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Some properties of corn grains and their flours I: Physicochemical, functional and chapati-making properties of flours

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Abstract

The variability in physical (1000 kernel weight and bulk density) and mechanical (rupture force) properties of grains from different Indian corn varieties (African tall, Ageti, Early composite, Girja, Navjot, Parbhat, Partap, Pb sathi and Vijay) were studied. The functional (colour, gelatinization, retrogradation and pasting) and chapati-making properties of flours milled from corn varieties were evaluated. African tall flour showed the highest enthalpy of gelatinization (ΔH_{gel}), peak-, trough-, breakdown-, final-, and setback viscosities, and L^* (84.4) value and resulted in chapaties with higher extensibility (5.76 mm) and of light colour. African tall flour, with the lowest protein content, showed the lowest grain rupture force. Amylose content and hardness of starch gel from African tall were found to be the lowest among all corn varieties. Girja flour, with the lowest transition temperatures and ΔH_{gel}, showed the lowest extensibility of chapaties made from it. Pearson correlations between physical and textural properties of corn grains and the functional properties of their flours were established. Rupture force of corn grain and protein content of flour showed a negative correlation with peak viscosity of flour ($r = -0.917$, and -0.863, $p < 0.01$). The protein content of flours was negatively correlated with L^* ($r = -0.759$, $p < 0.01$) value and positively with b^* ($r = 0.635$, $p < 0.01$) value. Pasting temperature of flours showed a significant negative correlation with peak, trough, breakdown, final and setback viscosities ($r = -0.836$, -0.846, -0.778, -0.871, and -0.847, respectively, $p < 0.01$). Pearson correlation was also established between the grain and starch properties. Rupture force of corn grains was positively correlated with the amylose content of starch ($r = 0.950$, $p < 0.01$).

Keywords: Corn flour; Mechanical; Thermal; Pasting; Chapati

1. Introduction

In India, corn has become the third important food grain after wheat and rice. About 35% of the harvested corn is used as a direct food, usually in the form of unleavened bread (chapaties) though consumption in other forms (corn-on-the-cob, as corn kernels) has also increased. Chapati is the staple diet of a majority of people living in the Indian subcontinent. Corn flour is used to make chapaties, which are eaten mainly in a few Northern states of India. By and large, corn breads are more commonly consumed by the less affluent people (Mehta & Dais, 1999). Sinha and Sharada (1992) compared the chapati-making properties of corn flours, before and after alkali treatment, and found that untreated chapaties were more acceptable than treated ones.

There are five general classes of corn-flint corn, popcorn, flour corn, dent corn, and sweet corn (Watson, 1987a). Different types of corn have different proportions of horny and floury endosperm. The floury endosperm is softer and easier to break than the horny endosperm (Jamin & Flores, 1998). Different parts of corn have different physical and chemical properties. Yellow corn has a horny endosperm, and more carotenoids (74–86%), which are the source of yellow colour in corn, than the floury endosperm (9–23%) (Watson, 1987b). Hardness and breakage susceptibility are related properties that can affect the utilization of corn (Pomeranz, Martin, Traylor, & Lai, 1984). The chemical basis of kernel

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hardness and endosperm vitreousness of cereal grains has long been studied, but remains unexplained; it may depend on various constituents of cereal grains; the protein is very important as it forms a matrix surrounding and embedding starch granules (Christianson, Nielson, Khoo, Wolf, & Wall, 1969; Dombrink-Knutzman, 1994). Almeida-Dominguez, Suhendro, and Rooney (1997) studied the factors affecting the rapid visco analyzer (RVA) curves for the determination of corn kernel hardness.

Rombo, Taylor, and Minnaar (2004) studied the changes of starch physicochemical properties upon irradiation of corn and bean flour. Ravi, Manohar, and Haridas Rao (1999) studied the use of RVA for measuring the pasting characteristics of wheat flour, as influenced by the additives. The effect of addition of corn starch on the pasting properties of rice flour has been reported by Wang, Sun, Zeng, and Lu (2000). Flores-Farias et al. (2000) reported the pasting properties of commercial nixtamalised Mexican corn flour. Not much work is reported on the functional and chapati-making properties of corn flours. This prompted us to undertake the present investigation. The present investigation describes the physicochemical, functional and chapati-making properties of flours from different corn varieties grown in India. Also, an attempt has been made to correlate the various functional and chapati-making properties of the flours with the properties of their starches.

2. Materials and methods

2.1. Materials

Six improved corn varieties, namely Ageti, Navjot, Parbhat, Partap, Pb sathi and Vijay from the 2003 harvest, were obtained from Punjab Agricultural University, Ludhiana, India. Three improved corn varieties, namely African tall, Early composite and Girja from the 2003 harvest, were obtained from Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, Palampur, India. Seeds of different corn varieties, after degermination, were ground to pass through sieve no. 72 (British Sieve Standards) to obtain flour. The flour samples were then packed in air-tight containers.

