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Physicochemical and thermal properties of starches separated from corn produced from crosses of two germ pools

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Abstract

The changes in physicochemical and thermal properties of starches separated from corn, produced by crossing corn lines of MS and Tux pool, were studied. These heterotic pools were synthesized in a very systematic way by introgressing germplasm on the basis of genetic diversity, pedigree diversity and heterosis. Amylose content, swelling power, solubility and water-binding capacity (WBC) of starches separated from MS × Tux and Tux × MS pool corns were measured. Average amylose content, swelling power, solubility and WBC of MS × Tux pool corn starches were 20.1%, 21.71 g/g, 18.62% and 83.30%, respectively, against 19.6%, 23.23 g/g, 19.27% and 84.13% for those separated from the Tux × MS pool. Thermal properties of starches were measured with differential scanning calorimeter (DSC). Tux × MS pool corn starches showed higher swelling powers, solubilities, onset temperatures of gelatinization (T_o), peak temperature of gelatinization (T_p), conclusion temperature of gelatinization (T_c), enthalpies of gelatinization (ΔH_{gel}), peak height indices (PHI) and synereses than MS × Tux pool corn starches, while the reverse was observed for amylose contents. The relationships between different properties of starches were also determined using Pearson correlation coefficients. Amylose content was negatively correlated with swelling power and WBC ($p < 0.05$). T_o, T_p, T_c were positively correlated with each other as well as ΔH_{gel} and PHI ($p < 0.01$). ΔH_{gel} was positively correlated with syneresis ($p < 0.01$). The crosses, MS × Tux pool, resulted in corn having lower swelling powers, solubilities, transition temperatures but more stable pastes than the corn produced by crossing Tux × MS pool. The effect of selection of parents from the crosses among lines across pools was investigated.

Keywords: Corn crosses; Physicochemical; Amylose; Thermal; Syneresis

1. Introduction

A study of variability of starch functional traits in the various pools of the germplasm bank is needed before conducting rigorous inheritance studies in breeding programme. Germplasm banks are valuable resources for identifying natural variability of different plant and seed traits. Screening the accessions in a germplasm bank aids in the identification of plants with unusual properties, ranging from agronomic traits to functional and compositional traits of the seeds. Breeding and genetic tools can be used effectively to achieve several end-use quality attributes. Quality specifications of corn for food and feed uses are diverse and exacting. Achieving the quality attributes for different uses has traditionally been accomplished by using a range of post-harvest processing techniques such as milling or modifying starch and proteins. Seetharaman et al. (2001) characterized the thermal (transition temperatures and enthalpies of gelatinization) and functional properties of starch of several corn races from the Argentinean germplasm and identified unusual corn races with potential for further improvement. Singh, Johnson, White, Jane, and Pollak (2001) also screened 49 GEM accessions for thermal properties and paste and gel behaviour of the starches. Li, Berke, and Glover (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, Pollak, and White (1995), also used differential

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scanning calorimeter (DSC) to examine a set of normal corn dent hybrids and suggested that DSC had applications in breeding programme to screen germplasm for extreme values in developing breeding lines with unusual starch properties through crossing and recurrent selection. White, Abbas, Pollak, and Johnson (1990), studied intra and inter population 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 varying more in gelatinization properties but less in retrogradation properties. Identification of native starch sources is required for desired functionality and unique properties (Duxbury, 1989). The physicochemical properties and functional characteristics that are imparted by the starches to the aqueous systems and their uniqueness in various food applications vary with the biological origin (Svegmark & Hermansson, 1993). Interest in new value-added products in the industry has resulted in many studies being carried out on the morphological, rheological, thermal and textural properties of corn and potato starches (Evans & Haisman, 1979; Kim, Wiesenborn, Orr, & Grant, 1995; Lii, Tsai, & Tseng, 1996; Weisenborn, Orr, Casper, & Tacke, 1994). Li et al. (1994) characterized the thermal properties of 35 tropical and semitropical corn populations and reported significant differences for all measured thermal properties. The granule size distribution of the same 35 corn populations also was examined, and a significant difference in the average granule size was reported within and among the populations (Campbell, Li, Berke, & Glover, 1996). Several significant correlations were also established between granule size and thermal populations based on results from these populations. SEM has been used to relate granule morphology to starch genotype (Fannon, Hauber, & BeMiller, 1992). They discovered pores on the surface of corn, sorghum, and millet starch granules. Leach and Schoch (1961) suggested that these pores were related to the botanical source of the starch, as confirmed by Fannon et al. (1992). Limited information is available on the variability in functional and thermal properties of starches recovered from commercial maize inbreds and their crosses. The corn hybrids used in the present study were developed from the lines belonging to the two contrasting heterotic germ pools, namely MS and Tux pool. These heterotic pools were synthesized in a very systematic way by introgressing germplasm on the basis of genetic diversity, pedigree diversity and heterosis. These pools serve as a reservoir for the derivation of lines for use in developing of hybrids for the commercial cultivation as a long-term programme. The objective of the present investigation was: (1) to compare the physicochemical and thermal properties of starches separated from corn resulting from crossing of two heterotic pools, namely MS and Tux germ pools, (2) to explore the effect of selection of female and male parents from cross pools on the various properties.

