

Thermal Properties of Corn Starch Extraction Intermediates by Differential Scanning Calorimetry¹

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ABSTRACT

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Thermal properties of corn starch extraction intermediates from four types of corn were studied using differential scanning calorimetry. Starch at four different stages of extraction, including a standard single-kernel starch isolation procedure and three starch extraction intermediates, was isolated from mature corn kernels of B73 and Oh43 inbreds and the mutants of *waxy* (*wx*) and *amylose extender* (*ae*) in an Oh43 background. Differences in thermal properties and moisture and protein contents of starch from the extraction stages were statistically analyzed. Most thermal properties (gelatinization and retrogradation onset temperatures, gelatinization and retrogradation ranges, gelatinization and retrogradation peak temperatures, gelatinization and retrogradation enthalpies, peak height index, and percentage of retrogradation) of starches extracted at stage 3 intermediate (a procedure that did not include a final washing step) were

similar to those of starch extracted by the standard single-kernel isolation procedure. Values for gelatinization peak temperature, gelatinization enthalpy, and peak height index were different between the standard and the stage 3 intermediate. The values obtained from starches extracted at stage 3, however, were consistent and predictable, suggesting that this extraction intermediate might be used in screening programs in which many starch samples are evaluated. By using the stage 3 extraction, samples could be evaluated in three rather than four days and the procedure saved ≈ 0.5 hr of labor time. The other two starch extraction intermediates, which excluded filtering and washing or filtering, washing, and steeping, produced starch with thermal properties generally significantly different from starch extracted by the standard single-kernel isolation procedure.

Differential scanning calorimetry (DSC) has been widely used to study the gelatinization and retrogradation of starch. The thermal requirements for gelatinization and retrogradation are important physical properties of starch that can be measured by DSC. DSC has been used to observe the physical properties of normal maize genotypes (Krueger et al 1987a), mutant maize genotypes (White et al 1990; Wang et al 1992, 1993), legume starches (Biliaderis et al 1980), and wheat starches (Ward et al 1994).

Some compositional features of starch can be identified by the gelatinization peak produced by DSC. Russell (1987) and Sievert and Wursch (1993) used DSC to study the gelatinization of starches with different amylose-amylopectin contents. Their studies found that the amylose-amylopectin ratio affected the thermal properties of starches measured by DSC. Another study by Krueger et al (1987b) found that the higher the amylopectin content of the starch, the narrower the temperature range of gelatinization. Decreased granule size increased the gelatinization temperature, range, and enthalpy of the starch (Knutson et al 1982). The presence of substances such as sugars, proteins, fats, acids, and water also affects the gelatinization of starch (Whistler and James 1985).

The differential scanning calorimeter has been a useful instrument to study starch thermal properties for several reasons: 1) it can be used to measure gelatinization and retrogradation temperatures and enthalpies of samples with different water contents, 2) it is easy to operate, 3) there is no change in water content over the period of retrogradation because sample pans are hermetically sealed, and 4) only a small amount (≈ 4 mg) of starch is needed (Nakazawa et al 1985). Sample preparation, however, requires starch isolation having many steps, which takes about four days to complete (White et al 1990).

It would be useful to know the impact of each step in starch extraction on the DSC characteristics. Therefore, in this study, corn starch at four different stages of single-kernel starch isolation were evaluated. The stages included three intermediate points prepared by eliminating one or more steps of the original starch isolation and the final extraction stage. The objectives of this study were to evaluate the impact on DSC thermal properties of the extraction steps of starch from four types of corn, including B73 and Oh43 inbreds and *waxy* (*wx*) and *amylose extender* (*ae*) mutants.

MATERIALS AND METHODS

Mature corn (*Zea mays* L.) kernels of four types, B73 and Oh43 inbreds, and *waxy* (*wx*) and *amylose extender* (*ae*) mutants in an Oh43 background, were harvested from a summer nursery near Ames, IA, in 1991. Plants were self-pollinated and ears were harvested at full maturity. After harvest, corn ears were dried at 38°C for five days to 13% mc. The samples were stored in a cold room at 4°C and 45% rh until the kernels were needed for analysis.

The starch was evaluated at four stages of extraction. Stage 4 was the original single-kernel starch isolation method. Three replicates were run for each stage on each corn type, and three representative kernels were used in each replicate.

