starches was 324 Rapid Visco Analyser units (RVU) compared with 238 RVU in a commercial corn starch sample; PV was 244–377 RVU. Some landraces had low shear-thinning starches, implying good paste stability under hot conditions. Pasting properties were highly correlated among the sorghum starches. The starch gel hardness showed considerable variation (44–71 g) among the landraces. Gelatinization peak temperatures were 66–70°C. The thermal properties of starches were not correlated with starch swelling and pasting properties. Genotype grouping by highest and lowest values in each category would allow selection of sorghums based on a specific attribute depending on the desired end use.

Sorghum is an important cereal that can be grown economically in the semi-arid regions of the world, unlike barley, wheat, and rice. The major use of the red and brown sorghums grown in the Southern African Development Community (SADC) region has been in the form of malt for commercial production of the traditional sour, opaque beer. There has been a proliferation of urban-based small-scale processors of sorghum grain in the region but most still produce the standard meal and opaque beer malts. In the SADC region, maize is the main source of starch for commercial purposes. Sorghum, like other cereals, is a potentially good source of raw starch for a wide range of uses. A wet-milling procedure is commonly employed for commercial sorghum starch production (Watson et al 1955; Subramanian et al 1994; Subramanian and Hoseney 1995). Commercial starch production from sorghum has not been attractive for a number of reasons. Sorghum grain available for wet milling tends to be less consistent than maize in terms of size, color, and defects. Wet milling of sorghum will also give far less cooking oil than maize (Watson 1984). Sorghum also yields less starch, as some starch occurs in the thick pericarp and some peripheral cells are not opened during the grinding of steeped grain (Rooney 1973; Watson 1984). Sorghum starch is also associated with more highly cross-linked proteins than is maize starch (Hamaker et al 1995). Isolated sorghum starch tends to be less bright than maize starch and may be stained with pericarp or glume pigments in the field or during processing (Munck 1995). Yang and Seib (1995) improved the brightness of sorghum starch by washing with sodium hydroxide solution (0.25*M*). Steeping conditions for maize kernels in water, sulfite or alkali all resulted in starches with similar structures (Takeda et al 1988). Alkali extraction has been applied in isolating amaranth starch (Perez et al 1993; Zhao and Whistler 1994; Wu et al 1995) and the method has also been proposed and developed for starch extraction from cereals (Mistry 1991; Zhao and Whistler 1994). Alkali-extracted corn starch exhibits low pasting temperature and high peak viscosity and little shear-thinning, indicating higher starch swelling and maintenance of granular integrity for a longer time before fragmentation occurs (Mistry and Eckhoff 1992). We have also compared dilute alkali steeping with other treatments and their effects on sorghum starch pasting and thermal properties (Beta et al 2001). We preferred to use the former for our study.

Several factors are known to affect the starch properties of sorghum which, in turn, affect the quality of food products made from the grain. For example, genetic and environmental factors affect starch composition and gelatinization temperature. In Zimbabwe, large manufacturers use starch for a variety of food and nonfood uses such as thickeners, binders, and extenders but the technical characteristics required have not been well studied nor has the possible substitution with sorghum starch been investigated. The research on physicochemical properties of starch from sorghum genotypes is likely to have an impact on alternative uses of sorghums currently grown in the SADC region. Studies on sorghum starch properties have been limited to a few cultivars and hybrids. Zimbabwe is the center of origin for sorghum and, hence, is likely to harbor a wide range of genetic variation in sorghum grain properties. The objectives of this study were 1) to isolate starch from a wide range of sorghum landraces of Zimbabwean origin using an alkali steep and wet milling; and 2) determine variation in important starch physicochemical properties, including pasting, gel texture, and thermal properties.

MATERIALS AND METHODS

Samples

Sorghum genotypes (95) were provided by the sorghum breeding program of SADC/International Crops Research Institute (ICRISAT) Sorghum and Millet Improvement Program (SMIP) located at Matopos, Zimbabwe. Grains were grown in the 1996-97 season under uniform field conditions. The selection of genotypes represented sorghum landraces originating from different towns of the four provinces of Masvingo, Matabeleland East, Matabeleland North, and Matabeleland South of Zimbabwe. However, most of the landraces originated from Masvingo province. Genotypes were all collected in Zimbabwe. ICRISAT names are coded in Table I. This article is focused on genetic variation in the landraces, not on environmental effects. There is no environmental bias because the Zimbabwe landraces were grown in the same site at Aisleby, Zimbabwe. The seeds of entries used in the study were subject to the same production regime, age, and storage time. As landraces they were cultivated under farm conditions in natural environments from which they were collected during germplasm collection missions. The lines can be obtained from ICRISAT using the accession data.

