Compositional, Physical, and Wet-Milling Properties of Accessions Used in Germplasm Enhancement of Maize Project[1]

S. K. Singh,[2] L. A. Johnson,[2,3] L. M. Pollak,[4] and C. R. Hurburgh[5]

ABSTRACT

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Forty-nine accessions used in the Germplasm Enhancement of Maize (GEM) project, two commercial hybrids (Pioneer Brand Hybrids 3394 and 3489), and two Corn Belt inbreds (B73 and Mo17) were evaluated for compositional, physical, and wet-milling properties. GEM accessions had lower starch contents (65.9–69.1% vs. a mean of 72.2% for the commercial hybrids) and greater protein contents (12.0–14.4% vs. a mean of 8.2% for the commercial hybrids) than did the improved Corn Belt material. Absolute densities were consistently higher for the GEM accessions compared with the commercial hybrids (1.320 vs. 1.265 g/cm^3, respectively). The wet-milling characteristics of the GEM accessions were not nearly as good as for the commercial hybrids. Mean starch yields were only 54.3% for the GEM accessions versus 64.8% for the commercial hybrids. Residual protein levels in the starches recovered from the GEM accessions were much greater (0.45–2.03%) than for commercial corn hybrids (<0.3%).

Processing continues to consume increasing amounts of corn. Use of corn to produce starch, sweeteners, ethanol, and other fermentation products consumes more than 17% of the yearly production, most of which involves wet milling. Corn hybrids with improved wet-milling characteristics and unique starch properties are of interest to seed companies, corn processors, and end users of starch and other wet-milled corn products. High-yielding hybrids with higher contents of starch, protein, or oil in the kernel have been developed but little has been done to improve the millability of corn, proximate compositions of the recovered fractions, and the physical properties of corn that are important to grain processing.

High-yielding U.S. corn hybrids with improved agronomic traits have been developed by using adapted germplasm, but seldom have elite inbreds been crossed with exotic corn germplasm to develop new, useful breeding lines. The Germplasm Enhancement of Maize Project (GEM) is a unique cooperation of 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). GEM is the successor to the Latin American Maize Project (LAMP) (Salhuana et al 1998), which was launched in 1987 by the United States Department of Agriculture Agriculture Research Services (USDA-ARS) and 11 Latin American countries with funding from Pioneer Hi-Bred International (Johnston, IA). The principle goal of LAMP was to evaluate and maintain the irreplaceable corn germplasm bank of 12 Latin American countries and the United States.

LAMP evaluated 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, of which 51 were chosen to initiate GEM. Fox et al (1992) and Zehr et al (1995) have shown considerable variation in compositional, physical, and wet-milling properties in yellow dent hybrids and inbreds. Thus, we anticipated greater variation among the GEM accessions because of the diverse genetic background. The objective of the present study was to screen 49 GEM or future GEM accessions of U.S. and Latin American origin for compositional, physical, and wet-milling properties to identify accessions with unique properties that might be used to develop new lines with value-added traits.

MATERIALS AND METHODS

Grain Preparation

Forty-five Latin American and U.S. accessions from GEM were evaluated in this experiment (Table I). Of the 51 original GEM accessions, six were not included in this study because of insufficient seed supply. Substitutions were made with four accessions from the top 5% of 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 GEM accessions (North Central Regional Plant Introduction Station, Ames, IA), two commercial yellow dent corn hybrids (3394 and 3489 from Pioneer Hi-Bred International, Johnston, IA), and two public Corn Belt inbreds, B73 and Mo17 (Department of Agronomy, Iowa State University, Ames), were dried to <15% moisture by circulating ambient air (20–22°C). The corn was cleaned by passing the grain through a 6.3-mm round-hole U.S. standard sieve and removing by hand any remaining foreign material and broken kernels. Triplicate sample sets were prepared, placed into polyethylene bags, and stored at 4°C until used.

