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Thermal Starch Properties in Corn Belt and Exotic Corn Inbred Lines and Their Crosses

Linda M. Pollak
United States Department of Agriculture

Pamela J. White
Iowa State University, pjwhite@iastate.edu

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Abstract

More knowledge is needed about variability of starch functional traits in adapted and exotic germplasm and possible genetic effects of these traits before conducting rigorous inheritance studies and breeding programs for starch quality. We studied and compared the range of variability for starch functional traits in a set of Corn Belt inbred lines with a set of exotic inbred lines from Argentina, Uruguay, and South Africa. Reciprocal hybrids of some of the lines within each set were compared with their parents. Functional traits were examined by using differential scanning calorimetry on starch extracted from single kernels of genotypes. The set of Corn Belt lines had a wider range of values for most traits than did the set of exotic lines. For both sets of lines, the maximum value for peak height index was as high as that previously reported for the waxy endosperm mutant. Although the Corn Belt lines exhibited a wider range of values for range of retrogradation than the exotic lines, the exotic lines showed a wider range of values for percentage retrogradation. Hybrid values were not consistently higher, lower, midpoint, or similar with respect to the values of their parents. This was true regardless of germplasm type or functional trait. Reciprocal cross values showed trends suggesting reciprocal differences, although there was no trend suggesting greater effect of the female parent. These traits seem to be controlled by many modifying effects in addition to major effects. Results indicate that sufficient variability exists in Corn Belt germplasm to conduct breeding and inheritance studies effectively and that there should be potential for breeding for functional traits.

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Comments

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Thermal Starch Properties in Corn Belt and Exotic Corn Inbred Lines and Their Crosses[1]

LINDA M. POLLAK[2] and PAMELA J. WHITE[3]

ABSTRACT

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More knowledge is needed about variability of starch functional traits in adapted and exotic germplasm and possible genetic effects of these traits before conducting rigorous inheritance studies and breeding programs for starch quality. We studied and compared the range of variability for starch functional traits in a set of Corn Belt inbred lines with a set of exotic inbred lines from Argentina, Uruguay, and South Africa. Reciprocal hybrids of some of the lines within each set were compared with their parents. Functional traits were examined by using differential scanning calorimetry on starch extracted from single kernels of genotypes. The set of Corn Belt lines had a wider range of values for most traits than did the set of exotic lines. For both sets of lines, the maximum value for peak height index was as high as that previously reported for the waxy endosperm mutant. Although the Corn Belt lines exhibited a wider range of values for range of retrogradation than the exotic lines, the exotic lines showed a wider range of values for percentage retrogradation. Hybrid values were not consistently higher, lower, midpoint, or similar with respect to the values of their parents. This was true regardless of germplasm type or functional trait. Reciprocal cross values showed trends suggesting reciprocal differences, although there was no trend suggesting greater effect of the female parent. These traits seem to be controlled by many modifying effects in addition to major effects. Results indicate that sufficient variability exists in Corn Belt germplasm to conduct breeding and inheritance studies effectively and that there should be potential for breeding for functional traits.

Starch has many food and industrial uses, each of which often requires a specific functional property. The starch obtained from processing standard yellow dent corn is usually chemically modified to produce starch with a required functionality. Another approach would be to develop corn that naturally produces starches requiring less or even no chemical modification for its intended use. This approach might be especially valuable to the food industry because of the opportunities for the development of “all natural” convenience foods. Naturally modified starch in normal corn hybrids might possibly be beneficial to growers, if the large yield reduction that occurs with mutant corn is avoided.

Before corn with naturally modified starch can be developed, more knowledge is needed about how much natural variability exists in normal corn for functional starch properties and how genes control this variability. It is well known that mutant maize genes have large effects on starch development and properties (Creech 1965, Stevens and Elton 1971, Yeh et al 1981, Inouchi et al 1984, Brockett et al 1988, Wang et al 1992, Campbell et al 1994). Sanders et al (1990) showed that genetic background, other than major mutant genes, influenced thermal starch properties when comparing four corn (three sweet, one dent) inbred lines.

