Characteristics of normal and waxy corn: physicochemical, protein secondary structure, dough rheology and chapatti making properties

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Abstract The physicochemical, protein secondary structure, dough rheological and chapatti making properties of normal and waxy corn types were evaluated. Waxy corn grains showed the highest L^* and b^* value, while red-pigmented corn grains had the highest a^* value. Higher accumulation of K, Mg, Na and Ca minerals in corn was recorded, while Cu, Mn, Fe and Zn were present in trace. Meal prepared from waxy corn had higher L^* , a^* and b^* values as well as ash, protein and fat content. A significant decrease in various mixograph parameters was observed with increase in water level during dough development. A decrease in dynamic rheological parameters (G' , G'' and $\tan \delta$) of dough from all corn types was recorded with increase in water level. Dough developed from waxy corn meal had lower G' and G'' as compared to that from normal corn types. FTIR spectra of dough from different corn types at different water levels showed various peaks in amide-I region with most prominent peak at about 1650 cm^{-1} followed by 1640 – 1645 and 1610 – 1620 cm^{-1} regions. The peak intensities increased with increase in water level which was an indicative of the increase in intermolecular and antiparallel (IM + AP) β -sheet as well as α -helix and β -sheet structures. Dough developed from waxy corn showed change in peak intensities at high moisture level only. The chapatti made from normal

(yellow) corn showed higher consumers' acceptability score, while that from waxy corn was poor.

Keywords Corn dough · Mineral · Mixograph · Rheology · FTIR · Chapatti

Introduction

During chapatti making, the dough preparation requires dry flour mixed with an appropriate amount of water to form a coherent mass by doing mechanical work in order to get acceptable product (Hoseney and Finney 1974). The corn flour is found less acceptable for baked products due to lack of storage proteins exhibiting viscoelasticity in dough (Shewry et al. 2002). Yet, corn based products are seeking demand as a gluten free alternative substitute due to high prevalence of gluten sensitivity or celiac disease (Torbica et al. 2010). The major protein fraction in corn kernel is zein i.e. a prolamine and provide viscoelasticity to dough at $>20\%$ moisture and mixed at $35\text{ }^{\circ}\text{C}$ temperature (Lawton 1992). Petrofsky and Hoseney (1995) reported that different flours required different amount of water and different mixing time for optimum dough development. The corn of different colour like white, yellow, pigmented (red, orange, blue) and type viz. dent, flint and waxy type has been available with varying characteristics.

For studying the mixing behaviour and for measuring the quality of flour, mixograph is one of the most commonly used instruments in baking industry (Singh et al. 2016). During dough formation, water plays an important role in case of flour as water is necessary for (a) solubilisation of other ingredients, (b) carbohydrates and proteins hydration (c) starch-protein network development (Maache-Rezzoug et al. 1998). The essential role of water

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in determining the rheological behaviour of flour doughs was studied by Webb et al. (1970). The mixing behaviour of dough can be predicted using rheological testing that provides certain information to predict the quality of final product (Moreira et al. 2010). Campbell and Shah (1999) described the intimate relationship between mixing and rheology, as the flour compounds are subjected to mechanical work that promote changes in their rheological properties. The dough rheology measures the viscoelasticity behaviour of food and is affected by certain factors during the time after mixing which include continued hydration of flour components, stress relaxation after mixing and water redistribution (Hibberd 1970).

Fourier transform infrared (FTIR) spectroscopy is a well-established technique for determining the protein secondary structure and chemical microstructure of foods (Wetzel and Reffner 1993). It is a flexible method of determining qualitative and quantitative information using very less amount of sample (Ferreira et al. 2001). Duodu et al. (2001) studied the secondary structure of corn zein films and determined that the protein was mainly in α -helical form along-with some β -sheet character.