2. Materials and methods

2.1. Materials

A pair of heterotic pools, namely MS pool and Tux pool, were used to develop hybrids for commercial cultivation. Corn crosses obtained by crossing two different germ pools (MS × Tux and Tux × MS pool) were procured from the Regional Research Station, Punjab Agricultural University, Gurdaspur, India, from the 2001 harvest. MS × Tux means female of MS pool crossed with the male of Tux pool while Tux × MS pool means female of Tux crossed with the male of MS pool. There is little heterosis in crosses within the pool and there is high heterosis when the lines are crossed a cross pools.

2.2. Starch isolation

About 500 g of clean, sound and whole corn (10–20% moisture content) were added to 1.25 l of distilled water containing sodium hydrogen sulfite (0.1% SO_2). The mixture was maintained at 50 ± 2 °C for about 18–20 h with intermittent circulation of the liquid. After 20 h, the steep water was drained off and corn was ground in laboratory grinder. About 250 g of steeped corn were ground with 250 ml of distilled water. The ground slurry was screened through nylon cloth (100 mesh), and the residue was washed with distilled water until it was free of starch. The filtrate was passed successively over 200 and 325 mesh screens. The starch-protein slurry was then allowed to stand for 4–5 h. The supernatant was removed by suction and the settled starch layer was resuspended in distilled water and centrifuged in wide-mouthed cups at 2800 rpm for 5 min. The upper non-white layer was scraped off. The white layer was resuspended in distilled water and recentrifuged 3–4 times. The starch was then collected and dried in an oven at 40 °C for 12 h.

2.3. Physicochemical properties of starch

2.3.1. Amylose content (%)

Amylose content of the isolated starch was determined by using the method of Williams, Kuzina, and Hlynka (1970). 20 mg of starch sample were taken and 10 ml of 0.5 N KOH were added into it. The suspension was thoroughly mixed. The dispersed sample was transferred to a 100 ml volumetric flask and diluted to the mark with distilled water. An aliquot of test starch solution (10 ml) was pipetted into the 50 ml volumetric flask and 5 ml of 0.1 N HCl were added, followed by 0.5 ml of iodine reagent. The volume was diluted to 50 ml and the absorbance was measured at 625 nm. The measurement of the amylose was determined from a standard curve developed using amylose and amylopectin blends.

2.3.2. Swelling power (g/g) and solubility (%)

Swelling power and solubility were determined, in triplicate, using the method of Leach, McCowen, and Schoch (1959).

2.3.3. Transmittance (%)

Transmittances of starch paste from different corn crosses were measured as described by Craig, Maningat, Seib, and Hoseney (1989). A 1% aqueous suspension of starch from each corn cross was heated in a water bath at 90 °C for 1 h with constant stirring. The starch paste was cooled for 1 h at 30 °C. The samples were stored for five days at 4 °C in a refrigerator and transmittance was determined every 24 h by measuring absorbance at 640 nm against a water blank with a Shimadzu UV-1601 spectrophotometer (Shimadzu Corporation, Kyoto, Japan).

2.3.4. Water-binding capacity (%)

Water-binding capacity (WBC) of the starches from different corn crosses was determined using the method described by Yamazaki (1953) as modified by Medcalf and Gilles (1965). A suspension of 5 g starch (dry weight) in 75 ml distilled water was agitated for 1 h and centrifuged (3000*g*) for 10 min. The free water was removed from wet starch, drained for 10 min and wet starch was weighed.