Stage 1

Stage 1 consisted of crushing the dry kernels with a hammer, removing the seed coat, separating the germs, and collecting the starch without drying it under the fan.

Stage 2

Stage 2 is briefly described in three steps (a-c). First (a), three corn kernels were placed in screw-top 25-mL test tubes. Sodium meta-bisulfite 0.45% (≥ 2 mL) were added to each tube before incubation in a 50°C water bath for 48 hr (± 2 hr) to soften the kernel, enhance peeling of the seed coat, and preserve the kernel during steeping. Second (b), after incubation, the sodium meta-bisulfite was decanted and the seed coat and germ were manually removed from the kernels. A mortar and pestle was used to grind endosperm as fine as possible. Third (c), the resulting starch was dried in front of the fan overnight. The dried starch was transferred to air-tight sample vials until needed for DSC analysis.

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Stage 3

For stage 3, the first two steps (a and b) were followed as for stage 2. Four additional steps (c–f) were included. First (c), the material was transferred to a microblender jar. The mortar was rinsed with distilled water (2–5 mL) into the microblender, and the material was blended for 4 min. Second (d), the contents of the microblender were poured onto a 325-mesh screen in a spectrum filtration apparatus. The residue from the blender was rinsed onto the screen with distilled water. Starch was rinsed through the screen with distilled water as thoroughly as possible. Third (e), the filtrate was transferred to a 250-mL beaker. The beakers were placed in the refrigerator overnight to allow the starch to settle. After sitting overnight, the water on the upper layer was decanted. Fourth (f), beakers of the resulting starch were placed in front of a fan overnight to dry the starch. The dried starch was transferred to air-tight sample vials until needed for DSC analysis.

Stage 4

Stage 4 was the single-kernel starch isolation described by White et al (1990). Stage 4 consisted of steps a–e of stage 3 with two additional steps. First (f), the starch was resuspended in ≈50–100 mL of distilled water, and the water was decanted after 1.5–2 hr. Each sample was decanted a total of three times. Second (g), beakers of the resulting starch were placed in front of a fan overnight to dry the starch. The dried starch was transferred to air-tight sample vials until needed for DSC analysis.

Differential Scanning Calorimetry

DSC studies were performed on a Perkin-Elmer DSC7 analyzer equipped with a thermal analysis data station (Perkin-Elmer

Corp., Norwalk, CT). The starch was gelatinized as previously described by White et al (1990), and refrigerated-storage retrogradation was achieved by the procedure of White et al (1989). Starch (≈3.5 mg, dwb) was weighed into an aluminum pan (Perkin-Elmer 0219-0062), and 8 μL of distilled water was added. Stainless steel pans were used for the *ae* corn starch because of the high temperature required for gelatinization. The pan was hermetically sealed and allowed to equilibrate for ≈2 hr before analysis. Samples were heated from 30 to 120°C (30–180°C for *ae* starch) at a rate of 10°C/min. Onset (T_o), peak (T_p), and enthalpy (ΔH) were calculated automatically. Because the peaks were symmetrical in shape, the gelatinization range (R) was computed as $2(T_p - T_o)$ as described by Krueger et al (1987a). Enthalpies were calculated on a starch dry-weight basis with protein content being subtracted from the weight. The peak height index (PHI) was calculated by the ratio $\Delta H/(T_p - T_o)$ (Krueger et al 1987a). After cooling, the samples were stored in the refrigerator at 4°C for seven days. Retrogradation was measured by reheating the sample pans from 30 to 120°C, 30 to 180°C for *ae* starch, at a rate of 10°C/min (White et al 1989). Percent retrogradation was calculated from the ratio of enthalpy of retrogradation to enthalpy of gelatinization. After refrigerated-storage retrogradation analysis by DSC, the pans containing the samples were kept in the refrigerator until moisture analyses could be performed.