2.2. 1000 kernel weight

Corn grains were randomly selected and 1000 kernels of corn grains were counted. The counted grains were then weighed and expressed in grammes. All the measurements were triplicated.

2.3. Bulk density of corn grains

Corn grains were gently filled in a 100 ml graduated cylinder, previously tared. The bottom of the cylinder was gently tapped on a laboratory bench, several times, until there was no further diminution of the sample level after filling to the 100 ml mark. Bulk density was calculated as weight of sample per unit volume of sample (g/ml). All the measurements were triplicated.

2.4. Mechanical properties of corn grains

Corn grains, free of stress cracks, were used in this study. Before being used for the grinding test, corn lots were tempered at fixed moisture content (11.5% wb) using the method of Louis-Alexandre, Mestres, and Faure (1991). Grains were soaked in distilled water for 1 h then brought to $11.5 \pm 0.5\%$ moisture content by holding at 30 °C over saturated solutions of $Mg(NO_3)_2$. Grain hardness was determined as force required to break a kernel using the Instron universal testing machine (Model-4464, Instron, Buckinghamshire, England) equipped with a 2 kN load cell. A deformation rate of 1 mm/min was used in compression. Single corn grain was placed between two parallel plates and gradually compressed, while simultaneously recording the force and the corresponding deformation that occurred until the grain ruptured. At this point the force suddenly decreased, while the deformation continued. The force required to break the kernel was recorded. Ten readings were performed for each sample.

2.5. Colour characteristics of corn grit and flour

Colour measurements of corn grit and flour samples were carried out using a Hunter colorimeter Model D 25 optical Sensor (Hunter Associates Laboratory Inc., Reston, VA, USA) on the basis of L^*, a^* and b^* values. A glass cell, containing sample, was placed above the light source, covered with a white plate and L^*, a^* and b^* colour values were recorded. The instrument (45°/0° geometry, 10° observer) was calibrated against a standard red coloured reference tile ($L_s = 25.54$, $a_s = 28.89$, $b_s = 12.03$). Total colour difference (ΔE) was calculated by applying the equation

$$\Delta E = [(L_s - L)^2 + (a_s - a)^2 + (b_s - b)^2]^{1/2}$$

The L^* value indicates the lightness, 0–100 representing dark to light. The a^* value gives the degree of the red–green colour, with a higher positive a^* value indicating more red. The b^* value indicates the degree of the yellow–blue colour, with a higher positive b^* value indicating more yellow.

2.6. Proximate composition of corn flour

Corn flour was tested for moisture, ash, fat, fibre and protein contents by employing the standard methods of analysis (AOAC, 1990). The carbohydrate content was calculated by difference. All the results were recorded on a dry weight basis (dwb).

2.7. Chapati-making properties of corn flour

Corn flour (150 g) was mixed with optimum water (Gujral & Singh, 1999; Singh, Singh, & Kaur, 1998) for 3 min in a laboratory mixer (National Manufacturing Company, Lincoln, NE). The dough was rested for half an hour. Dough (50 g) was rounded, placed on a rolling board and then sheeted to a diameter of 155 mm and thickness of 2 mm using a rolling pin. The dough was rolled in one direction. The raw chapati was immediately placed on a hot plate (tawa) and baked for 15 s at 220 °C on one side and then 10 s at 220 °C on the other side. It was again turned and baked for 35 s at 290 °C. The chapati was allowed to cool for 10 min at 25 °C and then placed in polythene pouches and placed in an air-tight container at 25 °C. Rectangular strips of 7×1 cm were cut from the centre of the chapati using a metal template. This strip of chapati was then tested for extensibility on the TA/XT2 Texture analyzer (Stable Micro Systems, Surrey, England). One clamp was attached to the moving arm of TA/XT2 and the other was attached to the platform. A load cell of 20 N was used at a cross head speed of 1 mm/s to pull the chapati strip apart until it ruptured. The force displacement curve was obtained and from this peak force to rupture (N) and extensibility (mm) were calculated (Sharma, Mulvaney, & Rizvi, 2000).

2.8. Thermal properties of corn flours

Thermal characteristics of flours were studied by using a differential scanning calorimeter-821^e (Mettler Toledo, Switzerland) as described by Sandhu, Singh, and Malhi (2005). After conducting thermal analysis, the samples were stored in the refrigerator at 4 °C for 7 days for retrogradation studies. The sample pans were reheated at the rate of 10 °C/min from 20 to 100 °C after 7 days to measure retrogradation. The enthalpies of retrogradation (ΔH_{ret}) were evaluated and percentage of retrogradation ($\%R$) was calculated as $\%R$ = ratio of enthalpy of retrogradation to enthalpy of gelatinization $\times$ 100. All the measurements were triplicated.