Compositional Properties

Moisture contents of the corn were determined by using Approved Method 44-15A (AACC 2000). Starch, protein, and crude free fat contents (dry basis) were estimated in triplicate by using a grain analyzer (Infratec model 1225), a near-infrared transmittance analyzer (Tecator, Hoganas, Sweden). The grain analyzer calibration process is described in Rippke et al (1996). A running database of corn spectra on U.S. and international samples has been updated yearly, beginning in 1986. All known types of flint and dent corn are included in this database. Calibrations were validated annually and updated as needed based on validation results. Wet-chemistry references were provided by Woodson Tenant Labs (Des Moines, IA) for protein, oil, and starch; and by the Iowa State University Grain Quality Laboratory for moisture and density. The reference methods were Kjeldahl (protein), ether extraction (oil), glucose hydrolysis (starch), air oven (moisture), and nitrogen pycnometer (density). Specific methods are described in Rippke et al (1996).

Physical Properties

Kernel absolute density was determined by using a pycnometer (AccuPyc 1330, Micrometrics, Norcross, GA). Test weight was determined by using Federal Grain Inspection Services (FGIS 1988)

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

[3] Corresponding author. E-mail: ljohnson@iastate.edu Phone: 515-294-0160.

[4] Research Geneticist, USDA-ARS, Corn Insects and Crop Genetics Research Unit, Department of Agronomy, Iowa State University, Ames, IA 50011.

[5] Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011.

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standard methods. The 1,000-kernel weight was determined by using an electronic counter (Syntron, Homer City, PA) to count kernels and by weighing on an analytical balance. Values were determined in triplicate and adjusted to 15% moisture basis by using adjustment equations for moisture reported by Dorsey-Redding et al (1990).

Wet-Milling Properties

Corn was wet milled in triplicate by using a 100-g laboratory-scale wet-milling procedure originally developed by Eckhoff et al (1996) and modified by Singh et al (1997). Moisture contents of wet-milled fractions were determined according to AOAC method 14.004 (AOAC 1984). Protein contents of the wet-milled fractions were determined in duplicate according to the Corn Refiners' Association (CRA) macro-Kjeldahl method A-18 (CRA 1986). Because of the limited amount of each fraction available when using the modified 100-g procedure, only the starch and gluten fractions were analyzed for protein contents.

Statistical Analysis

Unpaired parametric, multiple comparison tests (SAS Institute, Cary, NC) were used to determine least significant differences (LSD) at $P < 0.05$, 0.01, and 0.001 levels. SAS procedure CORR was used to determine correlations.

RESULTS AND DISCUSSION

Compositional, physical, and wet-milling properties of the GEM accessions varied greatly (Tables II and III). In addition to tables, the properties of the GEM accessions were compared with two commercial dent hybrids and two Corn Belt inbreds in the form of frequency distribution histograms (Figs. 1 and 2), where the x-axis represents the range of values observed for the property and the y-axis represents the number of observations for a given range of values. The height of the column represents the number of accessions falling within the specified range (column width).

Compositional Properties

Generally, the GEM accessions contained less starch in the grain than either of the two commercial hybrids or the two Corn Belt inbreds. The starch contents of the GEM accessions ranged from 65.9 to 69.1% (db) versus 71.1 to 73.3% for the two commercial dent hybrids and 68.0 to 69.7% for the two Corn Belt inbreds

TABLE I
Descriptions of 49 Germplasm Enhancement of Maize Project Accessions

Accession	PI	Race	Kernel Color/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 Republic 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 Republic 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	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 Virgin Islands 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 Virgin Islands 103	586761	Criollo	Yellow Semiflint	Tropical	Virgin Islands (British)

(Fig. 1A). The highest and lowest starch contents among the GEM accessions were observed in Golden Queen and Cuba 110, respectively. Zehr et al (1995) observed that starch yields during wet milling increased as starch contents increased, whereas Fox et al (1992) did not observe high correlation between starch yield and starch content, and concluded that the composition of the protein present must also affect wet-milling properties.

The GEM accessions had considerably greater grain protein contents; the mean value was 13.0% (db) for GEM versus 8.15% for the two commercial dent hybrids (Fig. 1B). High-protein content (especially that due to increased endosperm protein) generally leads to poor wet-milling properties (Fox et al 1992). The lowest and highest protein contents among the accessions were 12.0% for Piura 196 (from Peru) and 14.4% for Cuba 110, respectively. Cuba 110 also had the lowest starch and greatest fat contents (65.9 and 6.2%, respectively). Pioneer 3489 and B73 had relatively low protein contents, but Mo17 had relatively high protein content, which inbreds often have (probably due to small seed size).

