Thermal Properties and Paste and Gel Behaviors of Starches Recovered from Accessions Used in the Germplasm Enhancement of Maize Project

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Abstract

The objective of this study was to screen starches recovered from the corn accessions used in the Germplasm Enhancement of Maize (GEM) project for unusual thermal properties and paste and gel behaviors, so that they could be exploited in corn breeding programs to enhance traits important to corn utilization. In general, the values for gelatinization temperatures and peak height indices were greater, but heat of gelatinization values were less for the starches recovered from the GEM accessions (particularly BRA 052051 (SE 32)) than for starches from commercial Dent corn hybrids (11.3 vs. 13.6 J/g). Generally, retrogradation properties were similar among the GEM accessions, although there were specific accessions (particularly Lima 13) that possessed modestly lower percentage retrogradation (34 vs. 42%). Generally, peak viscosities, cold paste viscosities, and viscosity breakdowns were greater for the starches of the GEM accessions (particularly ARZM 01150, Antiqua 3, and URZM 01089, respectively) than for the starches of commercial hybrids. Pasting temperatures were about the same for all starches. Both 1-day and 7-day gel strengths were considerably greater for the starches recovered from the GEM accessions (particularly BRA 052051 (SE 32), 21.0 g for 1-day and FS8A(T), 66.2 g for 7-day). Although the differences in starch properties were statistically different, only the higher gel strengths of the starches recovered from the GEM accessions were of practical significance to the starch industry.

Disciplines

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Comments

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Thermal Properties and Paste and Gel Behaviors of Starches Recovered from Accessions Used in the Germplasm Enhancement of Maize Project[1]

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ABSTRACT

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The objective of this study was to screen starches recovered from the corn accessions used in the Germplasm Enhancement of Maize (GEM) project for unusual thermal properties and paste and gel behaviors, so that they could be exploited in corn breeding programs to enhance traits important to corn utilization. In general, the values for gelatinization temperatures and peak height indices were greater, but heat of gelatinization values were less for the starches recovered from the GEM accessions (particularly BRA 052051 (SE 32)) than for starches from commercial Dent corn hybrids (11.3 vs. 13.6 J/g). Generally, retrogradation properties were similar among the GEM accessions, although there were specific accessions (particularly Lima 13) that possessed modestly lower percentage retrogradation (34 vs. 42%). Generally, peak viscosities, cold paste viscosities, and viscosity breakdowns were greater for the starches of the GEM accessions (particularly ARZM 01150, Antiqua 3, and URZM 01089, respectively) than for the starches of commercial hybrids. Pasting temperatures were about the same for all starches. Both 1-day and 7-day gel strengths were considerably greater for the starches recovered from the GEM accessions (particularly BRA 052051 (SE 32), 21.0 g for 1-day and FS8A(T), 66.2 g for 7-day). Although the differences in starch properties were statistically different, only the higher gel strengths of the starches recovered from the GEM accessions were of practical significance to the starch industry.

Many are concerned about the narrowing genetic base of maize and about increased genetic vulnerability to changes in environmental and agronomic conditions, and new insect and disease pressures (National Academy of Sciences 1972; Brown 1975; Crossa and Gardner 1987). Exotic germplasm is of considerable interest to further improve maize and to maintain productivity in a period of changing environment and agricultural practices (Hallauer 1978; Geadlemann 1984). Exotic germplasm may also be source valuable corn traits important to processing and utilization.

Limited information is available on the variability in functional properties of starches recovered from commercial maize inbreds and even less for starches recovered from exotic maize germplasm. Li et al (1994) found significant genetic variability in thermal properties of starches isolated from tropical and semitropical maize germplasm, but the ranges in properties were small, especially compared with corn endosperm mutants. Campbell et al (1995) also used differential scanning calorimetry (DSC) to examine a set of normal Corn Belt Dent hybrids and suggested that DSC had application in breeding programs to screen germplasm for extreme values for developing breeding lines with unusual starch properties through crossing and recurrent selection. White et al (1990) studied intra- and interpopulation variability in thermal properties of starch from normal Southern Dent and exotic corn populations and found significant differences among plants of the same population as well as differences between populations. Pollak and White (1997) compared nine exotic maize inbreds, nine Corn Belt inbreds, and their crosses obtained from and grown in Argentina, Uruguay, and South Africa with Corn Belt inbreds and their crosses, and found that the Corn Belt inbreds varied more in gelatinization properties but less in retrogradation properties.

The Germplasm Enhancement of Maize Project (GEM) is a unique cooperation between the public and private sectors that has initiated efforts to strengthen U.S. corn hybrids for increased yields, agronomic characteristics, and value-added traits (Pollak and Salhuana 1998) by using exotic germplasm. GEM is the successor to the Latin American Maize Project (LAMP) (Salhuana et al 1998) that was launched in 1987 by the U.S. Department of Agriculture, Agriculture Research Services (USDA-ARS) and 11 Latin American countries with funding from Pioneer Hi-Bred International (Johnston, IA). The primary goal of LAMP was to evaluate and maintain the irreplaceable corn germplasm bank of Latin America and the United States.

LAMP evaluated over 12,000 accessions grown at 70 locations in the United States and Latin America. Screening was done on the basis of yield potential and agronomic characteristics. Of these accessions, 270 were selected as potential sources of high yields, with 51 chosen to initiate GEM.