The present work was designed to study the effect of varied water level on mixing behaviour of corn meal. The dough thus prepared using different amount of water was analysed for changes in rheological properties. The protein secondary structure of dough was also compared for variation in amount of water. On the basis of these parameters, chapatti was made from dough of different corn varieties and evaluated for texture, water activity and sensory acceptance.

Materials and methods

Material

Two white (YP/JCR-1, African Tall), two yellow (JCR-2067 and HQPM1) and two red-pigmented (JCR-2105 and JCR-2110) corn varieties were procured from Himachal Pradesh and waxy corn (IC 550353) was procured from J&K.

Physicochemical characteristics of corn grains

Hunter colour (L^* , a^* and b^*) of cleaned grains from different varieties was measured using Ultra Scan VIS Hunter Lab (Hunter Associates Laboratory Inc., Reston, VA, U.S.A.). 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.

Grains were selected randomly from corn varieties and 100 grains were counted and weighed and results for hundred grain weight (HGW) were expressed in grams.

Bulk density (BD) of different corn varieties was calculated by the method described by Sandhu et al. (2007). Bulk density was calculated as weight of sample per unit volume of sample (g/mL).

Mineral composition of corn varieties was done using Atomic Absorption Spectrometer (Agilent Technologies) by wet digestion method. Samples (1 g) in a porcelain crucible were heated to 600 °C in muffle furnace and ash formed was dissolved in 5 mL of 1 N nitric acid. The solution was then heated and filtered. The filtrates were analyzed for Cu, Mn, Fe, Zn, K, Mg, Na and Ca content. Instrument was calibrated using standard stock solutions of elements (Parmar et al. 2014).

Preparation of corn meal

The cleaned grains were ground using laboratory scale supermill (Newport scientific, Australia) and sieved through 72 mesh in order to obtain the meal with 95% of extraction rate by removing the coarsest bran particles. The sieved flours from different varieties were packed in airtight bags and kept in refrigerator for further analysis.

Corn meal characteristics

Physicochemical properties

Hunter colour (L^* , a^* and b^*) of corn meal was measured as described in previous section. The protein (%), fat (%) and ash (%) content of corn meal from different corn varieties was determined by AACC approved methods (AACC 2000).

Dough preparation and mixograph characteristics

The corn meal (10 g) was mixed with warm water using a bowl and mixographs were recorded electronically (National Mfg. Co. Lincoln, NE, USA). Four different levels viz. 7, 8, 9 and 10 mL of water was mixed with meal from different corn varieties and different parameters were evaluated including the mixograph peak time (MPT), mixograph peak width (MPW), left peak value (LPV), left peak width (LPW), right peak value (RPV), right peak width (RPW) and weakening slope (WS).

Dough dynamic rheology

The dynamic rheology of corn dough samples prepared in mixograph was studied using Anaton Paar Rheo Plus/32 Model MCR-301. The corn dough samples were left to rest for 10 min before each test. Changes in storage modulus (G'), loss modulus (G'') and $\tan \delta$ (G''/G') were recorded. Parallel plate geometry with 40 mm diameter and 2 mm gap was used for analysis by using the profile described by Shevkani et al. (2011).

Secondary structure analysis

The protein secondary structure of prepared dough samples were determined using FTIR spectrophotometer (Vertex 70, Bruker, Germany). The spectra were recorded on FTIR, equipped with an ATR (Attenuated Total Reflection) cell and a deuterated L-alanine doped triglycine sulphate (DLATGS) detector. The background was recorded using spectra of empty cells. An average of 200 scans was selected for all spectra. The OPUS software was used for measurements with wave numbers ranging from 800 to 2000 cm^{-1} (fingerprint region) and a 4 cm^{-1} resolution. The quantitative estimation of the secondary structure in dough was determined from the second-derivative spectra in the amide-I region.