Moisture Analysis

The aluminum pans were punctured with a needle on the lid (Eliasson et al 1988) and then dried at 130°C for 1 hr. The pans were cooled to room temperature in a desiccator for 1 hr and then weighed. This drying procedure was repeated several times until

TABLE I
Moisture and Protein and Characteristics (%) of Corn Starches from Inbreds at Different Stages of Starch Extraction

Stage	Oh43		B73		Oh43wx		Oh43ae		Starch ^a	TET ^b	EAH ^c
	Moisture	Protein	Moisture	Protein	Moisture	Protein	Moisture	Protein			
1	12.6 ± 0.5a ^d	9.8 ± 0.7a	11.2 ± 0.7a	9.5 ± 1.2a	9.3 ± 2.3b	9.0 ± 0.3a	14.8 ± 1.2a	13.6 ± 0.9a	Y, HE ^e	1–2 hr	1–2
2	8.8 ± 0.6b	9.4 ± 0.3a	11.7 ± 2.0a	8.2 ± 1.7a	9.5 ± 1.7ab	8.3 ± 0.0b	12.5 ± 2.4ab	11.3 ± 0.3b	Y, HO	2.5 days	1–1.5
3	13.2 ± 0.4a	3.9 ± 0.2b	10.9 ± 0.8a	2.5 ± 0.2b	12.0 ± 0.7a	1.9 ± 0.3c	9.4 ± 1.1bc	4.1 ± 1.0c	SY, HO	3.5 days	2–2.5
4	11.7 ± 2.0a	0.6 ± 0.1c	12.3 ± 0.9a	0.8 ± 0.4b	11.7 ± 0.8ab	1.1 ± 0.3d	8.8 ± 1.0c	2.3 ± 0.1d	W, HO ^f	4 days	2.5–3

^a Starch appearance: Y = yellow, SY = slightly yellow, W = white, HE = heterogeneous, HO = homogeneous. From Oh43 and B73 inbreds.

^b Total extraction time from Oh43 and B73 inbreds.

^c Extraction activity (hr) from Oh43 and B73 inbreds.

^d Values are the average of three replicates for each stage. Values within a column followed by the same letter are not significantly different ($P < 0.05$).

^e Color was spotty, ranging from white to yellow.

^f Color was consistent throughout starch.

TABLE II
Gelatinization^a and Apparent Amylose of Corn Starch from Inbreds at Different Stages of Starch Extraction

Stage	Inbred	Apparent Amylose (%)	Thermal Properties				
			T_o (°C)	T_p (°C)	R	ΔH (cal/g)	PHI
1	Oh43	24.2	69.9 ± 0.4a ^b	74.7 ± 0.7a	9.4 ± 0.7b	2.8 ± 0.0b	0.5 ± 0.0b
	B73	17.8	69.0 ± 0.3b	73.1 ± 0.3c	8.4 ± 0.4b	2.5 ± 0.1d	0.5 ± 0.0c
	Oh43wx	0	65.6 ± 1.8b	75.5 ± 1.8a	19.7 ± 6.8a	2.9 ± 0.2c	0.3 ± 0.1b
	Oh43ae	72.1	78.4 ± 3.0a	93.4 ± 2.2a	30.1 ± 1.5a	2.4 ± 0.1b	0.2 ± 0.0b
2	Oh43	24.2	66.6 ± 1.5b	73.9 ± 0.4b	14.7 ± 2.1a	2.1 ± 0.2c	0.2 ± 0.2c
	B73	17.8	68.2 ± 0.4c	73.8 ± 0.2ab	11.3 ± 0.6a	2.6 ± 0.0c	0.4 ± 0.0d
	Oh43wx	0	70.0 ± 0.3a	75.4 ± 0.1a	10.9 ± 0.8b	3.4 ± 0.1b	0.6 ± 0.0a
	Oh43ae	72.1	74.5 ± 0.4b	85.1 ± 2.1b	21.3 ± 4.4b	3.1 ± 0.5b	0.3 ± 0.0b
3	Oh43	24.2	71.1 ± 0.4a	74.4 ± 0.4ab	6.7 ± 0.3b	3.3 ± 0.1a	0.8 ± 0.1a
	B73	17.8	70.3 ± 0.0a	74.0 ± 0.1a	7.3 ± 0.2c	3.2 ± 0.1b	0.8 ± 0.0b
	Oh43wx	0	68.7 ± 0.3a	74.5 ± 0.3a	11.7 ± 0.3b	4.0 ± 0.2a	0.7 ± 0.0a
	Oh43ae	72.1	72.4 ± 0.2b	80.6 ± 0.6c	16.4 ± 1.3b	8.3 ± 2.4a	1.0 ± 0.3a
4	Oh43	24.2	70.7 ± 0.3a	74.0 ± 0.3ab	7.5 ± 1.3b	3.5 ± 0.1a	0.9 ± 0.1a
	B73	17.8	69.9 ± 0.2a	73.4 ± 0.2bc	7.0 ± 0.1c	3.4 ± 0.0a	0.9 ± 0.0a
	Oh43wx	0	68.5 ± 0.4a	74.3 ± 0.2a	11.5 ± 0.7b	4.0 ± 0.2a	0.7 ± 0.1a
	Oh43ae	72.1	72.3 ± 0.5b	81.4 ± 0.4c	18.2 ± 1.6b	6.4 ± 0.8a	0.7 ± 0.0a