2.9. Pasting properties of corn flours

Pasting properties of flours were studied using the Rapid Visco Analyzer (Newport Scientific Pty Ltd., Warriewood, NSW 2102, Australia). Viscosity profiles of flours were recorded using flour suspensions (10%, w/w; 28 g total weight). The temperature–time conditions included a heating step from 50 to 95 °C at 6 °C/min (after an equilibration time of 1 min at 50 °C), a holding phase at 95 °C for 5 min, a cooling step from 95 to 50 °C at 6 °C/min and a holding phase at 50 °C for 2 min. Parameters recorded were pasting temperature, peak-, trough- (minimum viscosity at 95 °C), final- (viscosity at 50 °C), breakdown- (peak-trough viscosity), and setback viscosity (final-trough viscosity). All the measurements were triplicated.

2.10. Statistical analysis

The data shown in all the tables were subjected to one-way analysis of variance (ANOVA). Pearson correlation coefficients (r) for the relationships between properties were also calculated using Minitab Statistical Software version 13 (Minitab Inc, USA).

3. Results and discussion

3.1. Physical and mechanical characteristics of corn grains

Physical (1000 kernel weight and bulk density) and mechanical (rupture force) properties of grains from different corn varieties are presented in Table 1. The 1000 kernel weight and bulk density varied significantly among corn varieties. The highest 1000 kernel weight for African tall (310 g) and the lowest for Pb sathi (102 g) were observed. Mestres, Matencio, and Louis-Alexandre (1995) reported 1000 kernel weight in a range from 193 to 315 g for different corn cultivars. Bulk density was found to be highest for Ageti (0.774 g/ml) and lowest for African tall (0.645 g/ml). The rupture force of the grains, measured using the Instron universal testing machine, also varied significantly (Table 1). Highest and the lowest rupture forces of 75.3 and 35.3 kg, respectively, for Pb sathi and African tall corn were observed. Variation in the mechanical properties may be attributed to variation in the proportions of floury or flint fractions in grains of different corn varieties. Grain hardness is the intrinsic characteristic and depends on the genetics and the environment (Dorsey-Redding, Hurburgh, Johnson, & Fox, 1991). Verma and Prasad (2000) reported rupture force varying from 156 to 689 N for Kisan composite variety with the variation in the moisture content.

Table 1
Physical, mechanical and Hunter colour properties of grains from different corn varieties

Variety	1000 kernel weight (g)	Bulk density (g/ml)	Rupture force (kg)	L^*	a^*	b^*	ΔE
African tall	310f	0.645a	35.3a	84.42c	−1.53a	10.77a	66.29d
Ageti	199b	0.774d	55.6e	77.75b	1.69b	25.28bc	60.34c
Early composite	250d	0.719bc	50.3d	74.41a	2.21c	25.85bc	57.37a
Girja	285e	0.702b	40.3b	75.14ab	2.18c	27.27cd	58.36b
Navjot	209bc	0.759cd	68.3g	75.90ab	2.53d	26.14c	58.57b
Parbhat	228c	0.768cd	62.2f	75.93ab	2.88e	27.17cd	58.69b
Partap	235cd	0.745c	44.8c	77.92b	2.11c	24.32b	60.09c
Pb sathi	102a	0.765cd	75.3h	74.02a	2.93e	27.49cd	57.12a
Vijay	222c	0.758cd	72.3h	74.92ab	3.23f	27.98d	57.89ab

Values with similar letters in a column do not differ significantly ($p < 0.05$).

3.2. Colour characteristics of corn grits and flours

Varietal difference was observed for various Hunter colour parameters among grits from different corn varieties (Table 1). L^* value of grits from different corn varieties ranged from 74.02 to 84.42, the lowest for Pb Sathi and the highest for African tall. The highest L^* parameter for African tall grit indicated its lighter colour than that of grits from other corn varieties. The a^* value (indicator of redness and greenness) ranged from −1.53 to 3.23, whereas b^* value (indicator of blueness and yellowness), ranged from 10.77 to 27.98 for grits of different corn varieties. The highest a^* and b^* value for Vijay grit and the lowest for African tall grit were observed. Hunter colour L^*, a^* and b^* values of 81.45, 2.86 and 23.49, respectively, for corn grits have been reported (Jamin & Flores, 1998). ΔE, which indicated total colour difference, for different corn varieties, ranged from 57.1 to 66.3. African tall grit was different from all other corn varieties in its highest L^* (84.42) and lowest a^* (−1.53) and b^* (10.77) values. This indicated that grit from this variety was light in colour, with slight green tint (due to negative a^* value). Grit from Vijay had a dark red colour due to its highest a^* value (3.23).