Chapatti making properties

On the basis of mixographic, rheological and secondary structure analysis of meal from different corn varieties, the best dough made was used for chapatti making. Corn meal (100 g) was mixed with optimum water (Gujral and Singh 1999) for 5 min in a laboratory mixer (National Manufacturing Company, Lincoln, NE). The dough was rested for half an hour. Dough (40 g) was rounded and then sheeted to a diameter of 130 mm and thickness of 1.5 mm using chapatti maker. The raw chapatti was immediately placed on a hot chapatti maker and baked from both sides. The chapatti was allowed to cool and then placed in polythene pouches. Rectangular strips (7×1 cm) were cut from the centre of the chapatti using a metal template and then tested for extensibility using 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 chapatti strip apart until it ruptured. The force to rupture (N) and extensibility (mm) were calculated (Sharma et al. 2000). Water activity of chapatti made from each corn variety after cooling for 1 h was calculated using an AquaLab 4TE series apparatus.

The sensory evaluation was done for prepared corn chapattis following the method of Lu et al. (2010) with minor modifications. Fifteen untrained panellists from Department of Food science and Technology, Guru Nanak Dev University, Amritsar, evaluated chapattis for visual appearance (texture), colour, mouth feel and overall acceptability (means of measured sensory characteristics) on a nine-point hedonic scale (1: highly dislike to 9: highly like). Panellists rinsed their mouths using water after each analysis to minimise any residual effect.

Statistical analysis

The data reported are average of three replications. The data given in tables were subjected to one-way analysis of variance (ANOVA) to identify the significant differences among the varieties. Pearson correlation coefficients (r) were calculated using Minitab Statistical Software version 13 (Minitab Inc, USA) for obtaining the relationships between properties.

Results and discussion

Grain characteristics

BD, HGW and hunter colour characteristics of grains from normal and waxy corn are reported in Table 1. A significant variation in BD and HGW was observed among different corn types. Waxy corn showed the lowest (0.643 g/L), while normal corn (JCR-2110) showed the highest BD (0.821 g/mL). Sandhu et al. (2007) reported BD of corn grains in the range between 0.645 and 0.774 g/mL. HGW of different corn varieties ranged between 19.30 and 33.51 g. Similar range for HGW was reported earlier by Mestres et al. (1995). Colour parameters (L^* , a^* and b^*) varied significantly among different corn types. L^* value of white and red -pigmented corn grains was lower than that of yellow coloured and waxy corn grains (Thakur et al. 2015). Corn grains from JCR-2105 (red-pigmented corn) showed the lowest (47.41), while waxy corn grains showed the highest (69.70) L^* value. The lowest L^* value for red-pigmented corn indicated its dark colour grains which might be associated to higher pigment content that contributes to higher antioxidant activity (Zilic et al. 2012) and higher phenolic content (Thakur et al. 2017). Yellow colour of HQPM1 showed the lowest, while red-pigmented corn grains showed the highest a^* value. The red-pigmented corn with the highest a^* value indicated its dark red colour due to presence of pigments. The red-pigmented corn grains showed the lowest (12.0), whereas waxy corn grains showed the highest (29.16) b^* value. The higher b^* value for waxy and yellow corn indicated more yellowness

Table 1 Physicochemical composition of grain from different corn varieties

Variety	Colour	L^*	a^*	b^*	BD (g/ml)	HGW (g)
HQPM1	Yellow	69.08 ± 0.25^f	2.48 ± 0.17^a	22.28 ± 0.42^d	0.759 ± 0.020^c	20.34 ± 0.53^b
JCR-2067	Yellow	65.67 ± 0.59^e	6.11 ± 0.08^c	23.29 ± 0.50^c	0.786 ± 0.030^c	33.51 ± 0.41^f
African Tall	White	57.97 ± 0.58^c	4.68 ± 0.31^b	18.06 ± 0.60^b	0.712 ± 0.037^b	31.08 ± 0.54^e
YP/JCR-1	White	62.19 ± 0.92^d	2.54 ± 0.07^a	19.44 ± 0.21^c	0.777 ± 0.017^{bc}	20.12 ± 0.38^b
JCR-2105	Red-pigmented	47.41 ± 0.74^a	15.2 ± 0.62^e	12.30 ± 0.51^a	0.819 ± 0.036^d	29.08 ± 0.39^d
JCR-2110	Red-pigmented	51.38 ± 0.30^b	15.2 ± 0.55^e	12.90 ± 0.55^a	0.821 ± 0.022^d	27.88 ± 0.22^c
WAXY	Yellow-Golden	69.70 ± 0.39^f	7.30 ± 0.26^d	29.16 ± 0.20^f	0.643 ± 0.023^a	19.30 ± 0.28^a