The objective of the present study was to screen 49 GEM or future GEM accessions (already selected on the basis of yield potential and agronomic characteristics) for thermal properties and paste and gel behaviors of the starches. The GEM accessions possessing unique properties might be useful in developing hybrids with unique starches for added value or additional uses. A companion article examines the compositional, physical, and wet-milling properties of the grain from the same 49 GEM accessions (Singh et al 2001).

MATERIALS AND METHODS

Corn Samples

Forty-five Latin American and U.S. accessions from GEM were evaluated in this study (Table I). Of the 51 original GEM accessions, six were not included in the study because of insufficient seed supply. Substitutions were made with four accessions from the top 5% selected LAMP accessions from Peru (Lima 13, Lambayeque 46, Piura 196, and San Martin 116), which will be part of GEM in the future. The accessions (obtained from the North Central Regional Plant Introduction Station, Ames, IA), two commercial yellow Dent corn hybrids (Pioneer Brand Hybrids 3394 and 3489 from Pioneer Hi-Bred International, Inc., grown at Johnston, IA) and two public Corn Belt inbreds, B73 and Mo17 (grown at the Agronomy and Agricultural Engineering Farm, Iowa State University, near Ames, IA), were dried to <15% moisture by circulating ambient air (20–22°C) and cleaned by passing through a 6.35-mm round-hole U.S. standard sieve. Any remaining foreign material and broken kernels were removed by hand. Triplicate sample sets were prepared, placed into polyethylene bags, and stored at 4°C until used.

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Starch Recovery

Corn samples were wet milled using a 100-g laboratory-scale wet-milling procedure originally developed by Eckhoff et al (1996) and modified by Singh et al (1997) to recover the starches. In this procedure, corn is steeped at 50°C for 48 hr in a manner similar to industrial practice.

Thermal Properties

Thermal properties of the starches were determined using procedures reported by Campbell et al (1994) and differential scanning calorimetry (DSC) equipped with a thermal analyzer data station (DSC-7, Perkin-Elmer, Norwalk, CT). Starch samples (4 mg) and water (8 mg) were weighed in aluminum pans. The pans were sealed and allowed to equilibrate for 1 hr. The pans were heated from 30 to 120°C at a rate of 10°C/min in the DSC heating chamber. This was adequate to completely gelatinize the starch. Onset (T_o) and peak (T_p) temperatures and change in enthalpy (ΔH) for gelatinization were recorded. Peak height index (PHI) was calculated by dividing ΔH by $[2 \times (T_p - T_o)]$ (Krueger et al 1987). After gelatinization, sample pans were stored at 4°C for seven days and then heated from 30 to 90°C for retrogradation analysis. Values of T_o, T_p, and ΔH for retrogradation were determined by DSC. Percentage of retrogradation was calculated by dividing ΔH for retrogradation by the ΔH for gelatinization.

Paste Behavior

Paste behaviors of the starches were determined by using a Rapid Visco Analyser (RVA) (model RVA 4, Newport Scientific, Warriewood, NSW, Australia) following the standard procedure (STD2) in Thermocline for Windows (User's Manual, Newport Scientific). An 8% (dwb) starch slurry with a final weight of 28 g was used. The STD2 profile involved equilibrating the slurry for 1 min at 50°C and increasing the temperature to 95°C at the rate of 6°C/min. The temperature was held at 95°C for 5 min and then decreased to 50°C at the rate of 6°C/min. The temperature was held at 50°C for 2 min. Peak temperature (PT), peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown (BD), and setback (SB) values were recorded.

Gel Behavior

The starch pastes prepared in the RVA were poured into small aluminum canisters using the procedure described by Wang et al