Hunter colour parameters for flours from different corn varieties are summarized in Table 2. L^* value of flours from different corn varieties ranged from 81.94 to 86.96, the lowest being for Navjot and the highest for African tall flour. Flours from all corn varieties showed negative a^* values, indicating the presence of green tint. The b^* value for corn flours ranged from 7.83 to 24.12. The highest b^* value of Pb sathi (24.12) flour indicated its yellow colour (due to the presence of a higher amount of carotenoids), whereas the lowest value for the same was observed for African tall flour. Hunter colour L^*, a^* and b^* values of 83.65, −0.21 and 20.51, respectively, for corn flour have been reported (Jamin & Flores, 1998). ΔE, ranged from 65.23 to 68.60, the lowest being for Navjot and the highest for African tall flour. Navjot flour was significantly different from the flours of other corn varieties in its lowest L^* and ΔE, thereby indicating its dark colour as compared to other corn flours. African tall flour with its highest L^* and ΔE value was significantly lighter in colour than other corn flours. The protein contents of flours were negatively correlated with L^* value ($r = -0.759$, $p < 0.01$) and positively correlated with b^* ($r = 0.635$, $p < 0.01$) value. A significant positive correlation ($r = 0.656$, $p < 0.01$) of a^* value of corn grits with the protein content was observed. A similar positive correlation of protein content with a^* and b^* value and negative correlation with L^* has been reported for corn grits and flour (Jamin & Flores, 1998).

3.3. Proximate composition of corn flours

The proximate composition of flours varied significantly among different corn varieties (Table 3). Ash content of corn varieties ranged from 0.19% to 1.66%. An ash content of 0.21% for corn flour has been reported by Singh, Singh, Sharma, and Saxena (2003). The ranges for protein and fat content were from 5.18% to 7.82% and 1.56% to 2.42%, respectively. Pb sathi had the highest while African tall had the lowest protein and fat content among all the varieties studied. The fibre content ranged from 0.42% to 0.62%, the lowest being for Early composite and the highest for Parbhat. Protein, fat and fibre contents of 5.2%, 2.0% and 0.5%, respectively, for corn flour have been reported by Alexander (1987). The carbohydrate content, calculated by difference, was the lowest for Pb sathi (87.6%) and the highest for African tall (92.5%).

3.4. Gelatinization properties of corn flours

The results of DSC analysis of flours separated from different corn varieties are summarized in Table 4. T_o, T_p and T_c for different corn flours ranged from 66.6 to 71.4, 72.1 to 76.9 and 77.8 to 82.8 °C, respectively. Girja flour showed the lowest T_o, T_p and T_c whereas Parbhat flour showed the highest values for the same. The higher gelatinization temperature for Parbhat flour indicated that more energy is required to initiate gelatinization of the starch present in it. The difference in gelatinization temperature among different flours may be attributed to the difference in size, form and distribution of starch granules in the flours, and to the internal arrangement of starch fractions within the granule (Kaur & Singh, 2005). ΔH_{gel} for different corn flours varied from 5.53 to 8.46 J/g, the lowest and the highest being observed for Girja and African tall flour, respectively. PHI is a measure of uniformity of gelatinization and

Table 2
Hunter colour and chapati-making properties of flours from different corn varieties

Variety	L^*	a^*	b^*	ΔE	Peak force to rupture (N)	Extensibility (mm)
African tall	86.96d	−2.34bc	7.83a	68.60d	4.78ab	5.76e
Ageti	84.46c	−2.73a	21.69c	67.19c	6.48c	4.52c
Early composite	83.10b	−2.52b	23.82d	66.27b	6.23c	5.24d
Girja	83.72bc	−2.72a	21.63c	66.54bc	4.56a	2.60a
Navjot	81.94a	−2.66ab	23.18d	65.23a	4.78ab	3.84b
Parbhat	83.92bc	−2.41bc	21.47c	66.54bc	4.97ab	2.88a
Partap	85.34cd	−2.81a	19.39b	67.71cd	6.64c	3.52b
Pb sathi	82.65ab	−2.32bc	24.12d	65.85ab	5.14b	3.51b
Vijay	82.76ab	−2.28c	23.86d	65.87ab	4.53a	3.54b

Values with similar letters in a column do not differ significantly ($p < 0.05$).

