Shear Thinning Properties of Sorghum and Corn Starches[1]

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ABSTRACT

The paste viscosities of sorghum and corn starches were studied with a Brabender viscograph. Sorghum starches and the laboratory-prepared corn starch gave higher paste consistencies than did the two commercial corn starches. Considerable variation existed in shear thinning of starches. In general, sorghum starches shear-thinned more than corn starches, although certain sorghum starches gave low shear thinning. When the hot pastes were sheared at high speed, sorghum starches thinned more than corn starches. The gelatinization characteristics did not appear to be related to shear thinning of sorghum starches. Swelling power at 95°C was lower for corn starch than it was for sorghum starch. Solubility of both corn and sorghum starches at 95°C varied among the cultivars. The reasons for high shear thinning of certain sorghums requires further investigation.

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Sorghum and corn starches are similar in their properties (Watson 1970). The most important property is behavior of the pastes developed when starch is heated in water. Physical properties of starches, such as gelatinization, swelling, pasting behavior, and functionality, are affected by degree of crystallinity (Kulp and Lorenz 1981). Heating of starch in water results in loss of birefringence, swelling of the granules, and partial solubilization of the starch. The gelatinization temperature of starch varies with the amount of water, at levels less than 30% of the starch weight, and with the species from which the starch was obtained. As the granules swell, they become increasingly susceptible to shear. Also accompanying swelling is an increase in soluble starch. Most solubilization occurs above 85°C (Kulp 1972).

The viscosity of starch systems often decreases markedly as a result of stirring during 1 hr holding at 95°C (Hoseney 1986). This decrease in viscosity often is referred to as shear thinning. Starches vary in their amount of shear thinning and, generally, those with greater shear thinning are more soluble (Zobel 1984). Lorenz and Hinze (1976) reported that holding the temperature of the starch paste at 92°C for 30 min reduced the viscosity of millet starches and increased those of wheat and rye.

The purpose of this study was to compare the shear thinning of sorghum and corn starches. The shear thinning properties were then related to swelling power, solubility, and gelatinization endotherm properties of the starches.

MATERIALS AND METHODS

Sorghum Samples

A number of sorghum samples were used in the study. They included Kansas local, Dekalb 42Y, and Dorado sorghum cultivars grown in the United States. Two local sorghum varieties from Mexico, Bajio and Tamaulipas, representing two important sorghum-growing regions, were kindly supplied by Arancia S. A. De CV, Guadalajara, Mexico. The cultivars UANL-1-V-187 and Blanco 86 developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and released in Mexico also were received from Arancia S.A., Mexico. Corn from a local market was used for comparison. Grain was cleaned in a Carter Dockage Tester (model 73, Carter-Day Co., Minneapolis, MN). The chaff, brokens, and dust were removed with a Kice aspirator (Kice Industries, Wichita KS). Before analysis, grain was ground in a Udy cyclone mill (Udy Corporation, Fort Collins, CO) to pass through a 0.4-mm sieve. All the analyses were performed at least in duplicate. Mean values are given.

Starch Samples

Starch was isolated by the steeping and wet-milling procedure of Watson et al (1955) with minor modifications. Corn starch samples (lots 67281 and 64391) were supplied by A. E. Staley (Decatur, IL). Starch samples were used for analysis without defatting.

Shear Thinning of Starch Pastes

Amylograms were produced with a Brabender Viscograph-E operated with a bowl speed of 75 or 125 rpm. Starch (7.5% on a moisture-free basis) was mixed with 450 ml of distilled water (pH 6.74). The starch-water mixture was heated from 30 to 95°C at 1.5°C/min, then held at 95°C for 60 min. Shear thinning was defined as the drop in viscosity at 95°C from peak viscosity (PV) during the 60 or 120 min of stirring. The drop in viscosity at 15-min intervals was calculated as percent reduction from initial viscosity. The time to reach PV, as well as the rate of reduction in viscosity between PV and the viscosity at 95°C were also recorded.