The GEM accessions generally had greater fat contents than did the commercial dent hybrids and the Corn Belt inbreds; the mean was 5.2% versus 3.85 and 4.05% for the two commercial dent hybrids and the two Corn Belt inbreds, respectively (Fig. 1C). Piura 196 had the lowest and Cuba 110 the highest fat contents (3.9 and 6.5%, respectively). Pioneer 3394 had low and Pioneer 3489, B73, and Mo17 had moderately low fat contents.

Physical Properties

The 1,000-kernel weights of the GEM accessions varied widely (240–399 g), but the mean for the GEM accessions was lower than for the commercial dent hybrids. Thus, fiber yields in wet milling should be greater and yields of starch and gluten should be less for the mean of the GEM accessions because GEM kernels have greater ratios of surface area to mass. Test weights of the GEM accessions varied from 52.4 to 68.2 lb/bu but, on average, were nearly equivalent to the two commercial dent hybrids. Mo17 had lower test weight (60.9 lb/bu) and 1,000-kernel weight (205.1 g).

The absolute densities of the GEM accessions were considerably greater than for either the commercial dent hybrids or the Corn Belt inbreds, averaging 1.32 g/cm^3 for the GEM accessions versus 1.27 and 1.29 g/cm^3 for the two commercial dent hybrids and the two

TABLE II
Compositional, Physical, and Wet-Milling Properties of GEM Accessions[a]