There is little information on the amount of variability for starch characteristics in normal corn and almost no information on its genetic control. The studies that have been done used differential scanning calorimetry (DSC) to study thermal properties associated with starch gelatinization. DSC monitors changes in the physical and chemical properties of starches, offering a thermodynamic approach to the study of starch gelatinization (Donovan et al 1983). Krueger et al (1987a) found that starch from different normal inbred lines had significant thermal property variations, especially for enthalpy. White et al (1990) studied intra- and interpopulation variability in thermal properties of starch from normal open-pollinated corn populations genetically variable for appearance and yield. They found significant differences among plants within the same population as well as among different populations; however, one exotic population they evaluated showed no statistical variation among plants. They suggested that there are structural differences in the starch granules that may be genetically controlled. Li et al (1994) studied starch thermal properties in several tropical and semitropical corn populations. They found wide variability in this exotic germplasm for starch properties. Campbell et al (1995) examined a set of nonmutant corn inbreds and suggested that DSC may find application in breeding programs for screening germplasm for extreme values or population improvement through recurrent selection.

It is important to determine whether the range and variability of starch thermal traits is greater in exotic germplasm than in Corn Belt germplasm. If a wider range of these traits is found in exotic germplasm, then it may be a useful source of unusual thermal starch properties. If sufficient variability is found in Corn Belt germplasm, however, the possibility of developing hybrids with unusual thermal characteristics would be much easier. Comparing the values of thermal characteristics of hybrids versus parent inbred lines can give indications on the ease of breeding for these traits. The objectives of this study were to: 1) examine the ranges in thermal starch traits found in a set of Corn Belt inbred lines and a set of exotic lines, and 2) examine the ranges in thermal starch traits in reciprocal hybrids of lines from each set with high and low values for certain thermal starch traits. These results were used to determine whether breeding studies for the starch traits should be conducted and whether Corn Belt germplasm could be used in conducting these studies.

MATERIALS AND METHODS

Materials

Nine Corn Belt and nine exotic lines were analyzed. The Corn Belt lines were chosen to represent a wide range of variability of Corn Belt germplasm based on their pedigrees (Table I). The exotic lines were obtained from the North Central Regional Plant Introduction Station’s collection. Seven lines were orange flints of the Cateto race developed in Argentina and Uruguay. Two lines of white dent endosperm from South Africa were included to provide

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[2] Research geneticist, USDA-ARS Corn Insects and Crop Genetics Research Unit, Dept. Agronomy, Iowa State University, Ames, IA 50011. Corresponding author. E-mail: lmpollak@iastate.edu

[3] Professor, Dept. Food Science and Human Nutrition, Iowa State University.

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diversity from the orange flints of the Cateto lines. The lines were grown and self-pollinated in the same environment in Iowa to reduce the effect of environment. Reciprocal crosses were attempted among the lines within a set in all combinations. All seeds were stored in a cold room at ≈4°C and 45% rh until analyzed.

Starch Isolation and DSC

Starch was isolated from the kernels of each line with the method described by White et al (1990). Two random kernels (replicates) from each Corn Belt line were sampled and analyzed by using two DSC runs per kernel. For exotic lines, three random kernels (replicates) were sampled and analyzed by using two DSC runs per kernel. Starch was extracted from two random kernels (replicates) of each cross and analyzed by using two DSC runs per kernel. Analysis included gelatinizing ≈3.5 mg of starch (dwb) in sealed aluminum pans with a 2:1 water-to-starch ratio in a Perkin-Elmer DSC-7 that had an attached data station (Perkin-Elmer Corp., Norwalk, CT). A scanning rate of 10°C/min with a temperature range of 30–120°C was used. Starch samples were rescanned after storing seven days at 40°C to determine amount of retrogradation. The gelatinization procedure is explained fully by White et al (1990) and the retrogradation procedure by White et al (1989). Values were computed automatically for temperature in °C for onset of gelatinization (T_oG) and retrogradation (T_oR), peak temperature in °C of gelatinization (T_pG), and enthalpy in cal/g of gelatinization (ΔHG) and retrogradation (ΔHR). Enthalpies were calculated on a dry weight basis. Because the endotherms were largely symmetrical, the ranges in °C for gelatinization (RG) and retrogradation (RR) were calculated as $2(T_p - T_o)$ according to Krueger et al (1987b). Percentage retrogradation (%R), or the ratio of enthalpy of retrogradation to enthalpy of gelatinization, was calculated as ΔHR/ΔHG. Values for peak height index (PHI) provide a quantitative evaluation of variations in peak shape of gelatinization and were calculated as ΔHG /(T_pG – T_oG) (Krueger et al 1987a).

