

5-2001

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

S.K. Singh

Iowa State University

L. A. Jonhson

Iowa State University

Pamela J. White

Iowa State University, pjwhite@iastate.edu

Jay-Lin Jane

Iowa State University, jjane@iastate.edu

Linda M. Pollak

Follow this and additional works at: http://lib.dr.iastate.edu/fshn_ag_pubs

United States Department of Agriculture

 Part of the [Food Biotechnology Commons](#), [Food Processing Commons](#), and the [Human and Clinical Nutrition Commons](#)

The complete bibliographic information for this item can be found at http://lib.dr.iastate.edu/fshn_ag_pubs/134. For information on how to cite this item, please visit <http://lib.dr.iastate.edu/howtocite.html>.

This Article is brought to you for free and open access by the Food Science and Human Nutrition at Iowa State University Digital Repository. It has been accepted for inclusion in Food Science and Human Nutrition Publications by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.

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

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

Food Biotechnology | Food Processing | Food Science | Human and Clinical Nutrition

Comments

This article is from *Cereal Chemistry*, 2001, 78(3); 315-321. DOI: <http://dx.doi.org/10.1094/CCHEM.2001.78.3.315>.

Rights

Works produced by employees of the U.S. Government as part of their official duties are not copyrighted within the U.S. The content of this document is not copyrighted.

Thermal Properties and Paste and Gel Behaviors of Starches Recovered from Accessions Used in the Germplasm Enhancement of Maize Project¹

S. K. Singh,² L. A. Johnson,³ P. J. White,⁴ J.-L. Jane,⁴ and L. M. Pollak⁵

ABSTRACT

Cereal Chem. 78(3):315–321

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 per-

centage 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.

¹ Journal paper 18969 of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA. Research project 0178 supported by the Center for Crops Utilization Research, the Iowa Agriculture and Home Economics Experiment Station, and the U.S. Department of Agriculture.

² Graduate research assistant, Department of Food Science and Human Nutrition, Iowa State University, Ames, IA 50011.

³ Professor, Department of Food Science and Human Nutrition, and Director, Center for Crops Utilization Research, Iowa State University, Ames, IA 50011. Corresponding author. E-mail: ljohnson@iastate.edu

⁴ Professor, Department of Food Science and Human Nutrition, Iowa State University, Ames, IA 50011.

⁵ Research geneticist, USDA/ARS, Corn Insects and Crop Genetics Research Unit, Department of Agronomy, Iowa State University, Ames, IA 50011.

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 ThermoLine 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 Semiflnt | 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 Semiflnt | 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) (Krueger 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 gen-

erally 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.

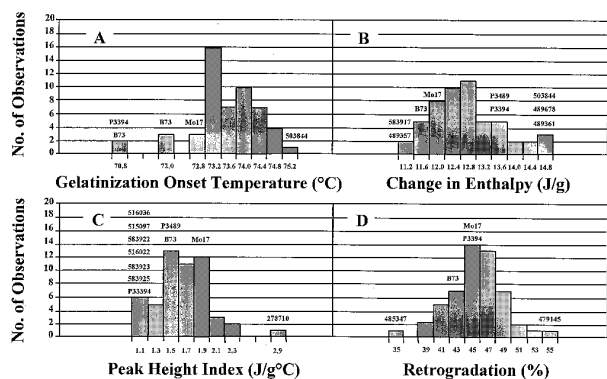


Fig. 1. Frequency distributions of thermal properties of starches from Germplasm Enhancement of Maize (GEM) project accessions. **A**, Gelatinization onset temperature; **B**, change in enthalpy of gelatinization; **C**, peak height index; **D**, % of retrogradation. Numbers on the x-axes are center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

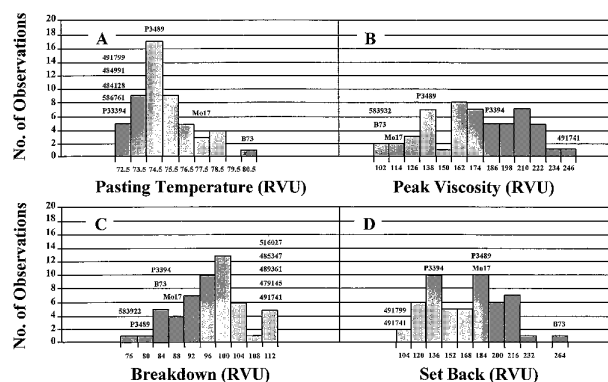


Fig. 2. Frequency distributions of paste behaviors of starches from Germplasm Enhancement of Maize (GEM) project accessions. **A**, Pasting temperature; **B**, peak viscosity; **C**, breakdown; **D**, setback. Numbers on the x-axes are center points for the column.

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

| Line | Gelatinization | | | | Retrogradation | | | |
|--------------------|----------------|-------|------------|------|----------------|-------|------------|---------|
| | 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). ΔH 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 ΔH for retrogradation to ΔH 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 retrogradation 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 |
| Guadalupe 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.

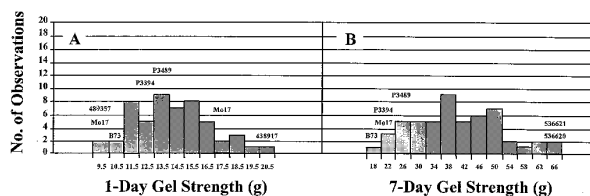


Fig. 3. Frequency distributions of gel behaviors of starches from Germplasm Enhancement of Maize (GEM) project accessions. **A**, 1-day gel strength; **B**, 7-day gel strength. Numbers on the x-axes are center points for the column.