2.4. Thermal properties

Thermal characteristics of isolated starches were studied by using DSC-821[e] (Mettler Toledo, Switzerland) equipped with a thermal analysis data station. Starch (3.5 mg, dry weight) was loaded into a 40 μl capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of Hamilton microsyringe to achieve a starch-water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in the DSC. The DSC analyzer was calibrated using indium and an empty aluminium pan was used as reference. Sample pans were heated at a rate of 10 °C/min from 20 to 100 °C. Thermal transitions of starch samples were defined as T_o (onset), T_p (peak of gelatinization) and T_c (conclusion), and ΔH_{gel} was referred to enthalpy of gelatinization. Enthalpies were calculated on a starch dry basis. These were calculated automatically. The gelatinization temperature range (R) and peak height index (PHI), was calculated as $2(T_p - T_o)$ and $\Delta H/(T_p - T_o)$, as described by Krueger, Knutson, Inglett, and Walker (1987).

2.5. Syneresis (%)

Starch suspension (2%, w/v) was heated at 85 °C for 30 min in a temperature controlled water bath, followed by rapid cooling in an ice water bath to room temperature. The starch samples were stored for 24, 72 and 120 h at 4 °C. Syneresis was measured as % of water released after centrifugation at 3200*g* for 15 min.

2.6. Statistical analysis

The data reported in all the tables are averages of triplicate observations. The data were subjected to statistical analysis using Minitab Statistical Software (Minitab Inc., USA) and Pearson coefficients were calculated.

3. Results and discussion

3.1. Physicochemical characteristics

Pedigrees of MS and Tux pools along with their lab numbers are provided in Table 1. Various

Table 1
List of corn lines from MS pool and Tux pool and their crosses

Lab no.	*(MS pool)*
662	(P_1 × EC253240-2- × P_1 × EC255239-1-1-)
663	(MS-M_O17.MSC_2-8-1 × J54LDC_4-58-)
664	(MSC_2IC_3-94)
665	(CML125 × SES23)
667	(MSC_2IC_2-20 × POP_{28}MBR)
669	(MSC_2IC_2-15)
672	(MSC_2IC_2-20-2 × POP_{28}MBR)
674	(MSC_2IC_2-5 × MSC_2IC_2-21)
677	(MSC_2IC_2-18- × MSC_2IC_2-15-)
678	(CIMMYT MBR plot 102)
679	($Psp_{26}C_{19}MH_{134}$)
	(Tux pool)
683	(POP_{28}TSR(S_2)-13 #)
684	(TuxC_2IC_3-7)
688	(Exp_{10}-5 # × TuxC_2IC_2-5)
689	(Tux-162- × TuxC_2IC_2-5)-4
690	(Tux-162- × TuxC_2IC_2-5)-12
692	(TuxC_2IC_2-140- × TuxC_2IC_2-181-)
693	(EH_{5041}-10 × TuxC_2IC_2-5)
694	(TuxC_2IC_2-5- × TuxC_2IC_2-122-)
695	(TuxC_2IC_2-12- × TuxC_2IC_2-22-)
696	(Cargill 633-54)
698	(MS-M_o17.MS_2-8- × JS_4LDL_4-58-)

Crosses: MS × Tux pool: 662 × 684, 663 × 684, 663 × 692, 664 × 692, 667 × 684, 667 × 692, 669 × 684, 674 × 684, 677 × 692, 678 × 684, 678 × 690, 679 × 684, 679 × 692.

Tux × MS pool: 683 × 672, 688 × 672, 689 × 672, 690 × 665, 690 × 674, 693 × 665, 694 × 674, 695 × 672, 695 × 674, 696 × 665, 696 × 672, 696 × 674, 698 × 690.

Table 2
Amylose content, swelling power, solubility and water-binding capacity of starches separated from different corn crosses[A]