Grain Quality Traits

The grain quality traits, provided by SADC/ICRISAT/SMIP, included quantitative information on grain size distribution (small, medium, and large) using different sieve sizes. Grain hardness was evaluated on a score of 1–5, hundred kernel weight (100KW), and grain density were measured as percent of floaters in a solution of

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sodium nitrate. A Na_2NO_3 solution with a density of 1.32 g/mL was used to estimate endosperm hardness by allowing sorghum grains to float (Hallgren and Murty 1983).

Starch Extraction

Starch was extracted using a combination of the methods used by Wu et al (1995), Perez et al (1993) and Zhao and Whistler (1994). Sorghum grain (100 g) was steeped in 0.25% (w/v) NaOH at 5°C for 24 hr. The steeped grains were washed and ground with an equal volume of water using a Waring blender at full speed for 5 min. The slurry was filtered through a 200-mesh sieve (75-µm opening). The material remaining on the sieve was rinsed with water. The grinding and filtering process was repeated on this material. After rinsing, the material still remaining on the sieve was discarded. The collected filtrate was allowed to stand for 1 hr. The filtrate was centrifuged at 2,000 rpm for 10 min. The gray-colored top protein layer was removed using a spatula. Excess water was added to resuspend the sample and centrifuge for 3 min. The washing and recentrifugation was repeated several times until the top starch layer was white. The starch was dried for 24 hr at 40°C.

Amylose and Amylopectin Content

An iodine-binding spectrophotometric method using 0.2% iodine in 2.0% potassium iodide and reading absorbance at 620 nm was used (Juliano et al 1981). Samples of starch (100 mg) were weighed in 100-mL volumetric flasks. Ethanol (1 mL, 95%) was used to wash the sample down the flask. NaOH (9 mL, 1*N*) was added to the starch sample before heating the flasks in a boiling water bath for 10 min. The samples were cooled and the volume made up to 100 mL with distilled water. The contents were mixed vigorously to disperse the starch. Amylose and amylopectin standard mixtures were prepared to 0–60% amylose content. For the iodine color development, a 5-mL aliquot of each solution was taken to which 1 mL of acetic acid (1*N*) was added. The contents were mixed. The solutions were allowed to stand for 20 min after the addition of 2 mL of iodine solution and mixing.

Pasting Profile Determination

Pasting properties of sorghum starches were determined using the Rapid Visco Analyser (RVA) (model 3D, Newport Scientific, Warriewood, Australia). Sorghum starch (3 g, 14% moisture basis) was mixed with 25 g of accurately weighed water in the aluminum canister. During the programmed heating and cooling cycle, the mixture was held at 50°C for 1 min, heated to 95°C in 7.5 min at 6°C/min, held at 95°C for 5 min before cooling to 50°C in 7.5 min, and holding at 50°C for 1 min (Bhattacharya et al 1997). Peak viscosity (PV), temperature at peak viscosity (P_{temp}), temperature at initial viscosity rise (T_i), time from initial to PV (Time), holding strength or hot paste viscosity (HPV), cold paste viscosity (CPV), rate of shear thinning (R_{ST}) or (PV – HPV)/(13.5 min – time at PV), breakdown (BD) or (PV – HPV), setback (SB) or (CPV – PV), setback ratio or (CPV/HPV), and stability ratio (stabr) or (HPV/PV) were recorded. Two replicates per sample were used.

Texture Analysis

The stirring paddle was removed from the aluminum canister after RVA testing. The sample was allowed to stand for 24 hr at room temperature (≈20°C) for gelation to take place. A texture analyzer (SMS model TA-XT2i, Stable Micro Systems, Godalming, England) 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 10 mm at a crosshead speed of 30 mm/min using a 7-mm cylindrical probe with a flat end. Textural parameters of hardness (maximum force on cycle one) (g) and adhesiveness (total negative area in cycle one) (g/sec) were automatically computed from the force-time curve obtained using the data processing

TABLE I

Pasting, Gelatinization, Textural Properties of Sorghum Starches and Grain Quality Parameters[a,b]