TABLE I
Description of 49 GEM Accessions

Accession	PI	Race	Kernel Color and Type	Area of Adaptation	Source
Cash	278710	Corn Belt Dent	Yellow Dent	Temperate	US, Ohio
Golden Queen	452040	Corn Belt Dent	Yellow Dent	Temperate	US, Ohio
Big White	452054	Southern Dent	White Dent	Temperate	US, Tennessee
CHZM 04030	467139	Camelia	Orange Flint	Temperate	Chile, Coquimbo
CHZM 05015	467165	Camelia	Orange Flint	Temperate	Chile, Valparaiso
URZM 01089	479145	Cateto Sulino	Orange Flint	Temperate	Uruguay
Cuba 117	483816	Argentino	Orange Flint	Tropical	Cuba
Dominican Rep. 150	484028	Mixed	Yellow Semident	Tropical	Dominican Republic
St. Croix 1	484036	St. Croix	Yellow Semident	Tropical	Virgin Islands (US)
Antigua 3	484991	Criollo	Yellow Semident	Tropical	Antigua & Barbuda
Lima 13	485347	Perla	Orange Flint	Tropical	Peru, Lima
Cuba 110	489357	Argentino	Orange Flint	Tropical	Cuba
Cuba 164	489361	Mixed	Orange Semiflint	Tropical	Cuba
Dominican Rep. 269	489678	Canilla	Yellow Semident	Tropical	Dominican Republic
ARZM 01150	491741	Dent. Blanco Rugoso	White Dent	Temperate	Argentina, Buenos Aires
ARZM 03056	491799	Dentado Blanco	White Dent	Temperate	Argentina, Entre Rios
ARZM 13026	492746	Cristalino Colorado	Orange Flint	Temperate	Argentina, La Rioja
ARZM 13035	492753	Cristalino Colorado	Orange Flint	Temperate	Argentina, La Rioja
ARZM 17026	493012	Cristalino Colorado	Orange Flint	Temperate	Argentina, San Luis
ARZM 17056	493039	Cristalino Colorado	Orange Flint	Temperate	Argentina, San Luis
Guadelupe 5	498569	Early Caribbean	Yellow Flint	Tropical	Guadeloupe
Guatemala 209	498583	Tuson	Yellow Flint	Tropical	Guatemala
Lambayeque 46	503732	Arizona	White Dent	Tropical	Peru, Lima
Piura 196	503844	Alazan	Red/White Cap Flour	Tropical	Peru, Lima
Barbados Group 2	503885	Tuson	Yellow Dent	Tropical	Barbados
Puerto Rico Group 3	504142	Mixed	Yellow Dent	Tropical	Puerto Rico
St. Croix Group 3	504148	Tuson	Yellow Dent	Tropical	Virgin Islands (US)
San Martin 116	515097	Cuban Flint	Yellow Flint	Tropical	Peru, San Martin
ARZM 16021	516022	Cristalino Colorado	Orange Flint	Temperate	Argentina, Mendoza
ARZM 16026	516027	Cristalino Colorado	Orange Flint	Temperate	Argentina, Mendoza
ARZM 16035	516036	Cristalino Colorado	Orange Flint	Temperate	Argentina, Mendoza
FS8A(S)	536619	Mixed	Yellow Semident	Temperate	US, Florida
FS8A(T)	536620	Mixed	Yellow Semident	Temperate	US, Florida
FS8B(S)	536621	Mixed	Yellow Semident	Temperate	US, Florida
FS8B(T)	536622	Mixed	Yellow Semident	Temperate	US, Florida
Pasco 14	571679	Unclassified	Yellow Dent	Tropical	Peru, Pasco
Chiapas 462	583888	Hybrido Blanco	White Dent	Tropical	Mexico, Chiapas
British VI 155	583901	Tuson	Yellow Dent	Tropical	Virgin Islands (British)
BRA 051403 (PE 01)	583911	Cateto	Orange Flint	Tropical	Brazil, Pernambuco
BRA 051501 (PE 011)	583912	Unclassified	Yellow Dent	Tropical	Brazil, Pernambuco
BRA 052051 (SE 32)	583917	Dente Amarelo	Yellow Dent	Tropical	Brazil, Sergipe
URZM 13061	583922	Cateto Sulino	Orange Flint	Temperate	Uruguay
URZM 13010	583923	Dente Branco	Orange Dent	Temperate	Uruguay
URZM 13088	583925	Cateto Sulino	Orange Flint	Temperate	Uruguay
URZM 13085	583927	Cateto Sulino	Orange Flint	Temperate	Uruguay
URZM 05071	583937	Riograndense	Orange Semident	Temperate	Uruguay
URZM 11002	583938	Dente Branco	White Dent	Temperate	Uruguay
URZM 10001	583942	Dente Branco	White Dent	Temperate	Uruguay
British VI 103	586761	Criollo	Yellow Semiflint	Tropical	Virgin Islands (British)

(1992) and stored at 4°C to cause gelation. The gel strengths (textures) of the starch gels were determined after one and seven days of storage at 4°C using a Voland texture analyzer (Texture Technologies, Scarsdale, NY). Gel strengths were measured at five different locations of freshly exposed surface.

Statistical Analysis

An unpaired parametric, multiple comparison test (SAS Institute, Cary, NC) was used to determine least significant differences (LSD) of properties among the accessions (three replicates) at the $P < 0.05$ level. SAS procedure CORR was used to determine correlation coefficients among the properties at $P < 0.05$, 0.01, and 0.001 levels.

RESULTS AND DISCUSSION

In addition to tables, the properties of starches recovered from the 49 GEM accessions, two widely grown commercial Dent hybrids, and two public Corn Belt inbreds are presented in the form of frequency distribution histograms, where the x-axis represents the property and the y-axis represents the number of observations (Figs. 1–3). These are provided to show the range in data and identify extreme outliers.

Thermal Properties of GEM Starches

We observed wide ranges in values for the thermal properties of the starches recovered from the GEM accessions (Tables II and III, Fig. 1), in most cases wider than has previously been reported (Li et al 1994; Pollak and White 1997). The onset gelatinization temperature (T_o) values for the GEM accessions were generally greater than those of the exotic lines and Corn Belt hybrids in other studies (Li et al 1994 Campbell et al 1995 Pollak and White 1997). The lowest (67.6°C) and highest (72.0°C) T_o values among the GEM accessions were for starches recovered from URZM 13061 (from Uruguay)