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

BD bulk density; HGW hundred grain weight

Table 2 Mineral composition of grains from different corn varieties

Variety	Cu (ppm)	Mn (ppm)	Fe (ppm)	Zn (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)
HQPM1	0.056 ± 0.02^{bc}	0.130 ± 0.05^c	0.887 ± 0.06^e	1.330 ± 0.04^{bc}	757 ± 39^c	243 ± 18^b	13.14 ± 0.10^b	7.84 ± 0.14^b
JCR-2067	0.067 ± 0.04^c	0.167 ± 0.03^d	0.392 ± 0.13^a	2.402 ± 0.08^d	533 ± 36^b	305 ± 24^c	16.10 ± 0.46^{cd}	7.28 ± 0.34^b
African Tall	0.037 ± 0.03^a	0.112 ± 0.05^a	0.540 ± 0.05^c	2.280 ± 0.02^d	504 ± 19^b	237 ± 16^b	15.07 ± 0.44^c	5.24 ± 0.06^a
YP/JCR-1	0.049 ± 0.05^b	0.168 ± 0.09^d	0.763 ± 0.04^d	1.267 ± 0.02^b	429 ± 8.3^a	153 ± 20^a	17.65 ± 0.29^d	7.51 ± 0.28^b
JCR-2105	0.048 ± 0.02^b	0.122 ± 0.06^{bc}	1.386 ± 0.33^f	1.172 ± 0.03^b	449 ± 84^a	136 ± 09^a	11.23 ± 0.20^a	7.25 ± 0.34^b
JCR-2110	0.072 ± 0.01^d	0.115 ± 0.07^a	1.358 ± 0.10^f	0.821 ± 0.07^a	733 ± 68^c	154 ± 17^a	12.54 ± 0.27^{ab}	9.65 ± 0.43^c
WAXY	0.061 ± 0.01^c	0.170 ± 0.02^d	0.490 ± 0.03^b	1.480 ± 0.04^c	862 ± 48^d	456 ± 13^d	18.32 ± 0.22^e	7.65 ± 0.40^b

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

as compared to that of white and red-pigmented corn (Thakur et al. 2015). This might be due to higher carotenoid and xanthophyll content in yellow corn as compared to white corn (Singh et al. 2011b). Chandler et al. (2013) also reported high carotenoid content in yellow corn grains, while white corn grains had very less amount of these.

Mineral content viz. Cu, Mn, Fe, Zn, K, Mg, Na and Ca for different corn varieties is given in Table 2. Different coloured corn varieties showed a significant variation in mineral composition of grains. The minerals in corn are mostly concentrated in germ and aleuron layer of kernel, hence utilization of whole grain would be beneficial for human health (Nuss and Tanumihardjo 2010). K and Mg content were higher than that of other elements viz. Cu, Mn, Fe, Zn, Na and Ca in different corn varieties which was in the agreement with the findings of Semassa et al. (2016). Ahmadi et al. (1993) reported that difference in mineral composition might be due to soil fertility, genetic and climatic factors. K content was present in the highest amount, while Cu content was the lowest. K and Mg content was the lowest in JCR-2105 and the highest in waxy corn. Red-pigmented corn varieties had higher Ca and Na content as compared to that of other varieties. A

lower Zn content and higher Ca content was recorded in red-pigmented corn as compared to other corn types. Higher K and Mg content in waxy corn than other corn types might be due to lower endosperm to brany layer ratio (Thakur et al. 2015).