Property	Mean	Limit	Genotype with Extreme Values in Category							Category
PV (RVU)	323.8	max	z-952(377)	z-871	z-0935	z-958	z-940	z-915brown	z-0878	>358
		min	z-0876(244)	z-938	z-900	z-0894	z-921	z-976	Esorg13	<277
HPV(RVU)	117	max	Red Swazi(156)	z-0918	z-976	z-921	z-089	z-0876	z-956-1	>144
		min	z-0914 (94)	z-925	Esorg13ct	z-960	z-0872	z-939	z-915brown	<113
CPV(RVU)	236	max	z-089 (298)	Red Swazi	z-921	z-0876	z-0918	z-900	z-0919	>267
		min	Esorg13ct(203)	z-891	z-960	z-925	z-939	z-872	z-0914	<209
BD (RVU)	207	max	z-952 (274)	z-0872	z-871	z-935	z-940	z-0931	z-915brown	>246
		min	z-0876 (103)	z-938	z-976	z-900	z-921	Red Swazi	Esorg13	<137
SB (RVU)	119	max	z-089 (155)	z-921	z-0868	z-0876	z-0919	z-0895	Red Swazi	>131
		min	z-891 (100)	z-942-2	z-960	Esorg13ct	z-939	z-0886	z-0872	<109
Stabr (RVU)	0.365	max	z-0876 (0.579)	Red Swazi	z-976	z-0918	z-921	z-938	z-900	>0.517
		min	z-0914 (0.268)	z-0872	z-952	z-925	z-915brown	z-940	z-0931	<0.286
T_p(°C)	68.3	max	z-0911(70.2)	z-0913	z-938	z-961	z-0899	z-912	Esorg13	>69.4
		min	z-0914(66.4)	z-0968	z-952	z-940	z-897	z-0931	z-941	<67.2
Hard (g)	60.1	max	z-957(71.4)	z-0935	z-089	z-950	z-0968	z-0895	z-940	>66.4
		min	z-932(43.9)	z-0933	z-907	z-960	z-0878	z-929	z-924	<54.0
Amylose (%)	28.5	max	z-967(33.6)	z-938	z-969	z-956-2	z-925	z-0869	z-951	>30.6
		min	z-958(24.0)	Esorg13ct	z-960	z-885	z-871	z-0909	z-883	<25.6
GH	3.4	max	z-0909(5.0)	z-924	z-0942	z-967	z-962	z-883	z-0931	>4.6
		min	z-0937(1.4)	z-953	z-908	z-0904	z-0878	z-907	z-0918	<2.3
100KW (g)	2.29	max	z-0904(4.6)	z-0914	z-0906	z-0945	z-089	z-0928	z-925	>3.2
		min	z-971(1.2)	z-0911	z-877	z-888	z-0919	z-969	z-972-1	<1.7
Density (%)	30.1	max	z-0904(100)	z-0937	z-953	z-0886	Esorg13ct	z-947	z-0939	>85
		min	z-885(0)	z-883	z-0914	z-965	z-942-2	z-0931	z-898	<6
SFS (%)	15.5	max	z-0904(98.4)	z-951	z-089	Mutode-II	z-0906	z-0928	z-925	>65
		min	z-877(0)	z-0880	z-888	z-0919	z-924	z-950	z-972-1	=0
SFM (%)	83.5	max	z-924(99.7)	z-912	z-0934-1	z-0934-2	z-0886	z-972-2	z-967	>98.9
		min	z-0904(1.4)	z-951	z-089	Mutode-II	z-0906	z-0928	z-925	<33.0

[a] Genotypes were all collected in Zimbabwe; ICRISAT names represent the following: z stands for ZIM, these landraces were collected by the Ministry of Agriculture, Zimbabwe; E stands for Enda, three of the landraces were collected from ENDA,a non-governmental organization in Zimbabwe. Red Swazi, Mutode II, Red Nyoni were used as controls in the ICRISAT breeding program for grain quality.

[b] PV = peak viscosity; HPV = hot paste viscosity; CPV =cold paste viscosity; BD = breakdown; SB = setback; Stabr = stability ratio; T_p = peak gelatinization temperature; Hard = starch gel hardness; GH = grain hardness on a 1-5 scale; 100KW = 100 kernel weight; Density = % grain floaters; SFS = grain size fraction, small; SFM = grain size fraction, medium.

software supplied with the instrument. Four repeat measurements were taken of each of the two gel replicates per sample.

Differential Scanning Calorimetry

Thermal properties of sorghum starches were determined using a differential scanning calorimetry (Mettler DSC-20, Mettler-Toledo AG Instruments, Naenikon-Uster, Switzerland) equipped with a ceramic sensor and a Mettler TC II data analysis station. Starch (2 mg, dwb) was weighed directly into a 40-µL aluminum standard pan and water was added to give a final weight of 6.5 mg. The pan was covered with the lid and hermetically sealed. The sample was allowed to equilibrate at room temperature for at least 1 hr before heating from 30 to 120°C at 10°C/min. The gelatinization temperature parameters of onset (T_o), peak (T_p), and conclusion (T_c), and gelatinization temperature range (T_r) or ($T_c - T_o$) were determined. Gelatinization enthalpy (ΔH) in J/g was also recorded. Two replicates per sample were used.