TABLE II
Thermal Properties[a] of Starches Recovered from GEM Accessions

Accession	Gelatinization				Retrogradation			
	T_o	T_p	ΔH	PHI	T_o	T_p	ΔH	% Retro
Cash	71.1	73.5	12.3	2.94	46.4	55.5	5.71	46.4
Golden Queen	69.3	73.8	12.6	1.40	44.9	53.7	5.63	44.8
Big White	70.1	73.0	14.5	2.19	46.4	54.6	6.05	41.8
CHZM 04030	70.1	74.0	13.0	1.66	44.2	52.8	6.11	46.9
CHZM 05015	70.7	74.3	13.7	1.85	44.7	53.9	6.28	46.0
URZM 01089	70.3	73.8	11.9	1.67	43.3	52.0	6.53	54.9
Cuba 117	69.5	73.3	13.9	1.82	43.9	53.8	6.88	49.7
Dominican Rep. 150	67.9	71.9	11.5	1.44	44.3	53.2	5.31	46.3
St. Croix 1	69.5	73.3	14.4	1.88	45.3	54.0	6.59	45.9
Antigua 3	70.9	74.1	12.7	2.06	44.6	53.7	6.19	48.8
Lima 13	68.7	72.6	12.9	1.65	44.9	52.9	4.56	35.4
Cuba 110	70.4	74.1	13.5	1.85	44.5	53.8	6.63	49.1
Cuba 164	70.8	73.5	14.6	2.27	44.9	54.3	6.77	46.3
Dominican Rep. 269	70.5	74.0	14.8	1.88	45.1	54.5	7.17	48.4
ARZM 01150	71.8	74.0	12.9	1.97	46.8	55.8	6.06	47.0
ARZM 03056	71.6	72.1	13.2	2.16	44.0	53.1	6.05	45.8
ARZM 13026	69.3	73.4	13.4	1.66	44.6	53.3	6.53	48.9
ARZM 13035	69.2	74.2	12.1	1.21	44.6	53.6	4.45	45.1
ARZM 17026	69.8	73.7	12.1	1.57	44.3	53.3	5.70	47.3
ARZM 17056	70.5	74.7	12.5	1.48	44.3	53.3	6.58	52.9
Guadelupe 5	69.7	73.3	12.4	1.69	46.5	55.3	5.91	47.8
Guatemala 209	69.6	73.6	12.7	1.60	44.0	52.8	6.01	47.4
Lambayeque 46	71.2	74.6	12.8	1.89	44.3	52.8	5.83	45.5
Piura 196	72.0	75.3	15.0	2.26	43.5	53.5	6.89	46.0
Barbados Group 2	70.9	73.6	12.9	1.84	44.2	53.6	5.78	44.7
Puerto Rico Group 3	69.9	73.4	13.0	1.87	43.7	52.7	5.49	42.6
St. Croix Group 3	70.2	73.2	13.0	1.76	44.4	53.6	5.58	42.9
San Martin 116	69.5	74.3	13.8	1.03	43.3	52.8	6.50	47.1
ARZM 16021	68.7	74.4	12.3	1.08	43.3	52.9	5.66	46.1
ARZM 16026	69.8	75.0	13.1	1.25	43.3	54.5	6.19	47.4
ARZM 16035	68.3	73.9	11.8	1.02	44.5	53.6	4.82	40.8
FS8A(S)	70.3	74.8	12.2	1.35	45.2	53.8	5.08	41.6
FS8A(T)	71.5	73.9	12.8	1.55	47.2	56.3	5.73	44.9
FS8B(S)	70.8	74.7	12.3	1.55	44.8	55.4	5.97	48.7
FS8B(T)	70.0	73.2	12.1	1.88	48.3	57.2	4.90	40.6
Pasco 14	70.2	73.8	12.6	1.79	45.1	54.5	5.62	44.6
Chiapas 462	70.4	74.5	12.7	1.55	43.7	52.7	5.64	44.5
British VI 155	69.8	73.3	12.3	1.75	44.9	54.1	5.55	45.1
BRA 051403 (PE 01)	70.7	74.2	12.8	1.83	44.1	53.2	5.55	43.4
BRA 051501 (PE 011)	70.0	73.7	12.2	1.67	48.0	56.4	5.14	42.0
BRA 052051 (SE 32)	71.2	73.3	11.3	1.57	46.3	54.1	5.42	48.1
URZM 13061	67.6	73.2	11.7	1.05	43.5	52.7	5.28	45.0
URZM 13010	67.7	73.1	12.5	1.15	44.7	53.1	5.00	40.0
URZM 13088	68.8	73.7	11.3	1.16	43.7	52.7	5.24	50.0
URZM 13085	69.1	73.2	12.0	1.26	43.8	52.9	5.98	44.0
URZM 05071	69.0	73.9	14.1	1.44	45.7	54.6	5.83	42.5
URZM 11002	68.8	73.0	12.8	1.58	44.6	52.8	4.70	45.4
URZM 10001	69.0	73.2	12.1	1.46	46.2	54.7	6.04	38.9
British VI 103	69.0	72.6	11.8	1.75	43.9	53.6	6.04	51.1
LSD[b]	0.6	0.5	0.5	0.29	1.0	0.9	0.42	3.2

[a] T_o = onset temperature (°C), T_p = peak temperature (°C), ΔH = change in enthalpy (J/g), PHI = peak height index (J/g × °C), % Retro = % retrogradation.
[b] Least significant difference ($P < 0.05$).

and Piura 196 (from Peru), respectively. In general, T_o of starches from the GEM accessions were greater than those of the commercial Dent hybrids and the Corn Belt inbreds (means of 69.9°C for the GEM accessions vs. 66.4 and 68.3°C for the commercial Dent hybrids and the Corn Belt inbreds, respectively).

Peak gelatinization temperatures (T_p) of starches recovered from GEM starches were 71.9–75.3°C (Dominican Republic 150 and Piura 196, respectively) (Tables II and III, Fig. 1A). Mean T_p values of starches recovered from the GEM accessions were greater than those of the commercial Dent hybrids and the Corn Belt inbreds (73.7°C for the GEM accessions vs. 71.3 and 71.8°C for the commercial Dent hybrids and the Corn Belt inbreds, respectively). Larger T_o and T_p values may be due to the compact nature of small starch granules and higher degree of molecular order of granules (Krueger et al 1987). T_o values also may be high due to increased chain lengths of amylopectin (Jane et al 1999). We further recognize that T_o and T_p values are also affected by the annealing conditions to which the starch is exposed during steeping of the grain (50°C, 48 hr) (Kreuger et al 1987), but similar conditions are practiced by all wet corn mills, and we chose to assess the starches as they would be recovered in industry practice.