^a Results are the average of three replicates for each stage. T_o = onset temperature, T_p = peak temperature, R = range of peak calculated as $2(T_p - T_o)$; ΔH = enthalpy of gelatinization (dwb, based on starch weight); PHI = peak height index = $\Delta H/(T_p - T_o)$.

^b Values for each thermal property within a stage followed by the same letter are not significantly different ($P < 0.05$).

the weight was constant. No moisture analysis was performed for *ae* samples because the stainless steel pans could not be punctured by the needle. Moisture content of these samples was calculated from the average of three *ae* starch samples prepared by the same stage but measured before DSC analysis.

Protein Analysis

Protein analysis was performed on ≈ 25 mg of sample by using the micro-Kjeldahl procedure ($N \times 6.25$), AACC Method 46-13 (AACC 1995). Cupric selenite (0.2 g) and potassium sulfate (0.3 g) were added to the sample as catalysts. Duplicate runs of three replicates for each stage of each corn type were analyzed, and the results were reported as percent protein.

Amylose Analysis

A simplified colorimetric procedure described by Knutson (1986) was done to determine the apparent amylose contents of each starch type. Starch (≈ 3 – 4 mg) was dissolved overnight in 10 mL of 90% dimethyl sulfoxide (DMSO) containing 6×10^{-3} M iodine, followed by dilution of 1 mL of this solution with 8 mL of water and thorough mixing. Samples were allowed to stand for 30 min to stabilize to maximum absorbance, which was measured at 600 nm. Duplicate runs of two replicates were analyzed, and the results were reported as apparent amylose.

All samples were washed with toluene to remove protein as described by Krueger et al (1987b). As a final step, the starches were washed with acetone and air-dried. Only *ae* starch was defatted by using Soxhlet extraction with 85% methyl alcohol because high-amylose starches are known to contain more lipid than normal starches (Morrison and Milligan 1982).

Statistical Analyses

Analysis of variance and comparisons among treatments were computed by using the Statistical Analysis System (SAS Institute: Cary, NC). The differences among treatments were computed by least significant differences (LSD) after a preliminary *F* test at the 5% probability level.

RESULTS AND DISCUSSION

Protein Content

The percent moisture and protein contents and characteristics of starches from the four stages of extraction are shown in Table I. The presence of a great amount of other substances in starch such as proteins, fats, and water may lower the T_o , broaden the *R*, lower the ΔH , and lower the PHI of starch gelatinization (Wang et al 1992, Whistler and James 1985). The percent protein decreased from stage 1 to stage 4 for all of the starches, indicating the addition in protein-removing purification steps with each stage from 1 to 4. Starches produced by stages 1 and 2 had high protein contents of greater than 8% (Table I). There were no significant differences in protein content between stages 1 and 2 for Oh43 and B73 starches and no significant differences in protein content between stages 3 and 4 for B73; however, the protein content of Oh43 starch from stage 3 was significantly different from that of starch from stage 4. Stage affected the protein content of *wx* and *ae* starches as noted by significant differences in protein content among all stages for isolating these starches.

Moisture Content

No significant differences were noted in moisture contents of the Oh43, B73, and *wx* starches extracted by four different stages, except for stage 2 for Oh43 starch and between stages 1 and 3 for *wx* starch. These data suggest that different extraction stages had little effect on the moisture contents of Oh43, B73, and *wx* starches produced. But stage had an effect on moisture content of *ae* starch as significant differences were noted in moisture contents of *ae* starch extracted by the four different stages.