Statistical Analysis

The general linear model procedure of the Statistical Analysis System (v. 6.10, SAS Institute, Cary, NC) was used for data analysis. Means were compared at the 5% significance level using Fisher's least squares difference (LSD). Pearson correlation coefficients (r) were calculated among starch pasting, textural, and gelatinization properties and sorghum grain quality traits using SAS Proc Corr.

RESULTS AND DISCUSSION

Because of the wide variation in grain quality and starch properties among the sorghum landraces, some individual genotypes with extreme characteristics and the means for the selected parameters are reported (Table I).

Grain Quality Traits

The sorghum landraces had a wide range of seed colors (not shown), from white to dark brown, depending on the presence of phenolic compounds in the pericarp (Rooney and Miller 1982). Thus, the starch obtained showed different shades of white, cream, and pink colors reflecting the presence of pigments in the pericarp that got leached into the endosperm during weathering in the field or during steeping for wet milling (Norris 1971). However, the starch obtained even from certain white-seeded cultivars could still be off-white due to a noncarotenoid pigment in the endosperm (Freeman and Watson 1971). The mean grain hardness was 3.4 based on a scale of 1–5, indicating an endosperm of intermediate texture among the landraces. A few genotypes displayed a corneous endosperm (>4.4). This study confirms what has been established on a limited number of genotypes (16): Zimbabwean sorghums have a floury to intermediate endosperm texture (Beta et al 1999). Grain color and endosperm texture were not expected to cause differences in sorghum starch properties (Craig and Stark 1984). The average kernel weight (KW) of sorghum is 2.3 g/100 kernels, less than the 2.5–3.5 g range for commercial U.S. sorghums (Serna-Saldivar and Rooney 1995). The density of 30% of the kernels, on average, was <1.32 g/mL, with some sorghum landraces having 80% of kernels floating in Na_2NO_3 solution. Grain size distribution indicated that most landraces had kernels of intermediate size (84% between 2.6 and 4.0 mm). The fraction of kernels >4.0 mm was only 0.7% on average.

Amylose and Amylopectin Content

The quality of cooked sorghum is associated with the total and soluble amylose content of the grain, and the soluble protein content (Cagampang and Kirleis 1984). The average amylose content was 28% (range 24–33 %). Normal endosperm sorghum types contain ≈23–30% amylose, so the landraces included neither waxy nor high-amylose genotypes. Carcea et al (1992) and Akingbala et al (1982) also measured the amylose content of a limited number of normal sorghum cultivars and found a range of 22–28 and 23.3–23.9%, respectively.

Pasting Characteristics

The behavior of an aqueous starch paste on heating, cooling, and standing at different temperatures can describe most of the potential end-use properties of starch in food systems. The RVA was used for testing sorghum starch pasting properties (Table I, Fig. 1). The mean P_{temp} was 82°C (data not shown), with landraces z-089 and z-891/z-908 giving starch with the highest (87°C), and lowest (78°C) values. P_{temp} of corn starch was much higher at 93.5°C. The results confirmed the observations of Abd Allah et al (1987), who concluded that sorghum starches had similar amylograph initial gelatinization but lower temperature at maximum viscosity than corn starch. The rate of shear thinning (R_{ST}) was 15–41 RVU/min with an average of 29 RVU/min. Starches from landraces z-0914