Differential Scanning Calorimetry

A Perkin-Elmer DSC-2 with an Intracooler system was used. The starch sample, determined on moisture-free basis (2.5–3.0 mg), was weighed into an aluminum pan. Using a syringe, water was added at a 1:3 ratio of starch to water. The pan was carefully sealed and heated in the calorimeter from 7 to 127°C at 10°C/min, at a sensitivity of 0.5 mcal/sec. An empty pan was used as a reference.

Swelling Power and Solubility

Swelling power and solubility of starch were determined as described by Leach et al (1959) with minor modifications. Starch (1 g) was heated with 30 ml of water to 95°C for 1 hr. Lump formation was prevented by using a magnetic stirrer. The mixture was centrifuged at 1,600 × *g* for 10 min. The supernatant was carefully removed, and the swollen starch sediment was weighed. Swelling power was the ratio in weight of the wet sediment to the initial weight of the dry starch. A 20-ml aliquot of supernatant was evaporated overnight at 130°C and weighed. The weight was corrected to the volume of supernatant and initial weight of the dry starch and expressed as percent soluble starch. The experiment was repeated four or more times. Mean values were reported.

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RESULTS AND DISCUSSION

Sorghum cultivars chosen for the study represented different growing regions and differences in grain color. Kansas local and Dekalb 42Y represent sorghum grown in the United States. Bajio and Tamaulipas represent the two important sorghum-growing regions in Mexico. The cultivars UANL-1-V-187 and Blanco 86 have been reported to give high grain yields and have good grain color. Corn was used for comparison. Sorghum starch did not show appreciable variation in size and shape of the granules as observed in an electron microscope (micrographs not shown). Watson (1970) reported that microscopic differentiation between corn and sorghum starch granules in a mixture is virtually impossible.

Swelling and Viscosity of Starch

The amylograph results for the corn and sorghum starches are given in Table I. Starch concentrations at 7.5% in water, corn starches 67281 and 64391 showed an initial viscosity rise at a temperature ~4°C lower than that for most of the sorghum starches. However, the bulk corn starch swelled at a slightly higher temperature. Dorado sorghum had an exceptionally high initial swelling temperature (77.5°C). The temperature at which PV was reached was slightly lower for corn starches 67281 and 64391 than it was for the sorghums.

Sorghum starch took less time to reach PV from initial swelling than did the corn starches. Dorado sorghum starch took the least time to reach PV. Thus, the sorghum starch swelled more rapidly than did the corn starch. The rate of decrease in hot paste viscosity occurring between PV and the viscosity at 95°C showed considerable variation. With the exception of Blanco 86 starch, sorghum starches had higher rates of viscosity decrease (expressed as BU/min) than did corn starches (Table I).

The hot paste consistency of corn starches at PV showed variation among cultivars for starch concentrations of 7.5% was used (Table II). The hot paste consistency for the bulk corn at PV was 554 BU, which was higher than that for the 67281 and 64391 corn starches. Among the sorghum starches, Dorado and Dekalb 42Y had nearly twice the PV of corn starch 64391. Starches of Kansas local, Bajio, Tamaulipas, UANL-1-V-187, and Blanco 86 were similar in their paste consistencies at PV, ranging from 537 to 570 BU.

Shear Thinning

Among the corn starches, bulk and 67281 shear-thinned less than did the 64391 starch (Table II). At the end of 60 min, the reduction in paste consistency was 26.2, 36.9, and 49.2% for bulk corn, 67281, and 64391 starches, respectively.

Shear thinning was higher for sorghum starches (Kansas local and Dekalb 42Y) than it was for other starches (Table II). Addition of 0.04% mercuric chloride, an amylase inhibitor, to Kansas local starch did not increase the paste consistency, indicating the absence of α-amylase in the starch (amylogram not shown). The starches from Dorado, Bajio, and Tamaulipas were similar in their rate of shear thinning (Table II). Dorado was similar to corn 67281 in its rate of shear thinning. Starches of UANL-1-V-187 and Blanco 86 had the lowest shear-thinning rates, even though their PVs were high. In fact, the starches from these two cultivars were lower than that of the corn starches in shear-thinning rate.