TABLE I
Inbred Lines and Their Origins Analyzed for Starch Thermal Traits

	Pedigree[a]	PI Number	Origin
Corn Belt inbreds			
A554	(Wf9 x WD)WD^2		Minnesota
A659	Minnesota Synthetic 3		Minnesota
A666	Minnesota Synthetic C		Minnesota
B77	W. L. Brown Pioneer 2-Ear Composite		Iowa
C103	Lancaster Sure Crop		Connecticut
CO109	Early Butler		Canada-Ottawa
H99	Illinois Syn. 60C		Purdue
Mo17	CI187-2 x C103		Missouri
Oh43	Oh40B x W8		Ohio
Exotic inbreds (lab number)			
A211		PI 186190	Uruguay
A214		PI 198901	Argentina
A217		PI 221794	South Africa
A218		PI 186218	Argentina
A225		PI 186182	Uruguay
A230		PI 186183	Uruguay
A235		PI 198892	Argentina
A236		PI 221734	South Africa
A238		PI 198906	Argentina

[a] Illinois Foundation Seeds.

Statistical Analysis

Analyses of variance (ANOVA) were computed for each trait for data combined over genotypes (Corn Belt lines, exotic lines, Corn Belt crosses, and exotic crosses) not weighted by replication (Hameed et al 1994). Two separate ANOVA were calculated, breaking down the overall genotype effect into many different genotypic effects. The overall effects due to genotype and the specific genotypic effects were tested by the mean square of the error (Steel and Torrie 1980). Highly significant and significant values were accepted at $P < 0.01$ and $P < 0.05$, respectively.

RESULTS AND DISCUSSION

Starch Variability Among Corn Belt and Exotic Lines

The nine Corn Belt inbred lines used in our study (Table I) were released during the pre-1948 through the 1978 era. Some of the lines, such as C103, Co109, H99, Mo17, and Oh43, have been important in the seed industry as inbred lines used in hybrids or as ancestors of commercially important lines. Others, such as A659, were released because of an outstanding agronomic characteristic or resistance to an important pest and, thus, may have contributed to commercially important lines. All the lines except A659 and Co109 have been assigned to breeding group A by the North Central Corn Breeding Research Committee. Beginning in 1950, the committee assigned lines to A or B groups somewhat arbitrarily, but with some attempt to provide maximum genetic diversity between

TABLE II
Means, Maximum, and Minimum Values and Standard Errors for Starch Thermal Traits of Corn Belt and Exotic Inbred Lines and Their Crosses

	Starch Thermal Traits[a]								
	T_oG (°C)	T_oR (°C)	T_pG (°C)	RG (°C)	RR (°C)	ΔHG (cal/g)	ΔHR (cal/g)	%R	PHI
Corn belt lines									
Mean	66.4	44.4	72.2	12.0	18.0	2.9	1.5	50.7	0.5
Maximum	71.2	46.4	75.5	17.6	19.7	3.2	1.7	53.0	0.8
Minimum	61.2	42.3	70.0	8.2	15.8	2.6	1.3	46.0	0.3
Standard error	1.16	0.41	0.66	1.13	0.38	0.06	0.05	0.76	0.06
Corn belt crosses									
Mean	68.9	44.9	72.9	8.0	18.3	3.0	1.4	48.1	0.8
Maximum	70.1	46.7	74.0	9.3	20.5	3.3	1.6	53.0	1.0
Minimum	66.4	43.5	70.6	6.0	16.5	2.6	1.2	42.0	0.6
Standard error	0.26	0.25	0.22	0.19	0.21	0.05	0.03	0.62	0.03
Exotic lines									
Mean	65.7	44.9	70.8	10.3	17.3	2.7	1.4	52.9	0.6
Maximum	68.1	46.0	72.1	13.5	19.2	3.0	1.7	63.0	0.8
Minimum	62.9	42.8	69.1	7.6	16.7	2.0	1.1	42.0	0.4
Standard error	0.65	0.35	0.37	0.73	0.26	0.10	0.07	2.35	0.05
Exotic crosses									
Mean	68.2	44.8	72.3	8.5	18.1	3.0	1.5	51.3	0.7
Maximum	70.6	48.1	74.3	10.9	19.5	3.5	1.7	57.0	0.8
Minimum	65.9	42.9	70.6	6.9	16.1	2.7	1.4	45.0	0.5
Standard error	0.35	0.29	0.27	0.28	0.19	0.05	0.02	0.70	0.02

[a] T_oG = onset temperature of gelatinization; T_oR = onset temperature of retrogradation; T_pG = peak temperature of gelatinization; RG = range of gelatinization; RR = range of retrogradation; ΔHG = enthalpy of gelatinization; ΔHR = enthalpy of retrogradation; %R = percentage retrogradation; and PHI = peak height index.