The lowest (11.3 J/g) and highest (15.0 J/g) ΔH values for gelatinization among the GEM accessions were in starches recovered from BRA 052051 (SE 32 from Brazil) and Piura 196, respectively (Tables II and III, Fig. 1B). The mean ΔH for gelatinization for the GEM accessions (12.8 J/g) was higher than means observed for other exotic populations [10.5 J/g (Li et al 1994), 11.3 J/g (Pollak and White 1997), 10.0 J/g (Campbell et al 1995)] and Corn Belt inbreds [12.1 J/g (Pollak and White 1997), 10.8 J/g (Campbell et al 1995)]. Changes in enthalpy for gelatinization (ΔH) of starches recovered from the GEM accessions were 11.3–15.0 J/g, but generally they were lower than for starches recovered from the commercial Dent hybrids (13.6 J/g) and greater than those of the Corn Belt inbreds (12.3 J/g). These differences in ΔH for gelatinization suggest that the starches from the GEM accessions might contain increased amylose, which results in less native alignment of hydrogen bonds within starch molecules (McPherson and Jane 1999).

Peak height index (PHI) is the ratio of ΔH for gelatinization to the gelatinization temperature range and is a measure of uniformity in gelatinization. PHI values for the starches recovered from the GEM accessions were 1.02–2.94 J/g/°C (Tables II and III, Fig. 1C). The lowest and highest PHI values among the GEM accessions were in starches recovered from ARZEM 16035 (from Argentina) and Cash (from Ohio), respectively. The mean PHI of the GEM accessions (1.64 J/g/°C) was greater than that of the commercial Dent hybrids (1.32 J/g/°C), but was about the same as that of the Corn Belt inbreds (1.78 J/g/°C). Several GEM accessions yielded starches that were much more uniform in gelatinization than were observed in a previous study where PHI were 1.67–2.51 J/g/°C among exotic lines and 1.25–2.09 J/g/°C among Corn Belt inbred lines (Pollak and White 1997). Larger values of PHI can be attributed to smaller but more uniform starch granule size, leading to greater ΔH for gelatinization and smaller gelatinization range.

The highest and lowest onset retrogradation temperatures (T_o) among the GEM accessions were for starches recovered from URZM 01089 (from Uruguay) and FS8B(T) (from Florida), respectively (Tables II and III). Several GEM accessions had retrogradation T_o values higher (1.7°C) than previously observed for exotic lines (Pollak and White 1997). Retrogradation T_o values for the starches recovered from the GEM accessions were 43.3–48.3°C vs. 43.9 and 44.7°C for the means of the commercial Dent hybrids and the Corn Belt inbreds, respectively.

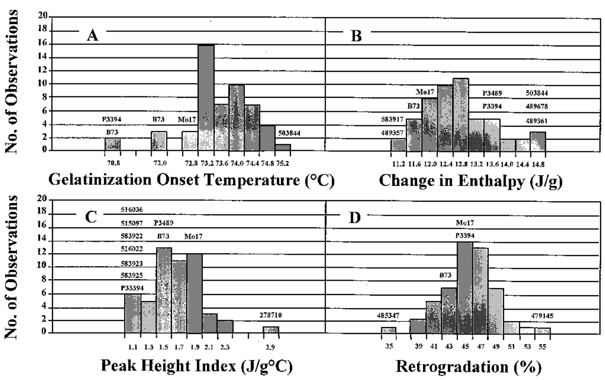

Fig. 1. Frequency distributions of thermal properties of starches from Germplasm Enhancement of Maize (GEM) project accessions. **A,** Gelatinization onset temperature; **B,** change in enthalpy of gelatinization; **C,** peak height index; **D,** % of retrogradation. Numbers on the x-axes are center points for the column.

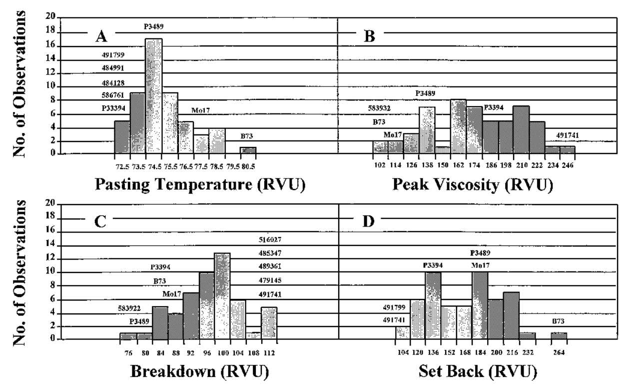

Fig. 2. Frequency distributions of paste behaviors of starches from Germplasm Enhancement of Maize (GEM) project accessions. **A,** Pasting temperature; **B,** peak viscosity; **C,** breakdown; **D,** setback. Numbers on the x-axes are center points for the column.

TABLE III
Comparison of Thermal Properties[a] of Starches Recovered from GEM Accessions, Commercial Dent Hybrids, and Corn Belt Inbreds

	Gelatinization				Retrogradation			
Line	T_o	T_p	ΔH	PHI	T_o	T_p	ΔH	% Retro
GEM accessions								
Maximum	72.0	75.3	15.0	2.94	48.3	57.2	7.17	54.9
Minimum	67.6	71.9	11.3	1.02	43.3	52.0	4.45	35.4
Mean	69.9	73.7	12.8	1.64	44.8	53.8	5.81	45.6
Commercial hybrids								
Pioneer 3394	64.8	70.6	13.5	1.15	43.3	52.7	6.09	45.2
Pioneer 3489	67.3	71.9	13.7	1.49	44.5	53.6	5.90	43.2
Common inbreds								
B73	67.1	70.8	11.8	1.57	45.2	54.7	5.12	43.4
Mo17	69.4	72.7	12.8	1.98	44.2	52.8	5.71	44.2

[a] T_o = onset temperature (°C), T_p = peak temperature (°C), ΔH = change in enthalpy (J/g), PHI = peak height index (J/g × °C), % Retro = % retrogradation.