Pools	Corn crosses (Lab no.)	Amylose content (%)	Swelling power (g/g)	Solubility (%)	Water-binding capacity (%)
	662 × 684	20.7 ± 0.31cd	21.76 ± 0.35b	19.04 ± 0.35bc	87.26 ± 0.55cd
	663 × 684	19.3 ± 0.41bc	20.50 ± 0.28ab	20.60 ± 0.46cd	82.25 ± 0.45bc
	663 × 692	22.1 ± 0.40d	21.60 ± 0.26b	18.27 ± 0.29bc	80.95 ± 0.25b
	664 × 692	20.1 ± 0.24c	20.99 ± 0.46ab	17.11 ± 0.65ab	78.36 ± 0.31ab
	667 × 684	20.1 ± 0.25c	22.66 ± 0.53bc	18.52 ± 0.41bc	84.14 ± 0.46bc
MS × Tux pool	667 × 692	21.5 ± 0.50cd	21.83 ± 0.65b	17.06 ± 0.63ab	77.66 ± 0.33a
	669 × 684	20.6 ± 0.20cd	21.08 ± 0.49ab	20.32 ± 0.49cd	84.12 ± 0.28bc
	674 × 684	19.6 ± 0.24bc	21.37 ± 0.35ab	19.50 ± 0.68bc	87.56 ± 0.27cd
	677 × 692	18.0 ± 0.40ab	22.75 ± 0.49bc	20.21 ± 0.61c	88.56 ± 0.43d
	678 × 684	18.8 ± 0.40ab	22.95 ± 0.54c	15.36 ± 0.58a	82.60 ± 0.29bc
	678 × 690	20.5 ± 0.35cd	21.71 ± 0.56b	16.38 ± 0.39ab	82.12 ± 0.36bc
	679 × 684	18.9 ± 0.25b	22.80 ± 0.59c	19.42 ± 0.48bc	83.18 ± 0.46bc
	679 × 692	20.6 ± 0.34cd	20.29 ± 0.62a	20.27 ± 0.28c	84.18 ± 0.26bc
Range		18.0–22.10	20.29–22.95	15.36–20.60	77.66–88.56
Mean		20.1	21.71	18.62	83.30
	683 × 672	19.0 ± 0.45b	23.01 ± 0.50c	20.11 ± 0.49c	86.27 ± 0.45cd
	688 × 672	20.2 ± 0.32c	23.57 ± 0.56cd	19.48 ± 0.35bc	80.75 ± 0.44b
	689 × 672	21.10 ± 0.36cd	22.20 ± 0.45bc	21.72 ± 0.49cd	85.20 ± 0.26c
	690 × 665	20.14 ± 0.46c	22.94 ± 0.35c	22.38 ± 0.39d	86.33 ± 0.34cd
	690 × 674	19.92 ± 0.32c	22.95 ± 0.53c	17.83 ± 0.56b	85.36 ± 0.38cd
Tux × MS pool	693 × 665	20.40 ± 0.45cd	24.50 ± 0.29d	18.04 ± 0.29b	79.86 ± 0.31ab
	694 × 674	18.3 ± 0.48ab	23.03 ± 0.46c	17.67 ± 0.46b	86.26 ± 0.35cd
	695 × 672	17.50 ± 0.32a	23.90 ± 0.64cd	18.99 ± 0.3bc	80.83 ± 0.24b
	695 × 674	21.00 ± 0.21cd	22.05 ± 0.46bc	18.36 ± 0.59bc	84.95 ± 0.31c
	696 × 665	18.52 ± 0.21ab	23.40 ± 0.57cd	19.09 ± 0.53bc	85.52 ± 0.32cd
	696 × 672	20.1 ± 0.46c	23.98 ± 0.62cd	15.65 ± 0.49ab	82.68 ± 0.45bc
	696 × 674	17.9 ± 0.23ab	23.30 ± 0.38cd	20.32 ± 0.46c	86.16 ± 0.46cd
	698 × 690	20.2 ± 0.49c	23.21 ± 0.41cd	20.93 ± 0.59cd	83.55 ± 0.46bc
Range		17.5–21.10	22.05–24.50	15.65–22.38	79.86–86.33
Mean		19.6	23.23	19.27	84.13

Values with similar letters in a column do not differ significantly ($p < 0.05$).
[A] Mean ± SD for triplicate measurements.

physicochemical properties (amylose content, swelling power, solubility and WBC) of different corn crosses are summarized in Table 2. MS × Tux and Tux × MS pool corn starches showed amylose contents in the range 18.01–22.10% and 17.50–21.10%, respectively. MS × Tux pool corn starches showed significantly higher amylose content than Tux × MS pool corn starches. Amylose contents in the range of 16.1–23.5% for starches from Argentinean corn accessions have been reported earlier (Seetharaman et al., 2001). The amylose content of the starch granules varies with the botanical source of the starch and is affected by the climatic and soil conditions during grain development (Morrison & Azudin, 1987; Morrison, Milligan, & Azudin, 1984; Yano, Okuno, & Fuwa, 1985). Average swelling powers of MS × Tux and Tux × MS pool corn starches were 21.71 and 23.23 g/g, respectively. Starches separated from the Tux × MS corn pool showed significantly higher swelling powers than those from the MS × Tux pool. Swelling of corn starch granules is the property of the amylopectin and the amylose acts as a diluent. Similar values of the swelling power for grain fractions of dent and popcorn starch have been reported earlier (Sandhu, Singh, & Kaur, 2004). MS × Tux and Tux × MS pool corn starches showed solubilities in the range 15.36–20.60% and 15.65–22.38%, respectively. The swelling power and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains. The extent of this interaction is influenced by the amylose/amylopectin ratio, and by the characteristics of amylose and amylopectin in terms of the molecular weight/distribution, degree and length of branching and conformation (Hoover, 2000). WBCs of starches from two corn pools did not differ significantly. Transmittance values of the cooked starch pastes from different crosses are summarized in Table 3. Transmittance, after 24, 48 and 72 h of storage for MS × Tux and Tux × MS pool corn starches ranged from 2.8–3.8, 2.2–3.0 and 2.0–2.6, respectively. No significant differences for light transmittance of cooked starch pastes were observed between MS × Tux and Tux × MS pool.