TABLE III
Significance of the Mean Squares of Genotype Effects from Two Analyses of Variance of Starch Thermal Traits of Corn Belt and Exotic Inbred Lines and Their Crosses

		Starch Thermal Traits[a]								
Source of Variation	**DF**	T_oG	T_oR	T_pG	**RG**	**RR**	ΔHG	ΔHR	**%R**	**PHI**
Genotype	51	**[b]	ns[c]	**	**	ns	**	*	ns	**
Corn belt lines	8	**	ns	**	**	ns	**	*	ns	**
Corn belt crosses	17	**	ns	**	**	ns	**	*	ns	**
Corn belt lines vs. corn belt crosses	1	**	ns	ns	**	ns	*	ns	*	**
Exotic lines	8	**	ns	**	**	ns	**	**	**	**
Exotic crosses	15	**	ns	**	**	ns	ns	ns	ns	*
Exotic lines vs. exotic crosses	1	**	ns	**	**	*	**	*	ns	**
Corn belt genotypes vs. exotic genotypes	1	ns	ns	**	ns	ns	**	ns	ns	ns
Genotype	51	**	ns	**	**	ns	**	*	ns	**
Corn belt lines	8	**	ns	**	**	ns	**	*	ns	**
Exotic lines	8	**	ns	**	**	ns	**	**	**	**
Corn belt lines vs. exotic lines	1	ns	ns	**	ns	ns	**	ns	ns	ns
Corn belt crosses	17	**	ns	**	**	ns	**	*	ns	**
Exotic crosses	15	**	ns	**	**	ns	ns	ns	ns	*
Corn belt crosses vs. exotic crosses	1	*	ns	**	*	ns	ns	*	**	*
Lines vs. crosses	1	**	ns	**	**	*	**	ns	*	**

[a] T_oG = onset temperature of gelatinization; T_oR = onset temperature of retrogradation; T_pG = peak temperature of gelatinization; RG = range of gelatinization; RR = range of retrogradation; ΔHG = enthalpy of gelatinization; ΔHR = enthalpy of retrogradation; %R = percentage retrogradation; and PHI = peak height index.

[b] *,** indicates significance at $P < 0.05$ and $P < 0.01$, respectively.

[c] Not significant.

TABLE IV
Means of Starch Thermal Traits for Corn Belt Inbred Lines and Their Reciprocal Crosses