Accession	Compositional (%db)			Physical			Wet-Milling (%db)[b]						
	Str	Pro	Fat	TWt	KWt	ADen	StrY	PiS	SRec	Glu	PiG	Germ	Fib
Cash	68.1	12.4	4.7	60.2	309.4	1.26	52.7	1.08	77.3	15.4	39.3	5.9	16.0
Golden Queen	69.1	12.4	4.0	63.1	329.8	1.28	58.6	0.83	84.7	12.9	45.1	5.8	12.4
Big White	69.0	12.2	4.8	60.3	310.4	1.30	58.8	0.69	85.2	14.7	38.4	3.7	12.7
CHZM 04030	68.4	12.5	4.8	64.2	248.1	1.35	51.6	1.02	75.4	19.4	38.1	4.7	13.5
CHZM 05015	66.7	13.3	5.4	64.4	309.2	1.34	48.9	1.65	73.3	20.1	34.1	5.3	15.7
URZM 01089	66.7	13.6	5.5	66.0	297.5	1.35	55.5	1.27	83.3	16.3	43.4	4.1	13.3
Cuba 117	67.6	13.5	5.4	66.8	261.3	1.36	52.2	1.29	77.3	19.5	36.7	4.3	13.6
Dominican Rep. 150	68.4	12.6	4.4	66.3	276.1	1.35	56.0	1.26	81.9	12.9	43.2	4.1	16.6
St. Croix 1	68.6	12.9	5.0	64.1	362.0	1.33	50.8	0.97	75.2	15.1	37.5	4.8	19.3
Antigua 3	67.8	12.7	5.3	66.5	330.5	1.35	53.1	0.97	78.4	13.9	43.8	4.3	16.9
Lima 13	66.7	13.8	5.5	52.3	305.4	1.33	53.7	1.01	80.5	14.9	41.8	3.1	17.0
Cuba 110	65.9	14.4	6.2	66.4	241.9	1.37	47.8	1.72	72.5	19.6	35.9	4.2	17.3
Cuba 164	68.6	12.5	4.9	65.6	271.8	1.34	55.5	0.81	80.6	16.0	40.1	3.8	14.7
Dom. Rep. 269	67.9	13.5	4.7	65.8	271.9	1.34	48.4	1.49	71.3	15.9	38.2	6.0	17.5
ARZM 01150	68.9	12.6	4.5	55.7	261.5	1.26	58.4	0.47	84.7	11.2	45.6	9.6	12.0
ARZM 03056	68.3	12.7	5.0	57.9	302.8	1.28	57.1	0.45	83.6	12.5	45.0	6.7	13.4
ARZM 13026	68.3	12.2	4.9	63.0	334.8	1.34	51.0	1.15	74.7	18.6	40.5	4.7	13.0
ARZM 13035	66.2	13.8	5.5	64.2	303.9	1.35	51.5	1.17	77.9	19.1	43.3	5.7	13.9
ARZM 17026	67.3	13.2	5.2	63.4	306.2	1.33	54.3	1.06	80.7	15.8	46.6	5.2	12.8
ARZM 17056	67.8	13.1	4.5	60.2	279.5	1.33	53.0	1.07	78.2	17.2	43.1	5.3	14.5
Guadelupe 5	67.4	13.2	4.6	67.9	295.2	1.36	49.8	1.50	73.9	15.1	42.4	6.3	18.2
Guatemala 209	66.9	13.7	5.9	67.6	312.1	1.36	50.7	1.14	75.7	17.3	41.7	5.2	15.2
Lambayeque 46	68.3	12.6	5.0	57.3	350.8	1.25	58.9	0.88	86.3	14.2	45.6	5.3	11.8
Piura 196	66.6	12.0	3.9	56.9	291.5	1.17	61.9	0.57	92.9	12.9	51.0	3.4	10.6
Barbados Group 2	68.0	13.0	4.8	64.3	382.7	1.32	56.9	1.07	83.7	14.3	47.1	5.5	13.1
Puerto Rica Group 3	67.4	12.1	4.6	62.3	397.9	1.32	56.0	0.72	83.1	13.7	47.1	5.1	15.2
St. Croix Group 3	67.9	12.7	5.0	64.1	350.4	1.33	53.2	0.84	78.4	14.9	42.7	5.9	15.9
San Martin 116	67.6	13.7	5.0	58.7	254.4	1.31	56.1	1.02	83.0	15.5	43.6	4.1	13.2
ARZM 16021	67.1	13.5	5.3	65.4	283.3	1.34	49.8	1.32	74.2	17.5	37.8	5.1	16.1
ARZM 16026	68.2	12.9	4.9	66.1	304.4	1.32	54.7	0.89	80.3	16.5	41.5	5.2	12.8
ARZM 16035	67.2	13.7	5.4	66.2	250.3	1.35	53.8	1.31	80.1	15.5	41.2	4.7	15.2
FS8A(S)	68.3	12.6	5.8	64.7	301.3	1.33	55.0	0.78	80.5	15.9	36.8	4.9	13.8
FS8A(T)	68.6	12.5	5.6	64.2	360.1	1.32	56.9	1.16	83.0	14.9	36.9	4.2	13.5
FS8B(S)	68.3	12.8	5.5	65.2	326.8	1.35	54.8	1.24	80.2	13.4	40.8	5.9	15.1
FS8B(T)	68.0	12.5	5.6	65.7	339.0	1.33	55.6	0.70	81.8	13.7	46.0	4.9	15.2
Pasco 14	66.3	13.6	5.7	68.2	326.6	1.36	51.7	0.91	78.0	15.4	42.5	4.2	16.9
Chiapas 462	67.5	13.5	5.2	63.4	392.6	1.32	54.7	1.12	79.8	11.8	47.4	6.0	14.9
British VI 155	68.1	12.7	4.9	64.8	380.6	1.33	57.2	1.09	84.1	15.6	40.5	4.0	12.4
BRA 051403 (PE 01)	67.6	13.4	5.5	65.9	321.7	1.34	55.5	2.03	82.0	14.8	44.3	5.1	13.2
BRA 051501 (PE 011)	66.7	13.1	5.3	64.8	399.4	1.33	55.3	1.21	82.9	13.6	46.3	5.5	14.8
BRA 052051 (SE 32)	67.1	13.3	5.7	65.5	334.6	1.33	52.7	1.32	78.5	15.3	41.6	4.9	15.3
URZM 13061	67.1	13.6	5.4	62.4	239.7	1.35	50.1	1.17	74.7	13.4	43.1	4.4	16.8
URZM 13010	67.6	12.7	5.5	58.4	282.2	1.28	57.1	0.58	84.5	12.9	48.0	6.3	13.3
URZM 13088	67.8	13.1	5.1	64.9	282.9	1.34	52.4	0.70	77.2	15.6	42.9	3.7	15.8
URZM 13085	67.4	13.3	5.0	66.0	298.7	1.35	54.8	1.36	81.3	15.4	47.7	3.4	15.6
URZM 05071	67.3	13.6	5.3	63.8	295.4	1.34	53.2	0.83	79.0	19.9	29.3	3.3	16.0
URZM 11002	67.6	12.4	5.7	59.1	272.6	1.29	57.1	0.81	84.5	11.4	49.9	5.6	14.1
URZM 10001	67.6	12.9	5.6	58.5	288.3	1.28	57.5	0.70	85.0	11.6	51.9	6.6	12.8
British VI 103	68.3	12.5	5.3	65.3	288.1	1.35	55.8	0.93	81.7	16.3	38.0	3.9	12.9
LSD[c]	0.25	0.01	0.7	0.4	18.9	0.003	2.5	0.45	3.1	1.9	2.6	0.8	1.2