Starch Appearance

The color of the starch (Table I) extracted at the four different stages was slightly different as visually noted by the authors. Stage 1 produced a very heterogeneous (i.e., color was spotty, ranging from white to yellow) starch. Stage 4 produced a white and homogeneous-looking (i.e., color was consistent throughout starch) starch, whereas, each of the other stages resulted in yellow to slightly yellow starch. The greater the yellow color of the starch, the greater the protein content (Table I).

Stages 1 and 2 consumed the least total time and labor hours. Stage 3, which produced starch the closest in appearance and protein content to that from stage 4, consumed less time than stage 4, both in total time and in labor hours but saved only one-half day and 0.5 hr, respectively. The total time consumed for stage 4 was the greatest and gave the most consistent results.

Gelatinization Properties

The thermal properties and apparent amylose content of the four types of starches are summarized in Table II. Thermograms of Oh43 and Oh43 *ae* starches are shown in Figs. 1 and 2, respectively. Stage 2 gave thermal property values that were generally significantly different from the values for the other three stages for Oh43 starch (amylose content of 24.2%) (Table II). There were no significant differences in thermal property values of gelatinization between stages 3 and 4. The thermal property values for stage 1 were significantly different from stages 3 and 4 only for ΔH and PHI. Stages 3 and 4 gave thermograms of similar shape, whereas stages 1 and 2 showed broader gelatinization ranges and lower PHI than stages 3 and 4 (Fig. 1). These differences in peak definition were likely a result of protein interaction with the starch or interference of protein denaturation during the thermal analysis, which will be discussed later.

For starch from B73 (amylose content of 17.8%), parameters for nearly all stages were significantly different from each other, with a few exceptions (Table II). Most notably, the stage affected *R*, ΔH , and PHI. In general, for Oh43 and B73 starches, stage 2 resulted in the most different gelatinization parameters among stages. Thermograms for B73 (thermograms not shown) starch were similar to those of Oh43.

There were no significant differences in T_o , *R*, and PHI of *wx* starch (amylose content of 0%) for stages 2, 3, and 4 (Table II), and no significant difference in T_p among all stages. No significant difference was found in ΔH values between stages 3 and 4; however, ΔH values of stages 1 and 2 were significantly lower than for stages 3 and 4 and different from each other. For *wx* starch (thermograms not shown), stage 1 gave the most different gelatinization parameters among the stages, stage 4 gave the highest PHI, and stage 1 showed the lowest PHI among the four stages.

Starch from the *ae* mutant had a high amylose content (72.1%) and, thus, did not exhibit a distinct peak; the endotherm extended beyond 100°C (Stevens and Elton 1971, Wang et al 1992). Starch from the *ae* mutant gave inconsistent gelatinization property values among runs for each replicate, causing a wide range in values. Even so, statistical analysis data (Table II) showed that ΔH and PHI in stages 1 and 2 were significantly lower and T_p was significantly greater than these values for stages 3 and 4. The values of T_o and *R* from stages 2, 3, and 4 were not significantly different from each other but were significantly lower than values from stage 1. Even though many statistically significant differences in the parameters were found, the practical significance of these differences may not be important. Stages 3 and 4 resulted in similar gelatinization properties for the *ae* starch. The *ae* starch, having a high amylose content, gave broad endotherms and low PHI for all stages (Fig. 2). Other researchers have noted similar DSC parameters for high *ae* starches (Wang et al 1992).

In general, data from Table II suggest that stage 2, for Oh43 starch, and stage 1, for *wx* and *ae* starches resulted in the most