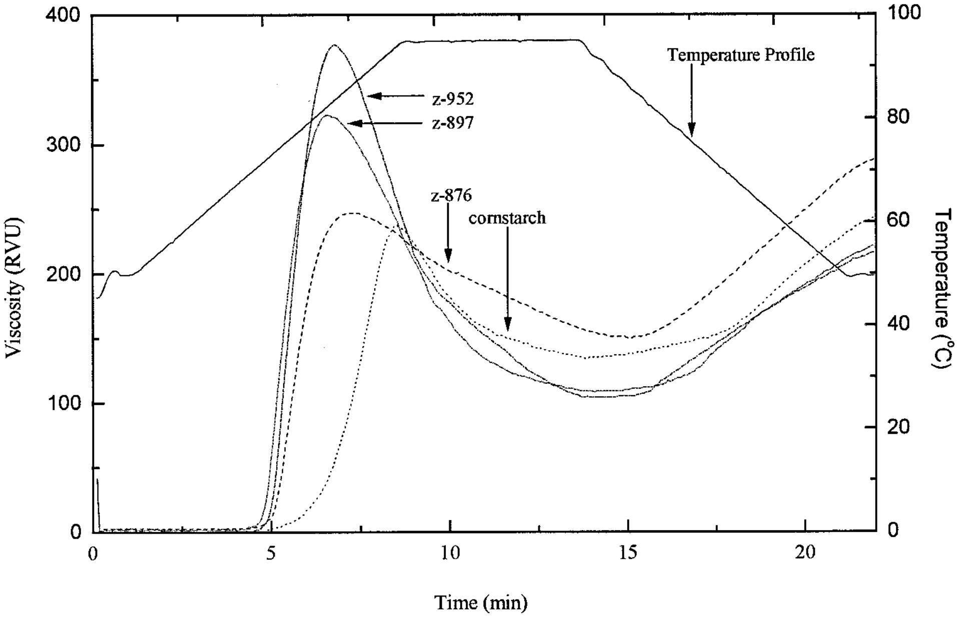

Fig. 1. Rapid Visco Analyser (RVA) pasting profiles of starches from sorghum landraces selected to illustrate genotypes with high, average, and low peak viscosity. Cornstarch pasting profile for comparison.

and z-952 had highest R_{ST} values. Landraces z-0876, z-976, z-900, and z-938 gave starches with the lowest rates of viscosity decrease. Sorghum starches, in general had higher R_{ST} than did corn starch, as previously observed by Subramaniam et al (1994) when studying two varieties and five cultivars.

Peak viscosity (PV) is related to the swelling power and indicates the water-binding capacity of the starch as it occurs at the equilibrium point between swelling and polymer leaching, which cause a viscosity increase, while rupture and polymer alignment cause a viscosity decrease (Newport Scientific 1998). The swelling power of starch and its solubility influences the cooking quality of sorghum (Subramanian and Jambunathan 1982). Landraces that gave starches with low and high PV values are listed in Table I. The mean PV was 324 RVU compared with 239 RVU given by a commercial corn starch (Fig. 1). Starches from landraces z-952 and z-876 had the highest (377 RVU) and lowest (244 RVU) PV values, respectively. Generally sorghum starches had higher swelling power compared with the commercial corn starch. The alkali extraction method used could have enhanced the peak viscosities for sorghum starches. An alkali-extraction process resulted in corn starch with high viscosity, high hydration capacity, and more heat and shear stability than the commercial corn starch (Mistry and Eckhoff 1992).

Holding the starch sample at a constant high temperature (95°C) with mechanical shear during the hold period of the test causes more granular disintegration, leaching out of solution, and alignment of amylose molecules, resulting in a greater decrease in viscosity (Newport Scientific 1998). The ability of a starch sample to withstand this heating and shear stress is an important factor for most food processing operations. Holding strength or hot paste viscosity (HPV), therefore, indicates a shear-thinning property of the starch. The mean HPV of 117 RVU given by sorghum starches (Table I) was comparable to 133 RVU given by the commercial corn starch. Starches from some landraces had high HPV values (>138 RVU). However, other landraces gave starches with relatively low HPV values (<104 RVU). A starch with a low HPV value would have a greater need for cross-linking than a starch with a high HPV value. In a study on shear thinning properties of sorghum starch, Subramanian et al (1994) concluded that hot pastes of starches from seven sorghum cultivars shear-thinned more than corn starches, although certain sorghum starches gave low shear thinning. However, Yang and Seib (1996) did not make similar observations from the hot pastes of starches isolated from two commercial yellow grain sorghum. In both studies, the number of sorghum starch samples used was limited. The greater swelling of sorghum starch may be responsible for high shear thinning observed in some landraces. However, Miller et al (1973) indicated that viscosity is not entirely caused by swelling, instead the fine structure and molecular weights of the amylose and amylopectin fractions are important in controlling shear thinning (Jane and Chen 1992). Several other authors have surmised that the morphology and rigidity of the swollen granules may be related to the degree of shear thinning (Doublier et al 1987; Ellis et al 1989).

On cooling a hot starch paste, a firm, viscoelastic gel was generally produced due to reassociation of starch molecules, especially amylose. The viscosity increased to a final viscosity. Final viscosity at 50°C (CPV) indicates the ability of the material to form a viscous paste or gel after cooking and cooling. CPV affects the textural and sensory properties of food and is considered important in some food processing operations such as canning. Landraces gave starches with high CPV values (>261 RVU) and low CPV values (<213 RVU). The mean CPV (236 RVU) was comparable to that of commercial corn starch (244 RVU). Yang and Seib (1996) also recorded the same paste consistency at 50°C of cooked sorghum and commercial corn starches on limited samples. The mean breakdown (BD) of sorghum starch pastes (207 RVU) was double that of commercial corn starch (106 RVU). Hence, sorghum starch showed less stability to paste breakdown compared with corn starch paste. Starches from landraces with the highest (>241 RVU) and lowest (<150 RVU) BD values are shown in Table I.