[a] Str = starch content, Pro = protein content, Fat = crude free fat content, TWt = test weight (lb/bu), KWt = thousand-kernel weight (g), ADen = absolute density (g/cm^3), StrY = starch yield, PiS = protein in starch, SRec = starch recovery, Glu = gluten, PiG = protein in gluten, Germ = germ yield, and Fib = fiber yield.

[b] Indicated as %db, except SRec, %.

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

Corn Belt inbreds, respectively (Fig. 1D). The lowest (1.17 g/cm^3) and greatest (1.37 g/cm^3) absolute densities were observed in Piura 196 and Cuba 110, respectively. Increased absolute density may adversely affect wet-milling properties (Zehr et al 1995) unless protein content is also decreased (Fox et al 1992). This combination of traits was not observed in the GEM accessions. Absolute densities of Pioneer 3394 and 3489 were within the lower 20%. B73 and Mo17 had greater absolute densities than did the commercial dent hybrids.

Wet-Milling Properties

The GEM accessions did not wet mill nearly as well as did the commercial dent hybrids (Table III, Fig. 2A). Starch yields averaged only 54.3% for the GEM accessions versus 64.9% for the two commercial dent hybrids and 60.2% for the two Corn Belt inbreds, which may be due to higher grain protein contents, kernel densities, and residual starch contents in fiber. Starch yield was greatest for Pioneer 3394, followed by Pioneer 3489 and B73. Mo17 yielded significantly less starch (58.1%) than did the two commercial dent hybrids or B73. The highest and lowest starch yields among the GEM accessions were achieved by Piura 196 (61.9%) and Cuba 110 (47.8%), respectively.

Starch recovery, which is the percentage ratio of starch yield divided by starch content, was greatest for Piura 196, followed by Pioneer 3394, B73, and Pioneer 3489 (Fig. 2B). Mo17 did not compare well with B73 and the commercial dent hybrids. Piura 196 yielded the highest amount of starch among the GEM accessions,