3.2. Thermal properties

Transition temperatures (T_o, T_p & T_c) for MS × Tux pool corn starches ranged from 64.04–67.30, 68.92–71.41 and 73.20–76.07 °C, while, for Tux × MS pool

Table 3
Effect of storage duration on the transmittance (%) of starches separated from different corn crosses[a]

Pools	Corn crosses (Lab no.)	Transmittance at 640 nm (%)		
		24 h	48 h	72 h
MS × Tux pool	662 × 684	2.8 ± 0.04	2.4 ± 0.05	2.2 ± 0.05
	663 × 684	3.6 ± 0.05	2.8 ± 0.06	2.4 ± 0.04
	663 × 692	2.8 ± 0.06	2.2 ± 0.03	2.0 ± 0.05
	664 × 692	3.2 ± 0.03	2.6 ± 0.02	2.4 ± 0.05
	667 × 684	3.0 ± 0.03	2.6 ± 0.03	2.2 ± 0.04
	667 × 692	3.2 ± 0.04	2.8 ± 0.06	2.4 ± 0.06
	669 × 684	3.0 ± 0.02	2.4 ± 0.05	2.0 ± 0.04
	674 × 684	3.8 ± 0.05	3.0 ± 0.04	2.6 ± 0.05
	677 × 692	2.8 ± 0.05	2.4 ± 0.04	2.4 ± 0.06
	678 × 684	3.2 ± 0.04	2.8 ± 0.06	2.6 ± 0.05
	678 × 690	3.0 ± 0.04	2.6 ± 0.05	2.4 ± 0.04
	679 × 684	2.6 ± 0.05	2.4 ± 0.05	2.0 ± 0.04
	679 × 692	3.8 ± 0.06	3.0 ± 0.06	2.6 ± 0.05
Range		2.6–3.8	2.2–3.0	2.0–2.6
Mean		3.13	2.63	2.32
Tux × MS pool	683 × 672	3.6 ± 0.06	2.8 ± 0.03	2.6 ± 0.05
	688 × 672	3.0 ± 0.05	2.6 ± 0.03	2.2 ± 0.06
	689 × 672	3.8 ± 0.03	3.0 ± 0.04	2.6 ± 0.04
	690 × 665	2.8 ± 0.04	2.2 ± 0.04	2.0 ± 0.04
	690 × 674	3.0 ± 0.02	2.4 ± 0.03	2.4 ± 0.05
	693 × 665	3.6 ± 0.02	2.8 ± 0.05	2.4 ± 0.05
	694 × 674	2.8 ± 0.05	2.2 ± 0.06	2.0 ± 0.03
	695 × 672	3.2 ± 0.04	2.8 ± 0.06	2.4 ± 0.05
	695 × 674	3.0 ± 0.05	2.6 ± 0.05	2.2 ± 0.05
	696 × 665	3.0 ± 0.06	2.4 ± 0.04	2.4 ± 0.05
	696 × 672	2.8 ± 0.05	2.6 ± 0.05	2.4 ± 0.04
	696 × 674	3.6 ± 0.06	2.8 ± 0.04	2.6 ± 0.05
	698 × 690	2.8 ± 0.05	2.2 ± 0.05	2.2 ± 0.04
Range		2.8–3.8	2.2–3.0	2.0–2.6
Mean		3.15	2.56	2.34

[a] Mean ± SD for triplicate measurements.

starches it ranged from 65.81–68.93, 70.25–72.13 and 74.59–76.82 °C, respectively. Seetharaman et al. (2001) reported T_o, R, ΔH_{gel}, and PHI in the range of 52.9–66.5 °C, 8.7–17.9, 8.8–12.2 J/g and 1.1–2.8, respectively, for the Argentinean corn accessions. Campbell et al. (1995) reported T_o and R of nonmutant corn inbreds to be 62.6–68.1 and 7.6–13.5 °C, respectively. Transition temperatures (T_o, T_p and T_c) of Tux × MS pool corn starches were significantly higher than MS × Tux pool