A high setback (SB) is indicative of gel instability under conditions of standard storage. It is associated with syneresis during freeze-thaw cycles, and substituted starches are commonly used where this presents a quality defect (Newport Scientific 1998). SB values for corn and sorghum starch pastes (mean 111 and 119 RVU, respectively) were comparable. Stability ratio for sorghum starch pastes averaged 0.365 compared with 0.552 for corn starch. Hence, corn starch gave a more stable paste than sorghum starches. Landraces gave starch pastes with high (>0.467) and low (<0.295) stability ratio. In a related study, sorghum starches from three cultivars, showed single-step viscoamylographic curves with pronounced pasting peaks, good pasting stability, and good SB on cooling (Carcea et al 1992). Similar conclusions could be drawn from this study for some sorghum landraces.

Textural Properties of the Starch Gels

Partial solubilization of starch molecules, which occurs during gelatinization (Waniska and Gomez 1992), appears to play a major role

TABLE II

Correlation Coefficients (*r* values) of Pasting, Gelatinization, and Textural Properties of Sorghum Starches and Grain Quality Parameters[a,b]

	PV	HPV	CPV	BD	SB	Stabr	T_p	GH	100KW	SFL	SFM	SFS	Hard	Adh	Amy	Ti	R_{ST}
HPV	–0.60***																
CPV	–0.58***	0.94***															
BD	0.96***	–0.80***	–0.77***														
SB	–0.43***	0.66***	0.87***	–0.55*													
Stabr	–0.87***	0.91***	0.86***	–0.97**	0.61***												
T_p	–0.14	0.16	0.17	–0.16	0.14	0.16											
GH	0.06	–0.09	–0.04	0.07	0.05	–0.10	–0.08										
100KW	0.07	0.04	–0.003	0.04	–0.06	–0.01	–0.21	–0.17									
SFL	0.06	–0.004	0.01	0.05	0.03	–0.03	–0.12	–0.23*	0.84***								
SFM	–0.06	0.001	–0.01	–0.05	–0.03	0.03	0.09	0.24*	–0.82***	–1.00***							
SFS	–0.09	–0.03	–0.01	–0.05	0.03	0.02	0.25*	0.001	–0.52***	–0.29**	0.23*						
Hard	–0.06	0.22	0.22	–0.13	0.16	0.18	–0.32***	0.03	0.08	–0.01	0.02	–0.18					
Adh	–0.04	–0.02	0.01	–0.02	0.04	0.001	0.19	0.06	–0.21*	–0.12	0.11	0.16	0.38***				
Amy	–0.05	0.10	0.12	–0.07	0.13	0.08	–0.16	0.03	0.07	0.09	–0.09	–0.08	0.36***	–0.13			
Ti	–0.13	0.19	0.27**	–0.17	0.33**	0.20*	0.64***	–0.002	–0.23*	–0.17	0.16	0.12	–0.08	0.20	–0.10		
R_{ST}	0.28**	–0.32**	–0.33**	0.32**	–0.27**	–0.33**	–0.01	0.01	0.11	0.05	–0.04	–0.02	0.12	–0.04	–0.07	–0.01	
Time	0.11	–0.13	–0.12	0.13	–0.09	–0.13	–0.18	0.03	–0.08	–0.03	0.04	–0.08	–0.19	0.05	–0.01	–0.09	–0.79***

[a] ***, **, * = $P < 0.001$, 0.01, and 0.05, respectively. $n = 94$.

[b] PV = peak viscosity; HPV = holding strength or hot peak viscosity; CPV = final or cool paste viscosity; BD = breakdown (PV – HPV); SB = setback (CPV – HPV); Stabr = stability ratio (HPV/PV); T_p = peak gelatinization temperature; GH = grain hardness (1–5 scale); 100KW = 100 kernel weight; Flo = % grain floaters in sodium nitrate solution; SFL = % large grain size fraction (> 4.0 mm); SFM = % medium grain size fraction (4.0–2.6 mm); SFS = % small size fraction (< 2.6 mm); Hard = starch gel hardness; Adh = starch gel adhesiveness; Amy = amylose content; Ti = temperature at initial viscosity rise; R_{ST} = rate of shear thinning; Time = time from initial viscosity to PV.

in the formation and textural characteristics of starch-based food gels. The hardness of the starch gels was 44–71 g, with a mean of 60 g. Landraces gave starches with soft (<54 g) and hard (>66 g) gels. Hardness, as measured by the texture analyzer is referred to by other terminology, depending on the application, including firmness and consistency. A firmer gel was prepared with starch from corneous rather than the floury endosperm of sorghum in another study (Cagampang and Kirleis 1985). Landraces that gave firmer starch gels possibly have starch polymers of high molecular weight (HMW) in the corneous endosperm compared with those that gave a softer gel, as observed by the same authors when three cultivars were used. The HMW starch polymers contributed more to solubilization (Jackson et al 1989) and retrogradation of starch (Cagampang and Kirleis 1985). Bello et al (1995) observed an association between a corneous endosperm texture of sorghum with an increased soluble starch and a firmer, thick porridge texture. Retrogradation of soluble amylose and amylopectin in fresh porridges appeared faster for HMW than for lower molecular weight polymers (Bello et al 1995).