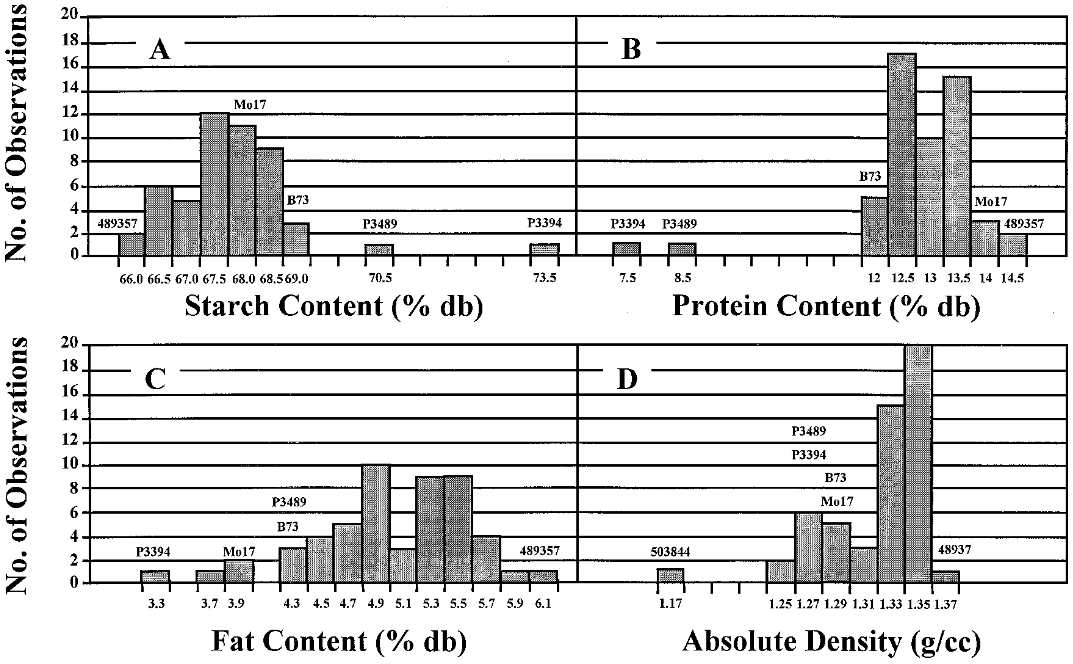

Fig. 1. Frequency distributions of compositional and physical properties of Germplasm Enhancement of Maize project accessions. **A,** starch content; **B,** protein content; **C,** fat content, **D,** absolute density. Numbers on the x-axis are center points for column.

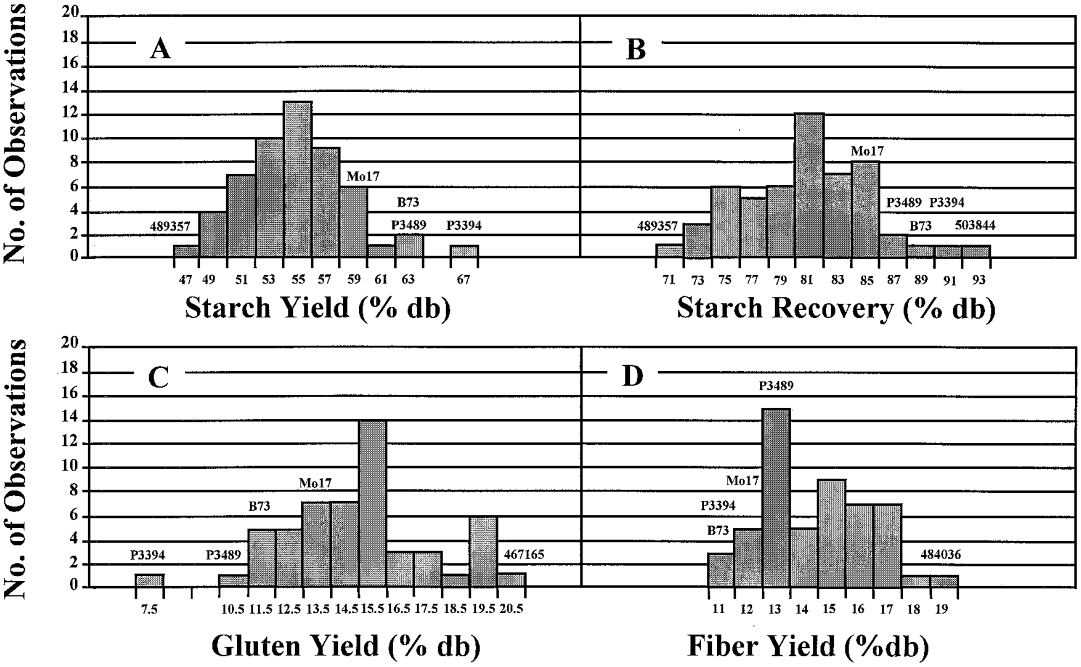

Fig. 2. Frequency distributions of wet-milling properties of Germplasm Enhancement of Maize project accessions. **A,** starch yield; **B,** starch recovery; **C,** gluten yield, **D,** fiber yield. Numbers on the x-axis are center points for column.

despite having relatively low starch content in the kernel. This accession had low absolute density and protein and fat contents that favor good wet milling. The lowest starch recovery was observed in Dominican Republic 269, which had relatively high protein content, low starch content, and high absolute density. The poor fiber-washing characteristics of Dominican Republic 269 resulted in lower starch and higher fiber yields. Protein contents of the starch were much greater than the usual acceptable limits (<0.3%) for all GEM accessions (averaging 1.05%), except for ARZM 01150 and ARZM 03056.