	Starch Thermal Traits[a]								
Pedigree	T_oG (°C)	T_oR (°C)	T_pG (°C)	**RG (°C)**	**RR (°C)**	ΔHG (cal/g)	ΔHR (cal/g)	**%R**	**PHI**
A554	65.0	44.2	71.0	12.0	18.9	2.7	1.3	49	0.4
A554 x B77	66.4	45.9	70.6	8.4	16.5	2.8	1.3	46	0.7
B77 x A554	69.9	44.3	73.9	8.1	19.6	2.6	1.2	46	0.7
B77	62.7	43.4	70.6	15.6	17.7	2.8	1.3	46	0.4
A554	65.0	44.2	71.0	12.0	18.9	2.7	1.3	49	0.4
A554 x Oh43	66.4	43.5	71.0	9.3	20.5	2.6	1.3	50	0.6
Oh43 x A554	68.9	44.8	73.0	8.1	17.8	3.1	1.5	47	0.8
Oh43	69.2	42.3	72.5	8.6	19.7	3.0	1.5	51	0.7
A659	61.2	46.4	70.0	17.6	15.8	2.6	1.3	50	0.3
A659 x B77	69.1	44.0	73.1	7.9	19.3	3.0	1.4	49	0.8
B77 x A659	69.1	43.8	73.4	8.6	18.2	3.0	1.5	50	0.7
B77	62.7	43.4	70.6	15.6	17.7	2.8	1.3	46	0.4
A659	61.2	46.4	70.0	17.6	15.8	2.6	1.3	50	0.3
A659 x C103	68.2	43.9	72.4	8.6	18.9	2.8	1.3	47	0.7
C103 x A659	69.4	43.9	73.6	8.4	18.8	3.1	1.6	53	0.7
C103	65.1	43.7	72.5	14.8	17.3	2.9	1.5	53	0.4
A666	66.6	44.9	72.5	11.8	18.1	2.9	1.4	50	0.5
A666 x Co109	69.8	43.7	72.8	6.0	17.7	3.0	1.5	49	1.0
Co109 x A666	68.6	46.1	72.5	7.8	17.9	2.9	1.3	45	0.7
Co109	65.5	44.2	70.5	10.1	17.9	2.8	1.5	53	0.6
A666	66.6	44.9	72.5	11.8	18.1	2.9	1.4	50	0.5
A666 x Mo17	69.9	46.2	73.2	6.7	17.3	3.1	1.5	47	0.9
Mo17 x A666	69.4	46.7	72.7	6.6	18.0	3.3	1.5	47	1.0
Mo17	71.2	45.1	75.5	8.9	19.0	3.2	1.7	53	0.7
B77	62.7	43.4	70.6	15.6	17.7	2.8	1.3	46	0.4
B77 x Oh43	68.7	44.1	72.7	8.0	18.4	3.1	1.5	48	0.8
Oh43 x B77	70.1	45.1	74.0	7.8	18.2	3.2	1.6	48	0.8
Oh43	69.2	42.3	72.5	8.6	19.7	3.0	1.5	51	0.7
Co109	65.5	44.2	70.5	10.1	17.9	2.8	1.5	53	0.6
Co109 x Mo17	67.8	46.5	72.1	8.5	18.0	2.8	1.2	42	0.7
Mo17 x Co109	69.7	44.6	73.7	8.0	18.3	3.1	1.6	51	0.8
Mo17	71.2	45.1	75.5	8.9	19.0	3.2	1.7	53	0.7
H99	71.0	45.5	75.1	8.2	17.6	3.1	1.6	51	0.8
H99 x Oh43	69.3	45.2	73.5	8.5	17.6	2.8	1.5	52	0.7
Oh43 x H99	69.5	45.0	73.7	8.3	17.8	3.0	1.5	49	0.7
Oh43	69.2	42.3	72.5	8.6	19.7	3.0	1.5	51	0.7
LSD[b]									
Between lines	3.6	0.8	1.4	2.3	0.8	0.1	0.1	1	0.12
Between crosses	1.5	4.0	1.5	1.3	3.5	0.2	0.3	8	0.13
Lines vs. crosses	0.9	1.0	0.6	0.9	0.9	0.1	0.1	2	0.4

[a] T_oG = onset temperature of gelatinization; T_oR = onset temperature of retrogradation; T_pG = peak temperature of gelatinization; RG = range of gelatinization; RR = range of retrogradation; ΔHG = enthalpy of gelatinization; ΔHR = enthalpy of retrogradation; %R = percentage retrogradation; and PHI = peak height index.

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

groups for the formation of productive hybrids and breeding populations. Later, assignments were made in an attempt to conform more closely to Lancaster (A) and Reid Yellow Dent (B) heterotic groups (A.R. Hallauer, Iowa State University, *personal communication*).

The exotic lines used in our study (Table II) were originally collected in Uruguay, Argentina, and South Africa, and have been maintained at the North Central Region Plant Introduction Station in Ames, IA, since the 1950 to 1954 era. The lines from Uruguay and Argentina belong to the Cateto race, characterized by orange flint kernels. Cateto lines in these countries are used to produce high-yielding hybrid combinations with dent lines (Goodman and Brown 1988) and have higher protein, oil, test weight, and hardness than does U.S. corn (Hill et al 1989).

The summary statistics presented in Table II show that the Corn Belt lines had a wider range of values for more traits than did the exotic lines, even though the Corn Belt lines were only derived from the Corn Belt race, and the exotic lines originated from more than one race of corn. Corn Belt lines had a wider range of values for T_oG, T_oR, T_pG, RG, RR, and PHI. The exotic lines had a wider range of values for ΔHG and ΔHR, as well as for %*R*. For both sets of lines, the maximum value for PHI was as high as that reported by Wang et al (1992) for the waxy endosperm mutant. Minimum values for PHI were similar to the value reported by Wang et al (1992) for normal starch. Although the Corn Belt lines exhibited a wider range of values for RR than the exotic lines, the exotic lines showed a wider range of values for %*R*.