Thermal Properties

The gelatinization temperature, which varies depending on the source of the starch, is important in processing because of the implications for energy requirements of cooking. The gelatinization

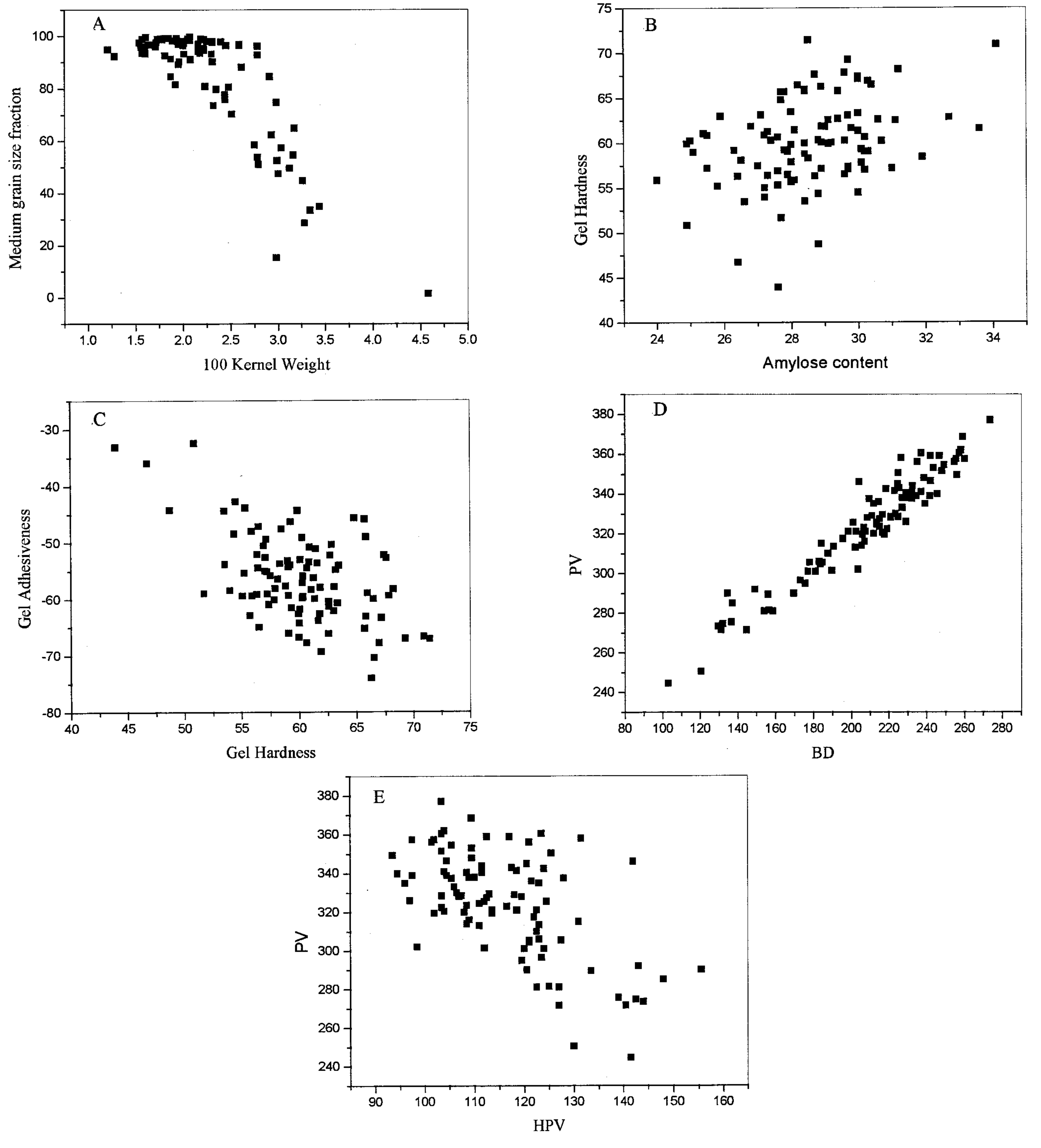

Fig. 2. Scatter plots illustrating relationships between pairs of variables. Points represent genotype means. **A,** SFM (grain size fraction, medium) vs. 100KW (100 kernel weight); **B,** Gel hardness vs. amylose content; **C,** gel adhesiveness vs. gel hardness; **D,** PV (peak viscosity) vs. BD (breakdown); **E,** PV (peak viscosity) vs. HPV (hot peak viscosity).