Gluten yields were much greater for the GEM accessions, averaging 14.9% versus 8.6 and 12.4% for the two commercial dent hybrids and the two Corn Belt inbreds, respectively. This was attributed to the high kernel protein contents and poor starch-gluten separation. The lowest gluten yield was achieved by Pioneer 3394, followed by Pioneer 3489, ARZM 01150, and B73 (Fig. 2C). Mo17 yielded moderately high amounts of gluten compared with the commercial dent hybrids and B73. Poor starch-gluten separation in Mo17 also resulted in reduced protein contents in gluten and increased protein contents in starch. Mo17 did not have good wet-milling properties, thus, its modern descendants may not be the best choices to use as inbred parents for producing hybrids destined to wet corn mills, unless the hybrid's other inbred parents have dominant genes for good wet-milling properties. We observed in poor wet-milling corn that the protein particles did not flow as discrete particles during the tabling of the millstarch, rather, they tended to flocculate and deposit on the surface of the starch bed.

Low protein content of the gluten fractions was observed in the GEM accessions, averaging 42.4% versus 44.5 and 49.7% for the two commercial dent hybrids and the two Corn Belt inbreds, respectively. Poor starch-gluten separation among the GEM accessions contributed to greater gluten yields with greater amounts of starch in gluten, resulting in low protein contents in the gluten.

Generally, fiber yields were much greater for the GEM accessions (Fig 2D), averaging 14.6% versus 11.7 and 11.9% for the two commercial dent hybrids and the two Corn Belt inbreds, respectively, which we attributed to poor fiber-washing characteristics and low 1,000-kernel weights (less volume to surface area, less endosperm to pericarp). The lowest fiber yield was observed for Piura 196, followed by Pioneer 3394, B73, Mo17, and Pioneer 3489, respectively. Poor fiber-washing characteristics of GEM accessions resulted in reduced starch yields and recoveries.

Despite having greater mean kernel oil contents, germ yields were lower for the GEM accessions, with a mean of 3.05% versus means of 4.6 and 5.9% for the two commercial dent hybrids and two Corn Belt inbreds, respectively. Despite previous comments about proportion of germs in GEM grain, this suggests that the GEM accessions do not have greater proportions of germ than is typical of Corn Belt dent corn.

Single Factor Correlation

Correlation coefficients between wet-milling properties and compositional and physical properties of the 49 GEM accessions are presented in Table IV. Starch yield and recovery were positively correlated with starch content and negatively correlated with protein content and absolute density. Zehr et al (1995) found similar correlations for 15 inbred lines. Based on 27 commercial dent hybrids, Fox et al (1992) could not find significant correlation of starch yield and starch recovery with starch content and absolute density, but did find a negative correlation of protein content with starch yield and recovery. Starch yields were also negatively correlated with fat content, 1,000-kernel weight, and test weight.

Residual protein content in starch was positively correlated with kernel protein content, fat content, and absolute density. Fox et al (1992) found similar correlations based on 27 commercial dent hybrids. The residual protein content of starch was negatively corre-

TABLE III
Comparison of Compositional, Physical, and Wet-Milling Properties of Germplasm Enhancement of Maize (GEM) Project Accessions, Commercial Dent Hybrids, and Corn Belt Inbreds[a]

Line	Compositional (%db)			Physical			Wet-Milling (%db)[b]						
	Str	Pro	Fat	TWt	KWt	ADen	StrY	PiS	SRec	Glu	PiG	Germ	Fib
GEM accessions													
Maximum	69.1	14.4	6.2	68.2	399.4	1.37	61.9	2.03	92.9	20.1	51.9	9.5	19.3
Minimum	65.9	12.0	3.9	52.4	239.7	1.17	47.8	0.45	71.3	11.2	29.3	3.1	10.6
Mean	67.7	13.0	5.2	63.4	308.5	1.32	54.3	1.05	80.1	14.9	42.4	5.0	14.6
Commercial hybrids													
Pioneer 3394	73.3	7.7	3.4	63.3	345.4	1.26	66.9	0.25	91.3	7.15	44.6	4.0	10.7
Pioneer 3489	71.1	8.6	4.3	63.2	357.4	1.27	62.6	0.29	88.0	10.1	44.4	5.2	12.7
Corn Belt inbreds													
B73	69.7	11.9	4.3	63.6	360.3	1.29	62.4	0.53	89.5	11.4	52.4	5.1	11.4
Mo17	68.0	14.1	3.8	60.9	205.1	1.29	58.1	1.45	85.4	13.4	47.0	6.8	12.5