The lowest and highest changes in enthalpy (ΔH) for retrogradation among the GEM accessions were for starches recovered from Lima 13 (from Peru) and Dominican Republic 269, respectively (Tables II and III). Δ*H* values for retrogradation for starches recovered from the GEM accessions were 4.56–7.17 J/g vs. means of 6.00 and 5.42 J/g for the commercial Dent hybrids and the Corn Belt inbreds, respectively.

The percentage ratio of Δ*H* for retrogradation to Δ*H* for gelatinization (% Retro) for some of the GEM accessions were lower (35.4%) than lowest values previously reported for exotic lines and populations [42.0% (Pollak and White 1997), 52.6% (Campbell et al 1995)] and for commercial inbreds [46.0% (Pollak and White 1997), 50.4% (Campbell et al 1995)]. The lowest and highest % Retro values among the GEM accessions were for starches recovered from Lima 13 and URZM 01089, respectively. A wide range of % Retro values were observed for the GEM accessions and they had a slightly greater mean value than for the commercial hybrids and the Corn Belt inbreds (45.6% vs. 44.3 and 43.8% for the commercial Dent hybrids and Corn Belt inbreds, respectively) (Tables II and III, Fig. 1D). Increased tendency of retrogration suggests increased proportion of amylose contents or length of outer amylopectin chains (Kasemsuwan et al 1995).

Paste Behaviors of GEM Starches

The starches from the GEM accessions had wide ranges for some paste behaviors (Tables IV and V, Fig. 2). The lowest (72.4°C) and highest (78.6°C) pasting temperatures (PT) among the starches recovered from the GEM accessions were ARZM 03056 and URZM 13061, respectively. The mean PT values for the starches recovered from the GEM accessions were similar for all starches (75.0°C for the GEM starches vs. 73.5 and 79.1°C for the commercial Dent hybrids and the Corn Belt inbreds, respectively).

TABLE IV
Paste and Gel Behaviors[a] of Starches Recovered from GEM Accessions

Accession	Paste						Gel Strength (g)	
	PV	HPV	CPV	PT	BD	SB	1 day	7 days
Cash	145	46	266	76	99	220	12.7	30.4
Golden Queen	194	97	239	75	97	142	13.6	40.1
Big White	214	121	244	73	94	123	14.0	35.2
CHZM 04030	127	29	243	78	98	214	12.4	32.0
CHZM 05015	135	30	243	78	105	213	12.0	32.4
URZM 01089	177	65	259	75	113	195	13.7	36.8
Cuba 117	142	44	237	76	98	194	11.1	31.9
Dominican Rep. 150	187	83	233	73	104	150	15.3	42.5
St. Croix 1	223	118	246	74	105	128	15.9	50.1
Antigua 3	215	119	281	73	96	162	16.1	50.9
Lima 13	71	61	278	75	111	217	13.9	36.9
Cuba 110	118	26	246	78	92	220	9.5	29.8
Cuba 164	225	113	241	74	112	129	12.4	52.3
Dominican Rep. 269	193	93	245	74	100	152	14.2	42.7
ARZM 01150	249	136	242	74	113	106	11.9	45.4
ARZM 03056	234	129	227	72	105	98	13.4	36.5
ARZM 13026	139	38	248	77	102	210	12.2	36.0
ARZM 13035	141	39	240	77	101	201	11.7	37.5
ARZM 17026	158	56	256	76	103	200	11.9	39.2
ARZM 17056	135	39	239	77	95	200	13.0	31.8
Guadelupe 5	141	40	237	79	101	197	15.2	43.3
Guatemala 209	176	71	248	76	104	176	14.9	61.0
Lambayeque 46	194	85	257	76	109	172	15.7	50.8
Piura 196	163	75	246	76	87	170	14.2	40.4
Barbados Group 2	180	91	230	74	90	140	15.4	46.0
Puerto Rico Group 3	186	103	234	74	83	130	13.7	51.7
St. Croix Group 3	216	126	250	74	90	124	17.4	58.5
San Martin 116	169	72	244	76	98	172	16.0	38.6
ARZM 16021	124	32	269	78	92	238	14.6	38.4
ARZM 16026	202	92	272	76	110	180	16.6	63.6
ARZM 16035	182	82	241	74	100	159	15.1	34.3
FS8A(S)	201	109	263	75	92	154	18.8	54.7
FS8A(T)	210	125	264	74	85	139	19.2	66.2
FS8B(S)	207	111	244	75	96	133	15.4	65.4
FS8B(T)	159	66	246	75	93	180	12.4	25.2
Pasco 14	216	119	232	74	97	113	17.9	46.8
Chiapas 462	206	124	244	74	82	120	14.5	45.6
British VI 155	204	103	243	74	101	140	16.1	49.5
BRA 051403 (PE 01)	179	92	233	75	87	141	16.5	45.9
BRA 051501 (PE 011)	190	91	246	74	99	155	18.8	49.3
BRA 052051 (SE 32)	217	126	243	74	90	117	21.0	51.5
URZM 13061	98	23	242	79	75	219	10.7	23.9
URZM 13010	161	63	250	75	97	187	11.4	25.0
URZM 13088	161	62	242	76	99	180	14.1	32.8
URZM 13085	176	75	240	75	101	164	15.7	36.5
URZM 05071	165	66	244	73	99	178	13.4	29.1
URZM 11002	161	67	244	75	94	177	11.3	27.3
URZM 10001	160	64	244	75	95	179	11.3	27.0
British VI 103	224	125	240	73	99	115	18.3	4.5
LSD[b]	9	6	8	2	9	9	1.0	3.2