peak temperature (T_p) averaged 68.3°C (66.4–70.2°C). Sorghum landraces gave starches with high (>69°C) and low (<67°C) R_{ST} values. T_p for sorghum starches from Zimbabwean landraces were lower than values (74–76°C) previously reported (Akingbala et al 1982). T_p values reported for eight corn starches extracted using alkali solutions (Mistry and Eckhoff 1992) are still slightly higher (72–75°C) than those of sorghum starches from Zimbabwean landraces. Gelatinization temperatures are influenced by both genetic and environmental differences. T_p values obtained in this investigation could be influenced by the intermediate to floury nature of the sorghum landraces, as starch isolated from the corneous endosperm section had higher T_p than that from the floury section when three cultivars were used (Cagampang and Kirleis 1985). The method of starch extraction could also result in significant differences in gelatinization properties. Corn starches extracted using lower alkali concentration had lower T_p and T_o than those extracted at higher alkali concentration (Mistry and Eckhoff 1992).

Correlation of Grain and Starch Properties

Grain hardness correlated weakly with medium grain size fraction (SFM) ($r = 0.24$) at $P < 0.05$. The range of dependent variable for sorghums with hard and soft endosperm texture was 4.0–5.0 and 1.4–2.5, respectively. This array of sorghum is in line with results from previous work on red sorghum hybrid lines evaluated in the ICRISAT breeding program (Gomez et al 1997). Correlation of grain quality traits with starch properties showed that sorghum grain hardness was correlated to starch amylose content ($r = 0.38$) and starch gel adhesiveness ($r = 0.36$) ($P < 0.001$) (Table II). Cagampang and Kirleis (1984) established a positive relationship between amylose content and vitreousness (corneousness) using 15 sorghum hybrids differing in degree of hardness. This could not be confirmed from our results, possibly due to the differences in methods used to measure grain hardness, as we used the more subjective method practiced in the SADC/ICRISAT breeding program. The 100KW was strongly correlated to SFM ($r = –0.82$) (Fig. 2) but weakly correlated to starch gel adhesiveness ($r = –0.21$), T_p ($r = –0.21$) and ΔH ($r = 0.24$) ($P < 0.05$). Subramanian and Jambunathan (1982) found a positive correlation between 100KW and amylose content using 45 hybrids. Lack of a similar relationship in our study could be due to the genetic differences between the landraces and hybrids.

Pasting parameters correlated significantly (Table II, Fig. 2). For example, PV was positively correlated to BD ($r = 0.96$) but negatively correlated to CPV ($r = –0.58$), HPV ($r = –0.60$), SB ($r = –0.43$), and stability ratio ($r = –0.87$) at $P < 0.05$. The textural parameter of gel hardness was weakly correlated to HPV ($r = 0.22$) CPV ($r = 0.22$), and T_p ($r = -0.32$) at $P < 0.05$. Campbell et al (1995) correlated starch pasting and thermal properties of six maize inbreds and a significant negative correlation ($r = –0.92$, $P < 0.05$) between viscosity peak temperature and T_p. Our work with a limited number of genotypes (10) showed a positive correlation ($r = 0.86$, $P < 0.05$) between onset pasting temperature and T_p (Beta et al 2000). Gel hardness was correlated to adhesiveness ($r = 0.38$) and amylose content ($r = 0.36$) at $P < 0.001$.

Gelatinization T_p was correlated to T_o ($r = 0.73$), T_c ($r = 0.68$), and T_i ($r = 0.64$) at $P < 0.001$. The enthalpy for gelatinization (ΔH) was correlated to other gelatinization parameters including T_r (Fig. 2) at $P < 0.001$. The gelatinization properties of starches from the Zimbabwean landraces were not correlated to shear-thinning properties, unlike previous observations on seven sorghum samples (Subramanian et al 1994). Starch properties could not be predicted from the grain quality traits used by the breeding program.

CONCLUSIONS

Starches from Zimbabwean sorghum landraces had higher PV and therefore higher swelling power compared with the commercial corn starch. Gelatinization temperatures of starches from the sorghum landraces were relatively low. Starch properties were not correlated with the grain quality parameters. Although strong correlations existed among the starch pasting properties, correlations between gelatinization, pasting, and textural properties were very weak. Genotype grouping by highest and lowest values in each category would allow selection of sorghums based on a specific attribute depending on the desired end use.

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