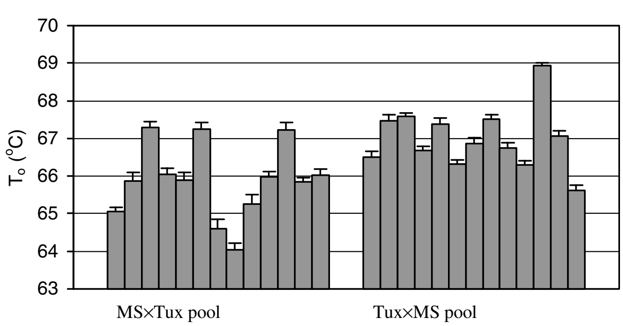

Fig. 1. T_o (°C) of starches from corn lines of MS × Tux pool (left) and Tux × MS pool (right).

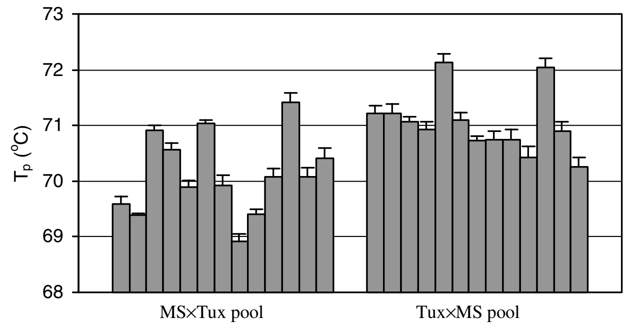

Fig. 2. T_p (°C) of starches from corn lines of MS × Tux pool (left) and Tux × MS pool (right).

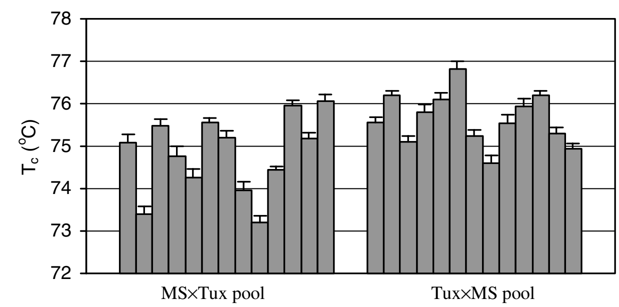

Fig. 3. T_c (°C) of starches from corn lines of MS × Tux pool (left) and Tux × MS pool (right).

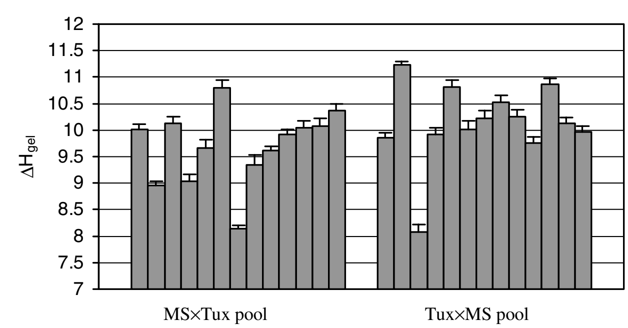

Fig. 4. ΔH_{gel} of starches from corn lines of MS × Tux pool (left) and Tux × MS pool (right).

corn starches (Figs. 1–3). The differences in corn starches may be due to differences in the compactness of starch granules and higher degrees of molecular order of granules (Krueger et al., 1987). MS × Tux and Tux × MS pool corn starches showed average ΔH_{gel} values of 9.70 and 10.1 J/g, respectively. Tux × MS pool corn starches showed significantly higher ΔH_{gel} values than MS × Tux pool corn starches (Fig. 4). The differences in ΔH_{gel} values may be due to varying amylose contents, which result in different alignments of hydrogen bonds within starch molecules (McPherson & Jane, 1999). PHI is the ratio of ΔH_{gel} to the gelatinization temperature range and is a measure of the uniformity in gelatinization. Average PHI values of 2.31 and 2.55 were observed for MS × Tux and Tux × MS pool corn starches,

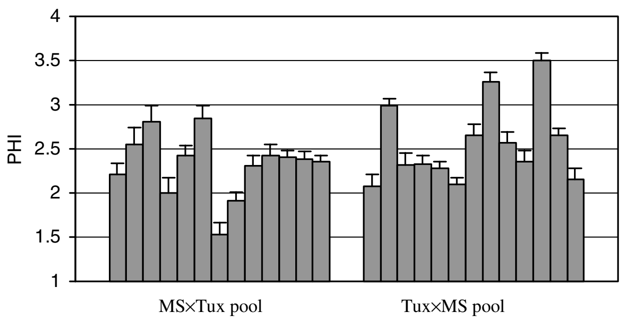

Fig. 5. PHI of starches from corn lines of MS × Tux pool (left) and Tux × MS pool (right).