[a] PV = peak viscosity, HPV = hot paste viscosity, CPV = cold paste viscosity, BD = breakdown (PV – HPV), SB = setback (CPV –HPV), all measured in Rapid Visco Analyser units (RVU). PT = pasting temperature (°C). Gel strengths after 1 and 7 days of storage at 4°C.

[b] Least significant difference ($P < 0.05$).

The lowest and highest peak viscosity (PV) values among the GEM accessions (98 and 248 RVU, respectively) were for starches recovered from URZM 13061 and ARZM 01150, respectively (Tables IV and V, Fig. 2B). The mean PV of the GEM accession starches was considerably greater than that of the commercial Dent hybrids and the Corn Belt inbreds (179 RVU vs. 161 and 110 RVU for the commercial Dent hybrids and Corn Belt inbreds, respectively). Some GEM accessions had quite high PV values. Higher PV value is attributed to increased proportions of amylopectin in starches, which may relate to greater swelling and reduced free water (Zeng et al 1997). Contrary to the thermal properties of starches from GEM accessions, which suggested higher levels of amylose, the paste behaviors of some starches (particularly BRA 052051 (SE) and British Virgin Islands 103) were more similar to waxy starches. Zeng et al (1997) found that harder grain produced starches with greater PV for a given amylose content. To some extent, this may explain the larger values of PV for starches from GEM accessions.

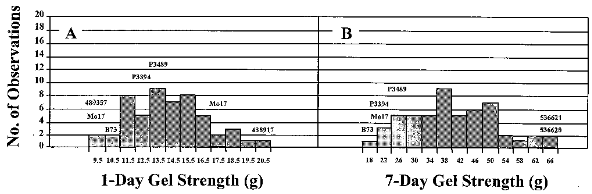

Fig. 3. Frequency distributions of gel behaviors of starches from Germplasm Enhancement of Maize (GEM) project accessions. **A,** 1-day gel strength; **B,** 7-day gel strength. Numbers on the x-axes are center points for the column.

Cold paste viscosity (CPV) values for the GEM accession starches ranged from 227 (ARZM 03056) to 281 RVU (Antigua 3) (Tables IV and V). The mean CPV values of GEM accessions were greater than those of the commercial hybrids but similar to those of the Corn Belt inbreds (247 RVU vs. 238 and 246 RVU for the commercial Dent hybrids and Corn Belt inbreds, respectively). Jane et al (1999) suggest that very long chain amylopectin mimic amylose to form helical complexes with lipid and intertwine with other chains to hold the integrity of starch granules during shearing and heating. After breakdown, long chain amylopectin and amylose may reassociate and thus increase the CPV.

The lowest and highest breakdown (BD) values were observed in starches recovered from URZM 13061 and ARZM 01150, respectively (Tables IV and V, Fig. 2C). BD values for starch pastes of the GEM accessions were 75–113 RVU compared with mean values of 82 and 86 RVU for the commercial Dent hybrids and the Corn Belt inbreds, respectively. Lower amylose content contributes to high swelling and thus lower BD values (Jane 1999). The more swollen the starch granule, the more sensitive the starch paste. Larger values of GEM starches suggest greater proportions of amylopectin.

The lowest and highest set back (SB) values were for starches recovered from ARZM 03056 and ARZM 16021, respectively (Tables IV and V, Fig. 2D). The SB values for pastes of starches recovered from the GEM accessions were 98–238 RVU vs. mean values of 159 and 221 RVU for the commercial Dent hybrids and the Corn Belt inbreds, respectively.

Gel Behaviors of GEM Starches

The lowest and highest one-day gel strengths were observed in starches recovered from Cuba 110 and BRA 052051 (SE 32), respectively (Tables IV and V, Fig. 3A). The one-day gel mean strengths

TABLE V
Comparison of Paste and Gel Behaviors[a] of Starches Recovered from GEM Accessions, Commercial Dent Hybrids, and Corn Belt Inbreds

	Paste						Gel Strength (g)	
Line	PV	HPV	CPV	PT	BD	SB	1 day	7 days
GEM accessions								
Maximum	249	136	281	79	113	238	21.0	66.2
Minimum	98	23	227	72	75	98	9.5	23.9
Mean	179	81	247	75	97	168	14.4	41.7
Commercial hybrids								
Pioneer 3394	183	97	235	73	86	138	12.9	23.5
Pioneer 3489	140	61	240	74	79	179	13.4	26.2
Common inbreds								
B73	101	17	277	80	84	260	10.0	17.0
Mo17	120	32	214	78	88	182	9.2	23.3

[a] PV = peak viscosity, HPV = hot paste viscosity, CPV = cold paste viscosity, BD = breakdown (PV – HPV), SB = setback (CPV –HPV), all measured in Rapid Visco Analyser units (RVU). PT = pasting temperature (°C). Gel strengths after 1 and 7 days of storage at 4°C.