Table 3
Proximate compositions of flours from different corn varieties

Variety	Ash (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
African tall	0.19a	1.56a	5.18a	0.58c	92.5d
Ageti	0.43c	1.59a	6.11c	0.55bc	91.3c
Early composite	0.24ab	2.03c	5.67b	0.42a	91.6cd
Girja	0.63d	1.68ab	5.92bc	0.52b	91.2c
Navjot	0.81e	1.91bc	6.78d	0.59c	89.9b
Parbhat	0.65d	1.71ab	6.15c	0.62d	90.8bc
Partap	0.30b	1.82b	5.47ab	0.47ab	91.9d
Pb sathi	1.66f	2.42d	7.82e	0.51b	87.6a
Vijay	0.69d	2.31d	7.16d	0.60cd	89.2b

Values with similar letters in a column do not differ significantly ($p < 0.05$).

Table 4
Gelatinization properties of flours from different corn varieties

Variety	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	PHI	R
African tall	68.6b	73.2b	78.4b	8.46d	1.83d	9.2a
Ageti	71.0e	76.1cd	82.1cd	5.88a	1.15b	10.2b
Early composite	68.1b	72.9b	78.5b	6.05a	1.26bc	9.6ab
Girja	66.6a	72.1a	77.8a	5.53a	1.01ab	11.0bc
Navjot	71.0e	76.7d	82.8d	7.38c	1.29bc	11.4c
Parbhat	71.4e	76.9d	82.8d	6.78b	1.23bc	11.0bc
Partap	70.1d	75.8c	81.8c	7.71c	1.35c	11.4c
Pb sathi	71.2e	75.9c	81.7c	5.93a	1.26bc	9.4a
Vijay	69.4c	75.6c	82.4cd	5.72a	0.92a	12.4d

T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; ΔH_{gel}, enthalpy of gelatinization (dwb, based on starch weight); R, gelatinization range $2(T_p - T_o)$, PHI, peak height index; $\Delta H_{gel}/(T_p - T_o)$.
Values with similar letters in a column do not differ significantly ($p < 0.05$).

was found to be the lowest for Vijay (0.92) and the highest for African tall flour (1.81). Rombo et al. (2004) reported T_o, T_p, ΔH_{gel}, R and PHI values of 63.5 °C, 71.8 °C, 10.21 J/g, 8.3 and 1.23, respectively in corn flour. R for different corn flours ranged from 9.2 to 12.4. The higher R of Vijay flour suggests the presence of crystallites of varying stability within the crystalline domains of its starch granules. T_o, T_p and T_c of the gelatinization of flours were higher than that of pure corn starch. This may be due to the presence of more protein and fibre in the corn flour than in corn starch. The presence of these components in the flour significantly increased the amount of water available to the starch as compared to that in pure starch–water system (Wang & Kim, 1998). An interrelationship between different DSC parameters was observed. T_o was positively correlated with T_p and T_c ($r = 0.954$ and 0.891, respectively, $p < 0.01$). The 1000 kernel weight of corn grains showed significant negative correlation with T_o and T_c of corn flour ($r = -0.707$ and -0.628, respectively, $p < 0.01$). A positive correlation was observed between the bulk density and transition temperatures of gelatinization ($r = 0.732$, 0.805 and 0.848, respectively, $p < 0.01$) of corn flours.

3.5. Retrogradation properties of corn flours

The retrogradation properties of corn flours were studied after storage of gelatinized flours at 4 °C for 7 days. Significant differences in retrogradation properties of different corn flours were observed (Table 5). African tall flour showed the lowest T_o (46.0 °C) and T_p (56.1 °C) while the Pb sathi flour had the highest value ($T_o = 47.3$ °C and $T_p = 57.1$ °C) for the same. The endothermic peaks of all the corn flours, after storage of gelatinized flours, appeared at a lower temperature than those for gelatinization. Recrystallization of amylopectin branch chains has been reported to occur in a less-ordered manner in stored starch gels than their native starches. The value of enthalpy of retrogradation (ΔH_{ret}) of corn flours was observed to be lower than ΔH_{gel}. The lower value of ΔH_{ret} than ΔH_{gel} of corn flour might be due to the weaker starch crystallinity of retrograded starch (Sasaki, Yasui, & Matsuki, 2000). ΔH_{ret} reflects the melting of double helices formed during gel storage (Ratnayake, Hoover, Shahidi, Perera, & Jane, 2001). ΔH_{ret} was found to be lowest for Girja (1.93 J/g) and highest for African tall (3.56 J/g) flour. Retrogradation (%) was found to be lowest for Girja (34.9%) and highest for Parbhat (46.5%) flour. The amylopectin and intermediate materials play a significant role in starch retrogradation during refrigerated storage.