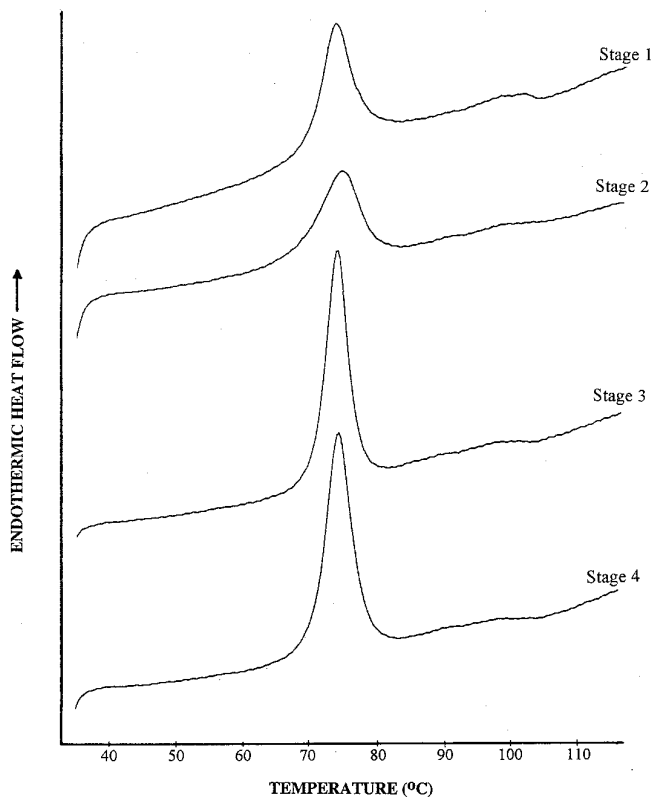


Fig. 1. Differential scanning calorimetry thermograms (gelatinization) of starch from Oh43 normal inbred at different stages of starch extraction.

different properties. For B73 starch, some parameters from starch extracted at both stages 1 and 2 were quite different from parameters at stages 3 and 4. But the ΔH of the replicates of starch extracted at stage 1 were not consistent. This result may have been caused by the difficulties in grinding the kernels to produce homogeneous starch. Stages 1 and 2 produced yellow starch (Table I), likely because of pigments and proteins remaining in the starch. These components may have contributed to the inconsistency in the data. Obviously, the great protein contents of starches from stages 1 and 2 changed starch properties significantly. The amount of protein left at stage 3 was much less and within the range previously shown to be acceptable for DSC analyses (White and Abbas 1989). In an article by White and Abbas (1989), native protein contents in corn starch of up to 5% were shown to produce DSC properties not significantly different ($P < 0.05$) from purified starches containing as little as 0.3% protein.

Refrigerated-Storage Retrogradation

Table III shows the DSC properties of the starch samples stored at 4°C for seven days (refrigerated-storage retrogradation), and Fig. 3 shows DSC retrogradation thermograms of Oh43. For most of the samples, the %R values were ≈ 50 –60%, which means that the energy needed to regelatinize the starches after seven days of storage at 4°C was ≈ 50 –60% of the energy needed to originally gelatinize the starches. Stage 2 generally gave significantly different parameters for retrogradation from the values for the other three stages for Oh43 starch. All parameters except R and ΔH were significantly different from the other three stages. Values from stage 1 tended to be the same as values from stages 3 and 4. Stage did not affect the R . Retrogradation thermograms of Oh43 starch from all stages were similar in shape (Fig. 3). The %R for stages 1 and 2, however, were greater than those values for stages 3 and 4, which was probably a direct reflection of the lesser ΔH of stages 1 and 2.

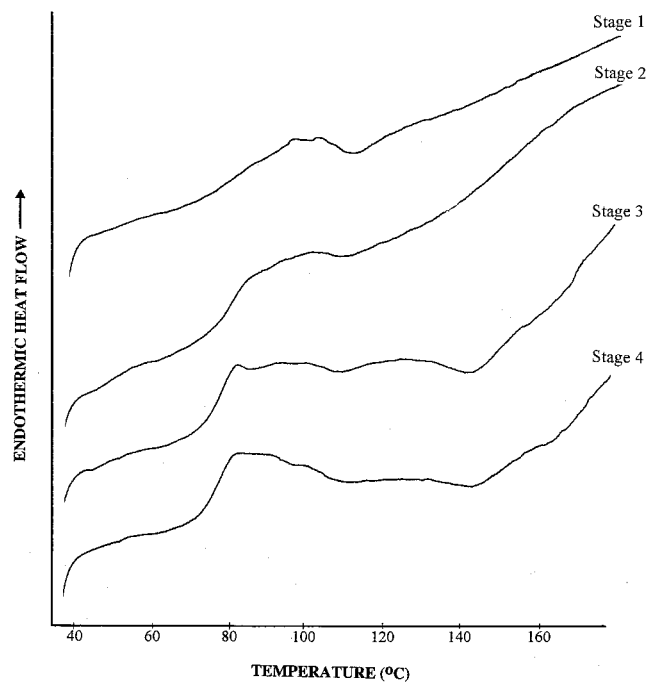


Fig. 2. Differential scanning calorimetry thermograms (gelatinization) of starch from Oh43ae inbred at different stages of starch extraction.