Heating a sorghum starch suspension (7.5% solids) to lower temperature (90°C) in the amylograph resulted in a lower paste consistency, similar to that of corn starch held at 95°C. Prolonged stirring at 90°C of this starch suspension did not produce shear thinning. This may be because the sorghum starch was not swollen to its full capacity under these conditions.

Paste Thinning at High Shear

The hot paste consistency also was compared at normal (75 rpm) and at high (125 rpm) shear rates. The amylograph data comparing corn starch 67281 and the sorghum starches Tamaulipas and UANL-1-V-187 are shown in Table III. All the starches shear-thinned more at the high shear rate than they did at the low shear rate when the hot paste was held at 95°C for 60 min. The consistency nearly stabilized after 60 min. The decrease in consistency at high shear rate was less for the starch from UANL-1-V-187, followed by that of corn starch and the Tamaulipas starch. For Tamaulipas, the decrease in viscosity was very large. Structural differences in starch pastes may be responsible for this difference, like those observed for maize, wheat, and oat starches (Doublier et al 1987a).

Gelatinization Studies with Calorimetry

The gelatinization energy (ΔH) varied among the sorghum starches, ranging from 3.04 to 3.61 cal/g. In corn starches, it was 3.11, 3.26, and 3.26 cal/g for the three samples (Table IV). The endotherm onset temperature (T_o) was generally higher for sorghum starch than it was for corn starch. This supports the observation from the amylograph that corn starch started to gelatinize at a lower temperature than did sorghum starch. Dekalb 42Y, Dorado, and Bajio starches had low ΔH and also gelatinized at temperatures 4–6°C lower than the that of other sorghum starches. Bulk corn gelatinized at a high temperature when compared to the other two corn starches. However, a relationship between shear-thinning properties and gelatinization characteristics was not found.

Swelling Power and Solubility

A comparison of swelling power and solubility of corn and sorghum starches at 95°C is given in Table V. Swelling power

TABLE I
Swelling and Viscosity Characteristics of Sorghum and Corn Starches[a]

	Temperature, °C		Time from Initial to Peak Viscosity (min)	Viscosity Decrease from Peak Viscosity to 95°C (BU/min)
	At Initial Viscosity Rise	At Peak Viscosity		
Sorghum				
Kansas local	70.0	87.0	11.5	13.0
Dekalb 42Y	71.5	87.5	10.5	17.5
Dorado	77.5	87.0	5.5	13.5
Bajio	70.0	88.0	12.0	13.0
Tamaulipas	70.3	88.0	11.7	12.0
UANL-1-V-187	69.3	87.0	11.7	13.7
Blanco 86	70.0	87.0	11.0	9.0
Corn				
67281	66.5	86.6	13.8	9.2
64391	66.0	86.6	13.0	11.5
Bulk	68.0	87.0	13.0	8.5
Standard error	± 1.00	± 0.19	± 0.72	± 0.86

[a] 7.5% concentration.

TABLE II
Viscosity (BU) of Starch[a] Held at 95°C for Different Intervals

Starch	Peak	Initial	Shear Time, min 15	30	45	60
Sorghum						
Kansas	570	500	398	368	347	330
Dekalb 42Y	606	515	399	360	323	297
Dorado	621	550	465	439	420	410
Bajio	537	475	387	368	358	353
Tamaulipas	540	482	397	375	363	355
UANL-1-V-187	549	473	439	425	418	410
Blanco 86	540	495	460	448	439	430
Corn						
67281	374	323	274	257	243	236
64391	295	227	171	160	154	150
Bulk	554	508	450	430	419	409
Standard error	±32.5	±31.6	±29.4	±28.7	±28.5	±28.3

[a] 7.5% concentration

TABLE III
Viscosity (BU) of Sorghum and Corn Starches[a] at Different Shear Rates