Physicochemical properties of corn meal

Hunter colour characteristics, ash, protein and fat content of flour from different corn varieties are summarized in Table 3. The L^* value of corn meal from different coloured varieties ranged between 52.56 and 75.73, the lowest being for JCR-2105 and the highest for waxy corn meal. L^* value of corn flour was reported to be 59.21 by Singh et al. (2003). A significant higher L^* and lower a^* and b^* values of meal as compared to their counterpart grains was recorded. This might be due to removal of bran from endosperm part used for meal making. The removal of bran from pigmented grains rich in pigments decreased the redness and yellowness of corn and increased the lightness. Katyal et al. (2016) reported that the presence of brany layer in flour imparted darker colour to the products. The a^* value of red-pigmented corn meal was 2.32 (JCR-2105) and 2.85 (JCR-2110), which was much lower than a^* of

Table 3 Physicochemical properties of meal made from different corn varieties

Variety	L^*	a^*	b^*	Ash content (%)	Protein content (%)	Fat content (%)
HQPM1	71.73 ± 0.12^f	-0.52 ± 0.01^a	20.55 ± 0.14^c	0.75 ± 0.01^a	6.29 ± 0.05^b	4.05 ± 0.02^c
JCR-2067	69.04 ± 0.09^e	1.21 ± 0.02^c	21.19 ± 0.12^c	1.15 ± 0.03^c	6.55 ± 0.08^b	3.87 ± 0.01^{bc}
African Tall	61.52 ± 0.15^c	1.25 ± 0.01^c	14.88 ± 0.11^b	0.89 ± 0.01^{ab}	7.02 ± 0.06^c	3.73 ± 0.05^b
YP/JCR-1	64.39 ± 0.21^d	0.29 ± 0.03^b	15.53 ± 0.13^b	0.95 ± 0.02^b	5.95 ± 0.02^a	2.89 ± 0.09^a
JCR-2105	52.56 ± 0.19^a	2.32 ± 0.02^d	10.39 ± 0.09^a	0.98 ± 0.03^b	7.25 ± 0.07^c	3.74 ± 0.03^b
JCR-2110	53.25 ± 0.11^b	2.85 ± 0.05^d	11.82 ± 0.07^a	0.94 ± 0.01^b	7.76 ± 0.08^d	3.67 ± 0.05^b
WAXY	72.48 ± 0.25^g	3.62 ± 0.02^e	25.06 ± 0.12^d	1.59 ± 0.02^d	8.32 ± 0.11^e	5.01 ± 0.04^d

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

grains (15.24 and 15.25) from these varieties. The decrease in redness after sieving showed that the pigments imparting redness to the grains were removed as bran, hence caused a reduction in a^* of flour from red-pigmented corn. The highest a^* and b^* values were recorded for meal from waxy corn.

Ash, protein and fat content of meal from different colored corn varieties ranged from 0.75 to 1.59%, 5.95 to 7.76% and 2.89 to 5.01%, respectively. Waxy corn meal had the highest ash content (1.59%) amongst all corn varieties. Ash content of meal from different corn varieties was reported in the range from 0.19% to 1.66% (Sandhu et al. 2007). YP/JCR-1 had the lowest, while waxy corn flour had the highest protein and fat content. A higher ash, protein and fat content of waxy corn than normal corn were also reported earlier (Collins et al. 2003). The results of ash, fat and protein content of corn meal were in accordance with Chel-Guerrero et al. (2015). Protein content was correlated positively to a^* of corn meal ($r = 0.941$, $p \leq 0.005$), consistent with the results reported by Katyal et al. (2016).