[a] Str = starch content, Pro = protein content, Fat = crude free fat content, TWt = test weight (lb/bu), KWt = thousand-kernel weight (g), ADen = absolute density (g/cm^3), StrY = starch yield, PiS = protein in starch, SRec = starch recovery, Glu = gluten, PiG = protein in gluten, Germ = germ yield, and Fib = fiber yield.

[b] Indicated as %db, except SRec, %.

TABLE IV
Correlation Coefficients Between Compositional and Physical Factors and Yields of Wet-Milled Products Based on 49 Germplasm Enhancement of Maize Project Accessions[a]

Property	Compositional			Physical		
	Str	Pro	Fat	ADen	KnWt	TWt
Starch yield	0.424***	–0.547***	–0.328***	–0.657***	0.213**	–0.522***
Gluten yield	–0.312***	0.377***	0.181	0.507***	–0.239**	0.416***
Fiber yield	–0.253**	0.142	0.130	0.310***	–0.126	0.278***
Germ yield	0.114	–0.155	–0.068	–0.207*	–0.073	–0.266**
Steep liquor solids	–0.405***	0.452***	0.307***	0.612***	0.008	0.632***
Filtrate solids	0.177	–0.223**	–0.154	–0.606***	–0.213**	–0.683***
Starch recovery	0.251**	–0.456***	–0.265**	–0.657***	0.205*	–0.517***
Protein in starch	–0.282***	0.448***	0.250**	0.432***	0.008	0.431***
Protein in gluten	–0.046	–0.177	–0.146	–0.470***	0.174	–0.462***

[a] *, **, and *** denote significance at 0.05, 0.01, and 0.001 probability levels, respectively. Str = Starch content, Pro = protein content, Fat = crude free fat content, ADen = absolute density, KnWt = thousand-kernel weight, and TWt = test weight.

lated with starch content of the GEM accessions. Protein in starch was also correlated with test weight.

Gluten yields were positively correlated with protein content and negatively correlated with starch content. Similar results were observed by Zehr et al (1995), but Fox et al (1992) did not observe correlation between gluten yield and starch content. Gluten yield was also positively correlated with absolute density and test weight, and negatively correlated with 1,000-kernel weight.

CONCLUSIONS

The GEM accessions did not wet mill nearly as well as commercial dent hybrids, which we attributed to several compositional and physical factors. The GEM accessions had considerably lower starch contents (particularly PI 489357, Cuba 110) and greater protein (particularly PI 489357) and fat contents (particularly PI 489357) than did the commercial dent hybrids and the Corn Belt inbreds. The higher levels of protein and fat in the kernels of the GEM accessions indicated that they are energy-dense and may be good for animal feed.

Increased grain protein contents resulted in increased absolute densities (particularly PI 489357), which adversely affected wet-milling properties. On the other hand, the increased protein content and absolute density increase hardness and would likely improve dry-milling characteristics, because the quantity of flaking grits, the primary product of dry milling, is known to increase with harder corn. Absolute densities and test weights of the GEM accessions were correlated with most of the wet-milling yields and proximate factors. Lower absolute density corn showed improved millability, but it could result in poor grain handling properties (increased breakage susceptibility, increased angle of repose).

These data suggest that the best GEM accessions for wet milling are those with lower absolute densities and test weights, greater starch contents, and lower fat and protein contents. PI 489357 was particularly poor in wet milling while PI 503844, Piura 196, yielded almost as much starch (with almost twice as much residual protein, however) as Pioneer 3489. Poor starch-gluten separation of the GEM accessions resulted in greater protein content in starch and lower protein content in gluten. Greater fiber yields of GEM accessions may be due to poor fiber-washing characteristics, higher surface area to volume (low 1,000-kernel weight), or both.

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