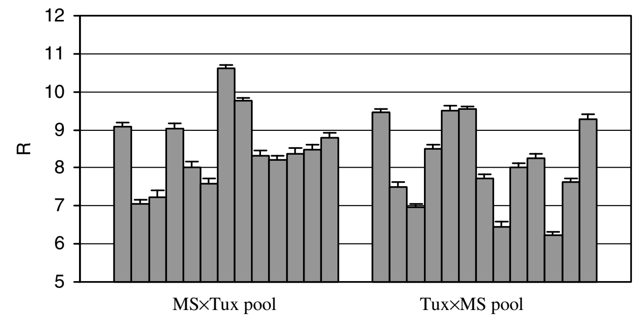

Fig. 6. *R* of starches from corn lines of MS × Tux pool (left) and Tux × MS pool (right).

respectively (Fig. 5). The *R*-values for MS × Tux and Tux × MS pool corn starches ranged from 7.04–10.62 and 6.22–9.54, respectively (Fig. 6). *R*-value decreased with the increase in the PHI and vice-versa.

3.3. Syneresis

The syneresis of gels prepared from starches separated from different corn crosses was measured as amount of water released from gels during storage (up to 120 h) at 4 °C (Table 4). The average values of syneresis of starches for MS × Tux pool corn starches after 24, 72 and 120 h of storage were 3.85%, 8.81% and 12.46%, respectively, whereas for Tux × MS pool starches they were 5.57%, 10.39% and 14.66%, respectively. Significantly higher syneresis values were observed for Tux × MS pool corn starches than for MS × Tux pool corn starches. During syneresis, amylose forms double-helical association of 40–70 glucose units (Jane & Robyt, 1984) whereas amylopectin crystallization occurs by

Table 4
Syneresis (%) of starches from different corn crosses[A]

Pools	Corn crosses (Lab no.)	24 h	72 h	120 h
	662 × 684	5.12 ± 0.21bc	10.18 ± 0.25bc	17.46 ± 0.26cd
	663 × 684	2.21 ± 0.18ab	7.13 ± 0.22ab	9.26 ± 0.20ab
	663 × 692	2.81 ± 0.16ab	9.16 ± 0.19bc	13.54 ± 0.17bc
	664 × 692	5.57 ± 0.19c	11.30 ± 0.20c	12.18 ± 0.15b
	667 × 684	4.40 ± 0.11bc	8.56 ± 0.21b	14.06 ± 0.21c
MS × Tux	667 × 692	4.88 ± 0.24bc	13.36 ± 0.22cd	17.52 ± 0.23cd
pool	669 × 684	1.86 ± 0.13a	5.01 ± 0.24a	7.90 ± 0.12a
	674 × 684	5.09 ± 0.18c	6.63 ± 0.23ab	12.15 ± 0.17b
	677 × 692	4.29 ± 0.19bc	8.36 ± 0.19b	9.08 ± 0.23ab
	678 × 684	4.11 ± 0.13bc	11.76 ± 0.18cd	13.49 ± 0.18bc
	678 × 690	4.79 ± 0.20bc	10.16 ± 0.16bc	15.13 ± 0.19cd
	679 × 684	3.25 ± 0.22ab	6.82 ± 0.24ab	12.55 ± 0.16bc
	679 × 692	1.70 ± 0.23a	5.69 ± 0.26ab	7.71 ± 0.18a
Range		1.7–5.57	5.01–13.36	7.71–17.46
Mean		3.85	8.81	12.46
	683 × 672	6.78 ± 0.22cd	11.67 ± 0.23cd	12.75 ± 0.23bc
	688 × 672	6.42 ± 0.12cd	13.89 ± 0.29d	19.49 ± 0.18d
	689 × 672	3.27 ± 0.25ab	9.49 ± 0.16bc	14.12 ± 0.21c
	690 × 665	5.48 ± 0.23c	9.79 ± 0.19bc	14.56 ± 0.13c
	690 × 674	5.68 ± 0.14cd	13.20 ± 0.21cd	18.08 ± 0.22cd
Tux × MS	693 × 665	8.59 ± 0.08d	16.54 ± 0.23e	19.49 ± 0.14d
pool	694 × 674	3.11 ± 0.12ab	5.60 ± 0.24ab	10.12 ± 0.16ab
	695 × 672	7.17 ± 0.13cd	11.27 ± 0.29c	13.25 ± 0.14bc
	695 × 674	8.61 ± 0.20d	12.70 ± 0.24cd	17.24 ± 0.17cd
	696 × 665	3.56 ± 0.23ab	5.50 ± 0.18ab	11.85 ± 0.21b
	696 × 672	3.96 ± 0.15b	7.39 ± 0.17ab	11.85 ± 0.13b
	696 × 674	3.95 ± 0.18b	5.56 ± 0.16ab	10.13 ± 0.19ab
	698 × 690	5.83 ± 0.13cd	12.47 ± 0.23cd	17.71 ± 0.14cd
Range		3.11–8.61	5.50–16.54	10.12–19.49
Mean		5.57	10.39	14.66