Mixographic properties

The mixograph parameters calculated during dough development of different corn varieties at different levels of water are shown in Table 4. Dough from corn meal was prepared by adding warm water that helped in aggregation of particles due to partial gelatinization of starch (Singh et al. 2011a). MPT indicates the time required for dough development that ranged between 0.30 and 8.87 min for different corn varieties. Waxy corn meal showed the lowest (0.30–1.52 min) and meal from red-pigmented corn varieties had the highest value for MPT. At low water level, MPT was the highest for JCR-2110 and JCR-2105 during dough development (8.87 and 8.31 min, respectively), which showed a significant decrease with increase in water level and was the lowest at 10:9 ratio of mixture (1.11 and 2.28 min, respectively). White coloured African tall and

YP/JCR-1 showed MPT between 1.40 and 4.58 min, while yellow HQPM1 and JCR-2067 had MPT between 1.25 and 7.97 min, respectively. The different amounts of water and mixing time may be required by different flours for optimum dough development (Petrofsky and Hoseneey 1995). Results reflected that time required for optimum dough development decreased as water content increased. The availability of more water during dough mixing may have significantly reduced the mixing time requirement for optimum dough development.

All mixographic parameters had the highest values for red-pigmented corn varieties followed by yellow corn and the lowest values were recorded for waxy corn meal. RPW indicated the width of peak 1 min after MPT, exhibiting dough tolerance during overmixing (Singh et al. 2016). Red-pigmented and yellow corn varieties showed higher RPV (indicative of strong and stable dough) and RPW than white and waxy corn.

The mixographic results showed that meal of red-pigmented and yellow corn varieties at 40% water resulted into dough with more consistency and stability than those obtained at higher water levels. The increase in water level showed a decline in dough consistency as well as stability. Fevzioglu et al. (2012) observed that the more consistent doughs were made when water was less.

WS is calculated as the difference of curve height at MPT and height at tail which indicates the rate of breakdown while mixing (Martinant et al. 1998). According to mixographic properties, the dough with longer mixing time, wider peak width and lower breakdown indicated strong and stable dough. The dough made from waxy corn meal had high value for WS (14.6) at low water level which indicated its high breakdown. WS decreased significantly with increase in water level and became lower when equal amount of water was mixed with flour. This might be due to high protein content of waxy corn meal that resulted into more water absorption for consistent dough development. Protein interaction and aggregation occurred during mixing that form a network (Khatkar et al.

Table 4 Mixographic properties of dough made from different corn varieties at varied water level