3.6. Pasting properties of corn flours

The results of pasting properties of flours from different corn varieties are summarized in Table 6. Significant difference in the pasting properties of flours from different corn

Table 5
Retrogradation properties of flours from different corn varieties

Variety	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{ret} (J/g)	R	%R
African tall	46.0a	56.1a	62.6ab	3.56d	20.2c	42.1c
Ageti	47.1b	56.4b	63.2bc	2.65bc	18.6a	45.1e
Early composite	46.3a	55.9a	62.0a	2.65bc	19.2b	43.8d
Girja	46.9ab	56.1a	61.8a	1.93a	18.4a	34.9a
Navjot	46.9ab	56.9bc	63.5bc	3.22cd	20.0bc	43.6d
Parbhat	46.6ab	56.8bc	63.8c	3.15cd	20.4c	46.5f
Partap	46.7ab	56.3b	62.9b	2.97c	19.2b	38.5b
Pb sathi	47.3b	57.1c	63.2bc	2.57b	19.6bc	43.3d
Vijay	47.0b	56.6bc	62.6ab	2.22ab	19.2b	38.8b

T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; ΔH_{ret}, enthalpy of retrogradation (dwb, based on starch weight); R, retrogradation range $2(T_p - T_o)$; %R, ratio of enthalpy of retrogradation to enthalpy of gelatinization × 100.
Values with similar letters in a column do not differ significantly ($p < 0.05$).

Table 6
Pasting properties of flours from different corn varieties

Variety	P_{Temp} (°C)	PV (cP)	TV (cP)	BV (cP)	FV (cP)	SV (cP)
African tall	74.9a	2740h	1782f	958g	4678h	2896i
Ageti	79.8c	1385d	1105d	280cd	3364e	2259f
Early composite	81.5d	1690e	1132d	558e	3518f	2386g
Girja	75.8a	1818g	1173d	645f	3145d	1972d
Navjot	79.9c	1180bc	1058cd	122b	3118d	2060e
Parbhat	81.5d	1250c	1028c	222c	2903c	1875c
Partap	77.4b	1727f	1318e	409d	4018g	2700h
Pb sathi	88.8f	771a	748a	23a	1776a	1028a
Vijay	84.6e	1125b	915b	210c	2118b	1203b

PV, peak viscosity; TV, trough viscosity, BV, breakdown viscosity; FV, final viscosity; SV, setback viscosity; P_{Temp}, pasting temperature.
Values with similar letters in a column do not differ significantly ($p < 0.05$).

varieties was observed (Fig. 1). The behaviour of the viscosity developed during cooking cycle (from 50 to 90 °C) reflects the capacity of the starch to absorb water and swell as the slurry is heated. Pasting temperature (PT) for the flours from various corn varieties ranged from 74.9 to 88.8 °C, the lowest being for African tall and the highest for Pb sathi. PT provides an indication of the minimum temperature required to cook the flour. African tall flour showed the highest value whereas Pb sathi showed the lowest value, for all pasting parameters except PT. All the flours showed gradual increase in viscosity with increase in temperature. The increase in viscosity with temperature may be attributed to the removal of water from the exuded amylose by the granules as they swell (Ghiasi, Varriano-Marstson, & Hoseney, 1982). Breakdown viscosity (BV) for different corn flours ranged from 23 to 958 cP, Pb sathi flour showed the least breakdown among all other corn flours. The lowest BV of Pb sathi flour indicated its paste stability. During the final cycle of cooling (from 95 to 50 °C), the viscosity increased owing to the alignment of the chains of amylose (Flores-Farias et al., 2000). Setback viscosity (SV) ranged from 1028 to 2896 cP, the lowest being for Pb sathi and the highest for African tall flour. The lowest SV of Pb sathi flour indicated its lower tendency to retrograde. Peak viscosity (PV) of corn flour was higher than that of starch. This may be due to the hydrophilic properties of protein and fibre present in the flour. T_o of gelatinization and retrogradation showed negative correlations with PV ($r = -0.608$, $p < 0.05$ and $r = -0.818$, $p < 0.01$) and BV ($r = -0.757$ and -0.785, $p < 0.01$). ΔH_{gel} was positively correlated with final viscosity (FV) and SV