The ANOVA results (Table III) indicate highly significant effects for T_oG, T_pG, RG, ΔHG, and PHI for both Corn Belt and exotic lines. Retrogradation traits (T_oR, RR, and PHI) are not significant, except for ΔHR.

Comparing Hybrids with Their Parents

Both Tables IV and V clearly show that results for hybrids are not consistently higher, lower, midpoint, or similar with respect to the values of their parents. This result holds true whether considering type of germplasm or starch trait. Because of this inconsistency in the starch values of the hybrid compared with the parents, Tables IV and V will be discussed in relation to the effects of particular inbreds on the starch behavior of their hybrids. The hybrids along with their inbreds presented in Tables IV and V represent the successful reciprocal crosses made among all possible inbreds planted in Iowa.

Because starch occurs in the endosperm and endosperm is triploid resulting from fusion of a sperm with two polar nuclei (Sass 1977), we might expect to see reciprocal differences in the hybrids such that the hybrids more closely resemble the female parent instead of the male. Also, if the particular starch trait measured by a DSC parameter is simply inherited with few modifying genes, we would expect to see general patterns in the values of the hybrids versus the inbred parents for all or most crosses for a particular DSC trait. Neither of these trends are seen in the data presented in Tables IV and V.

Corn Belt Germplasm

The effect of Corn Belt lines vs. Corn Belt crosses was highly significant for T_oG, RG, and PHI and significant for ΔHG and %R (Table III). Only these traits will be discussed with respect to Corn

TABLE V
Means of Starch Thermal Traits for Exotic Inbred Lines and Their Reciprocal Crosses

	Starch Thermal Traits[a]								
Pedigree	**T_oG (°C)**	**T_oR (°C)**	**T_pG (°C)**	**RG (°C)**	**RR (°C)**	**ΔHG (cal/g)**	**ΔHR (cal/g)**	**%R**	**PHI**
A211	66.6	44.7	71.5	9.8	16.7	2.7	1.1	42	0.59
A211 × A221	70.6	44.0	74.3	7.4	19.5	2.9	1.4	50	0.79
A221 × A211	69.1	45.5	72.5	6.9	17.7	2.8	1.4	50	0.83
A214	67.2	44.0	71.0	7.6	17.0	2.7	1.4	51	0.72
A214 × A218	67.4	44.4	71.3	7.8	17.9	2.8	1.5	52	0.72
A218 × A214	67.1	44.3	72.5	10.9	17.9	2.9	1.5	53	0.55
A218	64.3	45.9	71.0	13.5	16.7	2.5	1.2	49	0.40
A217	66.0	42.8	71.8	11.6	19.2	3.0	1.7	55	0.52
A217 × A221	70.5	44.5	74.1	7.3	18.2	2.9	1.5	52	0.81
A221 × A217	66.4	44.4	71.3	9.8	17.7	2.9	1.6	57	0.58
A221 × A225	69.1	45.5	72.5	6.9	17.7	2.8	1.4	50	0.83
A225 × A221	68.5	48.1	72.7	8.3	16.1	3.0	1.4	48	0.70
A225	64.6	46.0	70.1	10.9	16.9	2.0	1.3	63	0.37
A230	62.9	45.5	69.2	12.5	17.6	2.6	1.6	63	0.42
A230 × A235	69.2	42.9	73.5	8.6	18.1	3.2	1.7	54	0.75
A235 × A230	67.1	45.2	71.4	8.6	18.1	2.9	1.5	52	0.67
A235	68.1	45.2	72.1	8.1	17.0	3.0	1.5	50	0.78
A230	62.9	45.5	69.2	12.5	17.0	2.6	1.6	63	0.42
A230 × A238	68.2	43.9	72.7	9.0	19.0	3.0	1.6	54	0.67
A238 × A230	69.8	44.8	71.7	8.8	18.0	2.7	1.4	52	0.62
A238	67.9	45.7	71.7	7.6	17.1	2.9	1.6	56	0.76
A235	68.1	45.2	72.1	8.1	17.0	3.0	1.5	50	0.78
A235 × A236	66.8	44.0	70.6	7.8	17.9	3.0	1.5	51	0.78
A236 × A235	68.0	43.9	71.8	7.6	18.9	3.1	1.6	51	0.82
A236	63.4	44.4	69.1	11.4	17.1	2.6	1.2	47	0.47
A235	68.1	45.2	72.1	8.1	17.0	3.0	1.5	50	0.78
A235 × A238	68.2	45.1	72.5	8.6	17.9	3.5	1.6	48	0.82
A238 × A235	68.7	45.9	72.9	8.4	18.7	3.0	1.4	45	0.72
A238	67.9	45.7	71.7	7.6	17.1	2.9	1.6	56	0.76
LSD[b]									
Between lines	1.3	2.7	0.6	2.0	2.4	0.3	0.3	7	0.13
Between crosses	2.1	3.6	1.1	1.0	3.1	0.5	0.3	10	0.24
Lines vs. crosses	0.7	0.9	0.4	0.7	0.7	0.1	0.1	3	0.07