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

| Line | Paste | | | | | | Gel Strength (g) | |
|--------------------|-------|-----|-----|----|-----|-----|------------------|--------|
| | 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

| Thermal Properties | Paste | | | | | | Gel Strength (g) | |
|--------------------|----------------------|--------|--------|---------|----------|----------|------------------|--------|
| | 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_0 , T_p , and ΔH for gelatinization, retrogradation T_p , and PHI. Retrogradation T_0 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_0 , PHI, and retrogradation T_0 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_0 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_0 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 acces-

sions 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.

LITERATURE CITED

- Brown, W. L. 1975. A broader germplasm base in corn and sorghum. *Annu. Corn Sorghum Res. Conf. Proc.* 30:81-89.
- Campbell, M. R., White, P. J., and Pollak, L. M. 1994. Dosage effect at the sugary-2 locus on maize starch structure and function. *Cereal Chem.* 71:464-469.
- Campbell, M. R., Pollak, L. M., and White, P. J. 1995. Genetic variation for starch thermal and functional properties among nonmutant maize inbreds. *Cereal Chem.* 72:281-286.
- Crossa, J., and Gardner, C. O. 1987. Introgression of an exotic germplasm for improving an adapted maize population. *Crop Sci.* 27:187-190.
- Eckhoff, S. R., Singh, S. K., Zehr, B. E., Rausch, K. D., Fox, E. J., Mistry, A. K., Haken, A. E., Niu, Y. X., Zou, S. H., Buriak, P., Tumbelson, M. E., and Keeling, P. L. 1996. A 100-g laboratory corn wet milling procedure. *Cereal Chem.* 73:54-57.
- Geadelmann, E. E. 1984. Using exotic germplasm to improve northern corn. *Annu. Corn Sorghum Res. Conf. Proc.* 39:98-110.
- Hallauer, A. R. 1978. Potential of exotic germplasm for maize improvement. Pages 229-27 in: *International Maize Symposium*. W. L. Walden, ed. McGraw-Hill: New York.
- Jane, J., Chen, Y. Y., Lee, L. F., McPherson, A., Wong, K. S., Radosavljevic, M., and Kasemsuwan, T. 1999. Effect of amylopectin branch chain length and amylose content on the gelatinization and pasting properties of starch. *Cereal Chem.* 76:629-637.
- Kasemsuwan, T., Jane, J., Schnable, P., Stinard, P., and Robertson, D. 1995. Characterization of the dominant mutant amylose-extender (*Ae1-5180*) maize. *Cereal Chem.* 75:457-464.
- Krueger, B. R., Knutson, C. A., Inglett, G. E., and Walker, C. E. 1987. A differential scanning calorimetry study on the effect of annealing on gelatinization behavior of corn starch. *J. Food. Sci.* 52:715-718.
- Li, J., Berke, T. G., and Glover, D. V. 1994. Variation for thermal properties of starch in tropical maize germplasm. *Cereal Chem.* 71:87-90.
- McPherson, A., and Jane, J. 1999. Comparison of waxy potato with other root and tuber starches. *Carbohydr. Polym.* 40:57-70.
- National Academy of Sciences. 1972. Genetic vulnerability of major crops. In: *Report of Committee on Genetic Vulnerability of Major Crops*. Agric. Board, Div. Biol. Agric., NAS-NRC, Washington, DC.
- Pollak, L., and Salhuana, W. 1998. Lines for improved yields and value-added traits—Results from GEM. *Ann. Corn Sorghum Res. Conf.* 53:143-158.
- Pollak, L. M., and White, P. J. 1997. Thermal starch properties in Corn Belt and exotic corn inbred lines and their crosses. *Cereal Chem.* 74:412-416.
- Salhuana, W., Pollak, L., Ferrer, M., Paratori, O., and Vivo, G. 1998. Agronomic evaluation of maize accessions from Argentina, Chile, the United States, and Uruguay. *Crop Sci.* 38:866-872.
- Singh, S. K., Johnson, L. A., Pollak, L. M., Fox, S. R., and Bailey, T. B. 1997. Comparison of laboratory and pilot-plant corn wet-milling procedures. *Cereal Chem.* 74:40-48.
- Singh, S. K., Johnson, L. A., Pollak, L. M., and Hurburgh, C. R., Jr. 2001. Compositional, physical, and wet-milling properties of accessions used in Germplasm Enhancement of Maize project. *Cereal Chem.* 330-335.
- Wang, Y. -J., White, P. J., and Pollak, L. M. 1992. Thermal and gelling properties of mutant maize from the Oh43 inbred line. *Cereal Chem.* 69:328-334.
- Wang, Y. -J., White, P. J., and Pollak, L. M. 1993. Physicochemical properties of starches from mutant genotypes of Oh43 inbred line. *Cereal Chem.* 70:199-203.
- White, P. J., Abbas, I. R., Pollak, L. M., and Johnson, L. A. 1990. Intra- and inter-population variability of thermal properties of maize starch. *Cereal Chem.* 67:70-73.
- Zeng, M., Morris, C. F., Batey, I. L., and Wrigley, C. W. 1997. Sources of variation for starch gelatinization, pasting, and gelation properties of wheat. *Cereal Chem.* 74:63-71.