TABLE VI
Correlation Coefficients Between Thermal Properties and Paste and Gel Behaviors of Starches Recovered from 49 GEM Accessions Thermal Paste Gel Strength[a]

	Paste						Gel Strength (g)	
Thermal Properties	PV	HPV	CPV	PT	BD	SB	1 day	7 days
Gelatinization								
T_o	0.41***[b]	0.4***	–0.01	–0.25**	–0.36***	–0.39***	0.17	0.4***
T_p	0.24**	0.26**	0.09	–0.05	–0.36***	–0.23**	0.24**	0.4***
ΔH	0.26**	0.26**	–0.17*	–0.16	–0.19*	–0.29***	–0.12	0.1
PHI	0.25**	0.22*	0.01	–0.21*	–0.01	–0.22*	–0.09	0.1
Retrogradation								
T_o	–0.22*	0.20*	0.04	–0.22*	–0.08	–0.18*	0.15	0.1
T_p	0.22**	0.23*	–0.01	–0.23**	–0.15	–0.22*	0.15	0.2*
ΔH	0.08	0.03	–0.13	0.07	0.02	–0.09	–0.08	0.1
% Retro	–0.05	–0.10	–0.04	0.16	0.12	0.06	–0.021	0.1

[a] Thermal properties: T_o = onset temperature (°C), T_p = peak temperature (°C), ΔH = change in enthalpy (J/g), PHI = peak height index (J/g × °C), % Retro = % retrogradation. Paste and gel behaviors: PV = peak viscosity, HPV = hot paste viscosity, CPV = cold paste viscosity, BD = breakdown (PV – HPV), SB = setback (CPV –HPV), all measured in Rapid Visco Analyser units (RVU). PT = pasting temperature (°C). Gel strengths after 1 and 7 days of storage at 4°C.
[b] *,**,*** = Significant at $P < 0.05$, 0.01, and 0.001, respectively.

of starches recovered from the GEM accessions were 9.5–21.0 g vs. means of 13.2 and 9.6 g, for the commercial Dent hybrids and the Corn Belt inbreds, respectively.

The lowest and highest seven-day gel strengths were observed in starches recovered from URZM 13061 and FS8A(T), respectively (Tables IV and V, Fig. 3B). The seven-day gel mean strengths were 23.9–66.2 g vs. means of 24.9 and 20.2 g for the commercial Dent hybrids and the Corn Belt inbreds, respectively. Larger values of gel strengths could be due to larger proportions of long chain amylopectin and amylose.

Single Factor Correlation

Correlating thermal properties and paste and gel behaviors may be useful in reducing the number of tests needed to screen germplasm for starches with unique functional properties. Table VI shows correlation coefficients between the thermal properties and paste and gel behaviors of the starches from the 49 GEM accessions. PV and HPV were positively correlated with T_o, T_p, and ΔH for gelatinization, retrogradation T_p, and PHI. Retrogradation T_o was negatively correlated with PV but positively correlated with HPV. CPV was negatively correlated with ΔH for gelatinization. PT was negatively correlated with gelatinization T_o, PHI, and retrogradation T_o and T_p.

One might expect PT and gelatinization T_p to be strongly and positively correlated. However, gelatinization of starch is affected by the size of the granule, whereas the development of viscosity is largely due to the amylose and lipid contents present in the starch. Since the basic mechanism and constituents involved in the two events are different, their peak temperatures are also independent of each other. However, PT is always greater than peak gelatinization temperature. Gel strength after one day of storage was positively correlated with gelatinization T_p. Gel strength after seven days of storage was strongly and positively correlated with gelatinization T_o and T_p, and weakly and positively correlated with retrogradation T_p.

The correlations, however, were not sufficiently high to suggest that any of the tests can be eliminated when screening large numbers of starches. All tests provide relevant and useful information.

CONCLUSIONS

Most starches isolated from the GEM accessions possessed thermal properties and paste and gel behaviors statistically different ($P < 0.05$) from commercial hybrids and common Corn Belt hybrids. In general, the values for gelatinization T_o and PHI for starches were greater, but ΔH of gelatinization values were less for the GEM starches (particularly BRA 052051 (SE 32)) recovered from the accessions than for the starches recovered from commercial Dent corn hybrids (11.3 vs. 13.6 J/g). Generally, retrogradation properties were similar among accessions, although there were specific accessions (particularly ARZM 13035) that possessed modestly lower ΔH of retrogradation (4.45 vs. 6.00 J/g). PV, CPV, and BD values were greater for the starches of the GEM accessions (particularly ARZM 01150, Antiqua 3, and URZM 01089, respectively) than for the starches of the commercial hybrids. PT values were about the same for all starches. Both one-day and seven-day gel strengths were considerably greater for the starches recovered from the GEM accessions (particularly BRA 052051 (SE 32), 21.0 g after one day and FS8A(T), 66.2 g after seven days).

Many of these differences starch properties were probably too small to be of practical significance to starch users. However, recurrent selection using selected GEM accessions may lead to hybrids possessing unique and possibly valuable properties. Those identified as having extreme values may be useful in recurrent selection efforts to produce corn with unique starches (BRA 052051 (SE 32), ARZM 13035, ARZM 01150, URZM 01089, FS8A(T), and Antiqua 3). The gel strengths of the starches isolated from the GEM accessions were considerably greater and may have practical implications. The large genetic variation among the thermal properties and paste and gel behaviors of starches recovered from the GEM accessions may be useful in developing hybrids with novel starches. While a number of thermal properties were correlated at low rejection levels with paste and gel behaviors, the correlations were not such that paste and gel behaviors could be predicted from DSC thermal properties.

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