For B73 starch, stages 1 and 2 gave thermal property values similar to each other with T_p being the only difference. There were no significant differences in retrogradation values between stages 3 and 4. Stage did not affect the T_o or R . Retrogradation thermograms for B73 starch (thermograms not shown) were similar to those of Oh43.

For wx starch, stage 1 resulted in a significantly lower ΔH value than did the other three stages. Significantly greater %R values were found for stages 1 and 2 than for stages 3 and 4 as also noted above. Some other significant differences were noted among parameters as a result of the stage, but the actual numbers were small. Retrogradation thermograms for wx starch (thermograms not shown) were similar to those of Oh43.

Because starch from the *ae* mutant was difficult to analyze, the retrogradation values were extremely variable, resulting in inconsistent data for all stages. This problem is reflected in the lack of significant differences in the parameters among stages, even when absolute values seemed quite different. Table II shows that stage did not affect T_o , R , and %R. But stage 2 was significantly different from stages 1, 3, and 4 for T_p . Stage 1 gave the lowest ΔH value, but this value was not significantly different from the ΔH value for stage 2. Stages 3 and 4 gave similar retrogradation thermograms (not shown). Thermograms from stages 1 and 2 gave broad peaks with parameters being difficult to measure.

CONCLUSIONS

Starch extraction intermediates (stages 1–3) gave significant differences in protein content, appearance, and thermal properties of the starches when they were compared to the standard single-kernel starch isolation (stage 4). Different extraction stages, however, had little effect on moisture content of the starches produced, except for *ae* starch. The simpler the extraction procedure, the greater the protein content, which, in turn, influenced the gelatinization and retrogradation parameters. Stage 3, however, produced starch generally similar in thermal property values to stage 4. Stage 3 might be used to substitute for stage 4, but all thermal property values of the starch produced from stage 3 were not exactly the same as those of stage 4. Values were, however, rela-

TABLE III
Retrogradation^a of Corn Starch from Inbreds at Different Stages of Starch Extraction

Stage	Inbred	Thermal Property				
		T_o (°C)	T_p (°C)	R	ΔH (cal/g)	% R
1	Oh43	46.9 ± 0.9 ^a _b	55.5 ± 0.5 ^a	17.3 ± 0.9 ^a	1.4 ± 0.1 ^b	50.9 ± 2.1
	B73	46.9 ± 0.5 ^a	55.4 ± 0.7 ^a	17.0 ± 0.4 ^a	1.3 ± 0.1 ^b	53.9 ± 0.3 ^{ab}
	Oh43wx	46.9 ± 1.8 ^a	55.9 ± 1.2 ^a	18.0 ± 1.6 ^b	1.8 ± 0.2 ^b	63.4 ± 7.4 ^a
	Oh43ae	61.9 ± 10.1 ^a	89.4 ± 2.5 ^b	55.1 ± 22.5 ^a	1.7 ± 0.2 ^c	65.1 ± 15.2 ^a
2	Oh43	44.2 ± 0.4 ^b	53.4 ± 0.5 ^b	18.4 ± 1.1 ^a	1.5 ± 0.1 ^{ab}	68.6 ± 4.8 ^a
	B73	45.4 ± 0.6 ^a	54.0 ± 0.1 ^b	17.2 ± 1.4 ^a	1.5 ± 0.1 ^{ab}	55.1 ± 4.8 ^a
	Oh43wx	44.0 ± 1.3 ^b	53.8 ± 1.0 ^b	19.7 ± 0.6 ^a	2.2 ± 0.2 ^a	64.5 ± 3.2 ^a
	Oh43ae	65.1 ± 3.4 ^a	93.9 ± 0.5 ^a	57.7 ± 7.8 ^a	1.9 ± 0.5 ^{bc}	58.0 ± 7.9 ^a
3	Oh43	46.1 ± 0.2 ^a	54.8 ± 0.2 ^a	17.5 ± 0.6 ^a	1.6 ± 0.0 ^a	47.6 ± 1.1 ^b
	B73	46.4 ± 0.2 ^a	54.8 ± 0.3 ^{ab}	16.8 ± 0.9 ^a	1.6 ± 0.0 ^a	48.7 ± 0.4 ^{bc}
	Oh43wx	46.0 ± 1.2 ^{ab}	54.8 ± 0.5 ^{ab}	17.5 ± 1.6 ^b	2.2 ± 0.1 ^a	53.9 ± 2.1 ^b
	Oh43ae	54.9 ± 5.1 ^a	89.9 ± 0.9 ^b	69.8 ± 12.0 ^a	3.8 ± 0.8 ^a	47.31 ± 5.6 ^a
4	Oh43	45.9 ± 0.6 ^a	54.6 ± 0.6 ^a	17.5 ± 0.6 ^a	1.5 ± 0.1 ^{ab}	44.5 ± 3.9 ^b
	B73	45.8 ± 1.5 ^a	54.7 ± 0.8 ^{ab}	17.8 ± 1.6 ^a	1.5 ± 0.1 ^a	45.4 ± 1.9 ^c
	Oh43wx	43.8 ± 1.2 ^b	53.3 ± 0.9 ^b	19.1 ± 1.2 ^{ab}	2.1 ± 0.1 ^a	52.8 ± 1.5 ^b
	Oh43ae	57.2 ± 12.8 ^a	87.7 ± 3.1 ^b	61.1 ± 29.2 ^a	3.1 ± 0.9 ^{ab}	49.4 ± 17.7 ^a