Values with similar letters in a column do not differ significantly ($p < 0.05$).
[A] Mean ± SD for triplicate measurements.

Table 5
Pearson correlation coefficients for the physicochemical and thermal properties of starches

	Amylose	Swelling power	Solubility	WBC	T_o	T_p	T_c	ΔH_{gel}	R	PHI	Syneresis (72 h)
Swelling power	−0.416**										
Solubility	−0.065	−0.135									
WBC	−0.343*	0.018	0.458**								
T_o	0.097	0.430**	−0.318*	−0.364*							
T_p	0.208	0.436**	−0.316*	−0.316*	0.874**						
T_c	0.376*	0.334*	−0.199	−0.257	0.530*	0.772**					
ΔH_{gel}	−0.058	0.455**	−0.409*	−0.210	0.510**	0.491**	0.462**				
R	0.113	−0.215	0.169	0.258	−0.704**	−0.270	0.077	−0.292			
PHI	−0.111	0.384**	−0.338*	−0.322*	0.777**	0.443**	0.159	0.656**	−0.892**		
Syneresis (72 h)	0.332*	0.327*	−0.234	−0.473**	0.240	0.386*	0.296	0.340*	0.089	0.060	
Syneresis (120 h)	0.423**	0.399*	−0.199	−0.311*	0.264	0.389*	0.433**	0.442**	0.046	0.121	0.848**

* $p < 0.05$.
** $p < 0.01$.

association of the outermost short branches (Ring et al., 1987).

3.4. Pearson correlation coefficients for the relationships between different starch properties

Pearson correlation coefficients for the relationships between different properties are presented in Table 5. Amylose content was negatively correlated with swelling power ($r = -0.416$) and positively correlated with syneresis ($r = 0.423$) after 120 h of storage. Tester and Morrison (1990) and Morrison, Tester, Snape, Law, and Gidley (1993) reported that the swelling behaviour of cereal starches was primarily a property of their amylopectin contents, amylose acts as an inhibitor of swelling, especially in the presence of lipids. Amylose content did not significantly correlate with the DSC parameters except for T_c, which may be due to the lower (17.5–22.1%) range of the amylose content of starches from different corn crosses. These results are in accordance with those reported earlier (Seetharaman et al., 2001). WBC was inversely correlated with amylose content and syneresis ($p < 0.05$). T_o, T_p and PHI were negatively correlated with WBC ($p < 0.05$). Transition temperatures (T_o, T_p & T_c), ΔH_{gel} and PHI were positively correlated with swelling power of starches. ΔH_{gel} was positively correlated with syneresis ($r = 0.442$) after 120 h of storage. This may be due to the difference in crystallinity of the starch granules (Ward, Hoseney, & Seib, 1994). Interrelation among DSC parameters was observed. Transition temperatures (T_o, T_p & T_c) were positively correlated with each other. T_o and T_p were positively correlated with ΔH_{gel} and PHI and negatively correlated with R ($p < 0.01$). Krueger et al. (1987) reported an increase in T_o and ΔH_{gel} and a decrease in R in the dent corn lines. A positive relation between T_o and ΔH_{gel} with r-value of 0.72 for OH43 inbred lines has been reported by Wang, White, and Pollak (1992). Peak temperature (T_c) was positively correlated with syneresis ($p < 0.01$). PHI was positively correlated with ΔH_{gel} ($r = 0.656$) and negatively correlated with R ($r = -0.892$).

4. Conclusions

Starches separated from Tux × MS pool corn showed higher swelling power, transition temperatures (T_o, T_p & T_c), ΔH_{gel} and synereses than starches from MS × Tux pool corn. MS × Tux pool corn starches, on the other hand, showed higher amylose contents than Tux × MS pool corn starches. So, before going through a rigorous breeding programme, it is advisable to screen the germplasm for the desirable properties of the starches.

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