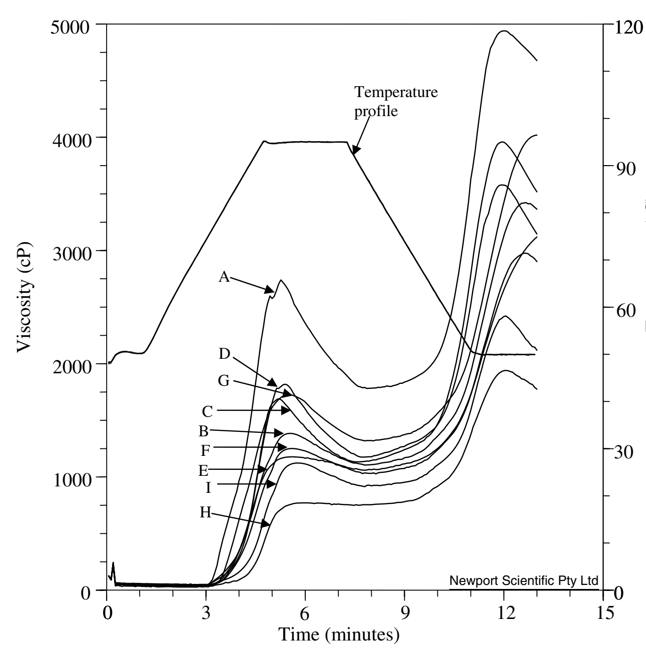

Fig. 1. Rapid Visco Analyzer pasting profiles of flours from different corn varieties: (A) African tall, (B) Ageti, (C) Early composite, (D) Girja, (E) Navjot, (F) Parbhat, (G) Partap, (H) Pb sathi, and (I) Vijay.

($r = 0.713$ and 0.672, respectively, $p < 0.01$). PV showed a negative correlation with ash and protein contents ($r = -0.744$ and -0.863, respectively, $p < 0.01$) whereas, PT showed positive correlation with these parameters ($r = 0.769$ and 0.871, respectively, $p < 0.01$). Interrelationship between various pasting parameters was observed. PV showed positive correlation with trough viscosity (TV), BD and FV ($r = 0.970$, 0.972, and 0.894, respectively, $p < 0.01$). PT showed negative correlations with PV, TV, BD, FV and SV ($r = -0.836$, -0.846, -0.778, -0.871, and -0.847, respectively, $p < 0.01$). Similar negative correlations of PT with PV and BV ($p < 0.01$) and positive correlations between PV and BV ($p < 0.01$) in rice flour have been reported (Limpisut & Jindal, 2002). Highly negative correlation between PV of flour and hardness of corn grain was observed ($r = -0.917$; $p < 0.01$). A similar negative correlation between the PV of corn flour and hardness of grain ($r = -0.95$, $p < 0.01$) has been reported (Almeida-Dominguez et al., 1997). Based on these results it could be inferred that corn grains with higher hardness had tightly packed starch granules and consequently developed lower viscosity levels. A significant negative correlation of protein with PV ($r = -0.863$, $p < 0.01$) of flour and a positive one with the rupture force of grain ($r = 0.922$, $p < 0.01$) was observed. The loosely packed starch granules with reduced protein-to-starch bonds in soft corn are able to hydrate and swell more rapidly in the presence of heat.

3.7. Chapati-making properties of corn flours

The textural properties of the chapaties made from different varieties of corn flour, measured using the TA/TX2 texture analyzer, differed significantly (Table 2). The force needed to extend the chapati strip increased during tensile deformation (extension) and reached a maximum before the strip ruptured, followed by a decrease. Chapaties from African tall flour showed the lower peak force to rupture (4.78 N) and higher extensibility (5.76 mm). The results revealed that the chapaties made from African tall flour had greater softness and extensibility than those from the other corn flours. Chapaties made from Girja flour showed the lowest extensibility of 2.6 mm. Gujral and Pathak (2002) reported an extensibility value of 11.01 mm and a peak force of rupture of 2.5 N for chapaties made from wheat flour supplemented with 10% corn flour. In general, chapaties made from corn flour had lower extensibilities than chapaties made from wheat flour. This might be due to the absence of gluten in corn flour (Gujral & Pathak, 2002). Chapaties made from African tall flour were superior to those from other corn varieties in terms of textural and colour properties.

3.8. Pearson correlations between different properties of grains, flours, starches and chapaties

Several significant correlations between the properties of corn grains, their flour, and chapaties with the properties of the starches were observed (Table 7). Granule swelling influenced the extensibility of the chapati. Extensibility of the chapaties was positively correlated with the SP ($r = 0.675$, $p < 0.01$) and PV ($r = 0.512$, $p < 0.05$) and negatively correlated with PT ($r = -0.589$, $p < 0.05$) of starch. Amylose content of starch was positively correlated with the transition temperatures of gelatinization and retrogradation of the flours. Amylose content of starch showed negative correlation with PV, TV, BV, FV and SV ($r = -0.868$, -0.790, -0.895, -0.812, and -0.789, respectively, $p < 0.01$) of flours. Amylose content of the starch was positively correlated with the rupture force of the grains ($r = 0.950$, $p < 0.01$). Dombrink-Kurtzman and Knutson (1997) reported higher amylose content of corn starch in hard endosperm than in soft endosperm. Relationships between the thermal properties of the flour and starch were observed. T_o, T_p and T_c of gelatinization of

Table 7
Pearson correlations between textural properties of the corn grains and the functional and chapati-making properties of their flours with the functional properties of their starches