^a Results are the average of three replicates for each stage. T_o = onset temperature, T_p = peak temperature, R = range of peak calculated as $2(T_p - T_o)$; ΔH = enthalpy of gelatinization (dwb, based on starch weight); % R = ratio of enthalpy of retrogradation to enthalpy of gelatinization.

^b Values for each thermal property within a stage followed by the same letter are not significantly different ($P < 0.05$).

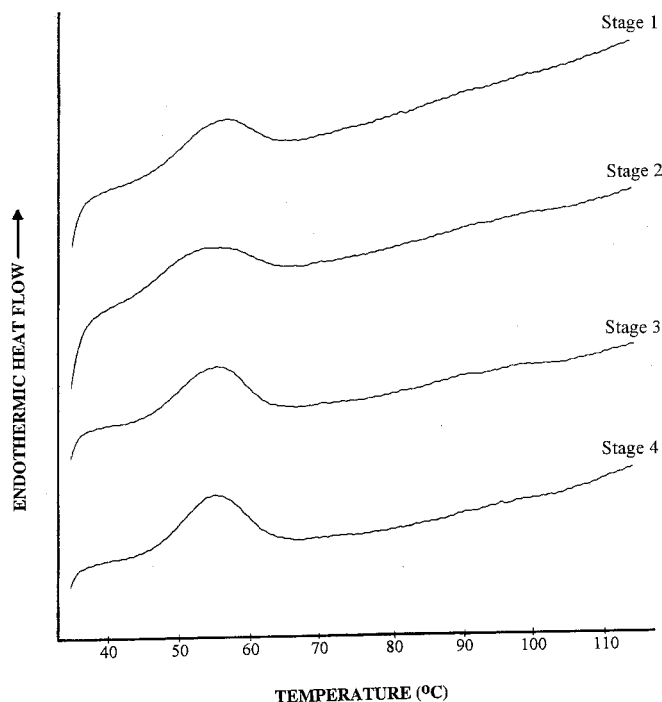


Fig. 3. Differential scanning calorimetry thermograms (retrogradation) of starch from Oh43 normal inbred at different stages of starch extraction.

tively consistent, which might allow this extraction intermediate to be used in a screening program in which many starch samples are evaluated. Stages 1 and 2 produced starches that were not pure or homogeneous enough to give consistent thermal properties of the starch. Evaluation of starch extraction intermediates in this study showed that every step in single-kernel starch isolation was significant in producing pure and homogeneous starch.

LITERATURE CITED

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