[a] T_oG = onset temperature of gelatinization; T_oR = onset temperature of retrogradation; T_pG = peak temperature of gelatinization; RG = range of gelatinization; RR = range of retrogradation; ΔHG = enthalpy of gelatinization; ΔHR = enthalpy of retrogradation; %R = percentage retrogradation; and PHI = peak height index.

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

Belt germplasm. For T_oG, reciprocal hybrids with the lines H99 and Oh43 as parents had values that were not significantly different from those of their parents (Table IV). The line Mo17 had the highest value for T_oG in the Corn Belt set (71.2°C). Crosses with Mo17 as a parent most closely resembled the high value of Mo17. The line A659 had the lowest value for T_oG in the Corn Belt set (61.2°C). Hybrids with A659 as a parent had values for T_oG significantly higher than either parent. Four sets of reciprocal hybrids had values significantly higher than those of their respective parents.

For hybrids, gelatinization (RG) occurred over a much narrower range of temperature than for the corresponding parents. This is very clear when looking at a line with a large RG value (A659) and its crosses with other lines with large RG values (B77 and C103). Reciprocal hybrids of these lines had narrow ranges. This also was evident by looking at PHI. Hybrids of these crosses had much narrower gelatinization peaks than the inbred parents.

Comparisons of crosses with their parents for ΔHG showed that most crosses involving the set of Corn Belt lines had significant differences between hybrids and inbred parents for ΔHG. Crosses between lines with high %R (Co109 and Mo17) had significantly lower %R values than the parents. For the cross with Co109 as a female, the %R value was significantly lower than the cross with Co109 as a male.

Exotic Germplasm

Highly significant differences for the exotic lines vs. exotic crosses genotypic effect for T_oG, T_pG, RG, ΔHG, and PHI and significant results for RR and ΔHR were found (Table III). Maximum values for exotic crosses exceeded those for exotic lines for T_oG and T_pG (Table II).

Seed for the exotic line A221 was lost; thus, results for A221 are not included in Table V. Two of the three crosses that had A221 as a male parent had significantly greater values for T_oG than the female parent (A211 and A217). The hybrid between lines with the lowest (A236) and highest (A235) values for T_oG, that had A235 as a male parent, had a value not significantly different than that of the high parent. The reciprocal hybrid (A235 as a female) has a value intermediate between the parents. All crosses with A230, whether A230 was used as a male or female, produced hybrids with significantly greater values than A230.

For T_pG, both crosses between A235 and A238 were significantly greater than the parent with the high value (A235). Two sets of reciprocal crosses using A235 as a parent crossed to lines with relatively high RG values had values for RG not significantly different from A235. Three sets of reciprocal crosses had values for RR for the crosses significantly greater than the parents. For ΔHG and ΔHR, there were also crosses with values significantly greater than either parent. PHI values for both the crosses and the Corn Belt germplasm were not as consistently narrow in gelatinization peak shape as the exotic lines.

CONCLUSIONS

The Corn Belt germplasm used in our study had a wider range of variability for most of the starch traits measured than the exotic germplasm, even though the racial variability was greater for the exotics than for the Corn Belt. No consistent conclusions could be made about the values of crosses in comparison with the values of their parents. The reciprocal crosses' values showed trends suggesting reciprocal differences, although there was no trend showing greater effect for the female parent. The results obtained by comparing hybrids with their parents suggest that these traits are likely controlled by many modifying effects in addition to major effects. Our results show that there should be potential for breeding for higher or lower values of the starch traits measured by DSC. Breeding efforts would be aided by studies conducted to determine mode of inheritance and to measure variance components among crosses due to reciprocal differences and reciprocal by environment interactions. Our results have shown that sufficient variability exists among Corn Belt lines to effectively conduct these types of experiments.

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