Starch properties	Grain and flour properties												
	T_o[a]	T_p[a]	T_c[a]	$T_o(R)$[a]	$T_p(R)$[a]	$T_c(R)$[a]	PV[a]	TV[a]	BV[a]	FV[a]	SV[a]	RF[a]	EXT[a]
AMY[a]	0.700[c]	0.766[c]	0.828[c]	0.676[c]	0.814[c]	0.577[b]	−0.868[c]	−0.790[c]	−0.895[c]	−0.812[c]	−0.789[c]	0.950[c]	−0.330
SP[a]	−0.703[c]	−0.819[c]	−0.815[c]	−0.484	−0.666[c]	−0.779[c]	0.527[b]	0.363	0.657[c]	0.293	0.248	−0.435	0.675[c]
T_o[a]	0.956[c]	0.904[c]	0.812[c]	0.220	0.733[c]	0.970[c]	−0.417	−0.204	−0.602[b]	−0.130	−0.090	0.491	−0.092
T_p[a]	0.947[c]	0.957[c]	0.897[c]	0.271	0.702[c]	0.971[c]	−0.464	−0.249	−0.649	−0.149	−0.096	0.507	−0.203
T_c[a]	0.907[c]	0.955[c]	0.926[c]	0.321	0.603	0.909[c]	−0.478	−0.271	−0.654[c]	−0.141	−0.074	0.484	−0.215
PV[a]	−0.780[c]	−0.880[c]	−0.866[c]	−0.418	−0.632[b]	−0.817[c]	−0.537[b]	0.350	0.690[c]	0.208	0.133	−0.453	0.512[b]
BV[a]	−0.738[c]	−0.859[c]	−0.851[c]	−0.315	−0.563[b]	−0.798[c]	0.474	0.289	0.628[b]	0.143	0.070	−0.410	0.486
FV[a]	−0.622[c]	−0.698[c]	−0.653[c]	−0.138	−0.428	−0.699[c]	0.324	0.153	0.473	−0.033	−0.118	−0.215	0.426
SV[a]	−0.587[b]	−0.681[c]	−0.644[c]	−0.070	−0.375	−0.678[c]	0.279	0.111	0.428	−0.073	−0.155	−0.487	0.404
PT[a]	0.572[c]	0.675[c]	0.649[c]	0.164	0.426	0.677[c]	−0.333	−0.189	−0.454	−0.064	−0.004	0.216	−0.589[b]

[a] AM, amylose content; SP, swelling power; T_o, gelatinization onset temperature; T_p, gelatinization peak temperature; T_c, gelatinization conclusion temperature; $T_o(R)$, retrogradation onset temperature; $T_p(R)$, retrogradation peak temperature; $T_c(R)$, retrogradation conclusion temperature; PV, peak viscosity; TV, trough viscosity; BD, breakdown viscosity; FV, final viscosity; SV, setback viscosity; PT, pasting temperature; RF, rupture force; EXT, extensibility.

[b] Correlation is significant at 0.05 level.

[c] Correlation is significant at 0.01 level.

starch was positively correlated with T_o ($r = 0.956$, 0.904, and 0.812, respectively, $p < 0.01$), T_p ($r = 0.947$, 0.957, and 0.897, respectively, $p < 0.01$) and T_c ($r = 0.907$, 0.955, and 0.926, respectively, $p < 0.01$) of gelatinization of flour. Relationships between the pasting properties of the starch and the gelatinization properties of the flours were observed. T_o, T_p and T_c of gelatinization of flours were negatively correlated with the PV ($r = -0.780$, -0.880, and -0.866, respectively, $p < 0.01$), BV (-0.738, -0.859, and -0.851, respectively, $p < 0.01$), FV ($r = -0.622$, -0.698, and -0.653, respectively, $p < 0.01$) and SB ($r = -0.587$, -0.681, and -0.644, respectively, $p < 0.01$) of the starch. PT of starch, however, showed positive correlations with the T_o, T_p and T_c of gelatinization of the flours ($r = 0.572$, 0.675, and 0.649, respectively, $p < 0.01$).

4. Conclusions

Chapati-making property was affected by the physicochemical and functional properties of the flours. African tall flour, showing higher L^* value, ΔH_{gel}, peak-, trough-, breakdown-, final- and setback viscosities gave chapaties with the highest extensibilities. African tall starch showed the lowest amylose content and hardness of its gel. African tall flour, with the lowest protein content, showed the lowest grain rupture force. Several significant correlations were observed among various properties of the grains and flours. Negative correlation of protein with peak viscosity and positive correlation with rupture force of grain were observed. The protein content of flour and grits was negatively correlated to L^* whereas it was positively correlated to b^*. Peak-, trough-, breakdown- and final viscosities were positively correlated with each other and were negatively correlated with pasting temperature.

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