Starch and Shear Rate	Peak	Initial	Time at 95° C, min 15	30	45	60	Percent Thinned[b]
Sorghum							
Tamaulipas							
75 rpm	540	482	397	375	363	355	34.3
125 rpm	676	580	408	360	340	329	51.4
UANL-1-V-187							
75 rpm	549	473	439	425	418	410	25.3
125 rpm	707	643	555	530	515	505	28.6
Corn							
67281							
75 rpm	374	323	274	257	243	236	36.9
125 rpm	487	424	349	309	290	278	43.0
Standard error	±50.1	±46.2	±38.8	±38.7	±39.3	±39.3	

[a] 7.5% concentration.
[b] Peak viscosity = 60-min viscosity/peak viscosity × 100 = percent thinned.

TABLE IV
Heat of Gelatinization and Endotherm Characteristics of Sorghum and Corn Starches

Starch	ΔH, cal/g	Endotherm Temperature Onset, °C
Sorghum		
Kansas	3.61	72.5
Dekalb 42Y	3.11	69.2
Dorado	3.04	67.3
Bajio	3.08	68.0
Tamaulipas	3.28	73.0
UANL-1-V-187	3.44	73.1
Blanco 86	3.44	71.7
Corn		
67281	3.26	67.4
64391	3.11	66.8
Bulk	3.26	70.8
Standard error	±0.063	± 0.87

TABLE V
Swelling Power and Solubility of Sorghum and Corn Starches[a]

Starch	Swelling Power, g/g	Solubility, %
Sorghum		
Kansas	25.4	14.0
Dekalb 42Y	21.7	17.9
Dorado	20.9	13.9
Bajio	20.9	18.5
Tamaulipas	21.8	18.0
UANL-1-V-187	22.9	15.0
Blanco 86	20.6	17.9
Corn		
67281	16.7	22.1
64391	14.6	25.6
Bulk	17.3	17.8
Standard error	± 1.01	± 1.14

[a] Values are mean from four independent determinations.

of corn starches ranged from 14.6 to 17.3 g/g for the three samples. For sorghum, the values ranged from 20.6 to 25.4 g/g. Solubility of corn as well as sorghum starches showed variation among the cultivars. Corn starches showed less swelling and generally greater solubility than did sorghum starches.

In general, sorghum starches swell to a greater extent than do corn starches. The greater swelling of sorghum starch may be responsible for high shear thinning, although Miller et al (1973) indicated that viscosity was not entirely caused by swelling. In addition, the starches from the various sorghum cultivars varied widely in shear thinning but had relatively constant swelling values. It has been reported that little or no relationship was observed between swelling power and Brabender pasting curves (Miller et al 1973, Kulp and Lorenz 1981).

Factors Affecting Shear Thinning

From the data presented here, it is difficult to determine what controls shear thinning. Takeda et al (1989) and Jane and Chen (1992) have suggested that the fine structure and molecular weights of the amylose and amylopectin fractions are important. Several other authors (Steeneken 1987, Williams and Bowler 1982, Doublier et al 1987b, Ellis et al 1989) have surmised that the morphology and rigidity of the swollent granules may be related to the degree of shear thinning.

CONCLUSIONS

In general, sorghum starch had a higher hot paste consistency than did corn starch. Swelling was greater for sorghum starch than for corn starch. When the hot paste at 95°C was stirred, sorghum starch shear-thinned more than did corn starch. However, our data suggest that marked variation exists among starches from different sorghum cultivars. With corn starch, the difference among the samples tested was not appreciable. Sorghum cultivars UANL-1-V-187 and Blanco 86 gave starch that had low shear thinning, suggesting that these starches were stable under hot conditions. However, the shear thinning increased when the hot paste was stirred at high speed.

Sorghum starch swelled more than corn starch. Solubility was comparatively higher for corn starch than it was for sorghum starch. It may be that the structural network of molecules within the sorghum starch granule is loose, resulting in high shear thinning. The calorimetry properties of sorghum starch do not appear to be related to its shear-thinning properties. Clearly, further work is needed to understand these shear-thinning properties.

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