Variety	Water level	MPT (min)	MPW (%)	LPV (%)	LPW (%)	RPV (%)	RPW (%)	WS (%Tq*min)
HQPM1	10:07	6.99 ± 0.06 ^f	16.1 ± 0.10 ^f	13.0 ± 0.14 ^c	16.2 ± 0.14 ^f	12.8 ± 0.08 ^f	15.5 ± 0.04 ^h	3.50 ± 0.03 ^c
	10:08	2.85 ± 0.04 ^c	15.5 ± 0.10 ^f	12.4 ± 0.06 ^e	14.1 ± 0.09 ^e	10.4 ± 0.04 ^e	14.1 ± 0.10 ^g	4.91 ± 0.04 ^d
	10:09	2.69 ± 0.04 ^c	14.4 ± 0.11 ^f	12.1 ± 0.11 ^e	13.0 ± 0.13 ^e	8.47 ± 0.09 ^d	13.4 ± 0.06 ^g	3.87 ± 0.03 ^c
	10:10	1.25 ± 0.06 ^b	12.1 ± 0.19 ^e	11.1 ± 0.13 ^e	11.0 ± 0.09 ^d	7.77 ± 0.06 ^d	8.57 ± 0.07 ^d	3.76 ± 0.04 ^d
JCR-2067	10:07	7.97 ± 0.07 ^g	19.9 ± 0.07 ^g	11.4 ± 0.08 ^e	17.3 ± 0.16 ^f	11.9 ± 0.08 ^f	17.7 ± 0.08 ⁱ	3.62 ± 0.04 ^c
	10:08	2.81 ± 0.08 ^c	12.6 ± 0.04 ^e	9.46 ± 0.03 ^d	11.3 ± 0.17 ^d	9.79 ± 0.04 ^e	11.7 ± 0.06 ^f	3.81 ± 0.06 ^c
	10:09	2.66 ± 0.04 ^c	10.1 ± 0.08 ^e	7.59 ± 0.02 ^d	8.96 ± 0.05 ^c	9.62 ± 0.05 ^e	11.2 ± 0.07 ^f	3.87 ± 0.04 ^c
	10:10	1.45 ± 0.02 ^b	7.26 ± 0.08 ^d	4.24 ± 0.03 ^c	5.37 ± 0.06 ^b	6.01 ± 0.10 ^c	8.05 ± 0.04 ^d	2.21 ± 0.05 ^b
African tall	10:07	4.58 ± 0.03 ^e	9.56 ± 0.04 ^d	6.25 ± 0.07 ^c	7.98 ± 0.07 ^c	6.95 ± 0.04 ^c	9.21 ± 0.05 ^e	3.94 ± 0.04 ^c
	10:08	2.07 ± 0.04 ^c	8.65 ± 0.10 ^d	5.57 ± 0.09 ^c	7.53 ± 0.04 ^c	6.30 ± 0.06 ^c	8.52 ± 0.06 ^d	2.55 ± 0.03 ^b
	10:09	1.51 ± 0.02 ^b	3.63 ± 0.03 ^b	3.02 ± 0.12 ^b	5.23 ± 0.06 ^b	2.65 ± 0.03 ^a	3.34 ± 0.03 ^a	1.58 ± 0.04 ^a
	10:10	1.40 ± 0.08 ^b	1.97 ± 0.03 ^a	1.02 ± 0.04 ^a	4.12 ± 0.09 ^b	1.65 ± 0.06 ^a	2.39 ± 0.08 ^a	1.55 ± 0.02 ^a
YP/JCR-1	10:07	3.44 ± 0.04 ^d	8.17 ± 0.06 ^d	4.97 ± 0.07 ^b	7.03 ± 0.09 ^c	4.98 ± 0.04 ^b	6.46 ± 0.06 ^c	4.77 ± 0.04 ^d
	10:08	2.07 ± 0.03 ^c	7.16 ± 0.03 ^d	4.45 ± 0.04 ^b	5.88 ± 0.04 ^b	3.51 ± 0.06 ^b	6.60 ± 0.03 ^c	4.50 ± 0.03 ^d
	10:09	1.81 ± 0.04 ^b	4.23 ± 0.05 ^b	3.56 ± 0.03 ^b	4.25 ± 0.03 ^b	2.82 ± 0.07 ^a	3.54 ± 0.02 ^a	2.33 ± 0.04 ^b
	10:10	1.44 ± 0.05 ^b	4.09 ± 0.04 ^b	2.64 ± 0.02 ^a	3.78 ± 0.06 ^a	2.17 ± 0.02 ^a	3.19 ± 0.04 ^a	1.96 ± 0.05 ^b
JCR-2105	10:07	8.31 ± 0.09 ^h	39.4 ± 0.28 ^h	26.9 ± 0.07 ^g	36.0 ± 0.33 ^h	26.5 ± 0.14 ^j	25.5 ± 0.09 ^k	4.93 ± 0.09 ^d
	10:08	6.02 ± 0.04 ^f	18.2 ± 0.32 ^g	18.8 ± 0.09 ^f	19.2 ± 0.13 ^g	19.0 ± 0.18 ⁱ	21.7 ± 0.11 ^j	2.89 ± 0.03 ^b
	10:09	2.28 ± 0.02 ^c	15.5 ± 0.15 ^f	10.8 ± 0.04 ^c	11.5 ± 0.04 ^d	15.8 ± 0.06 ^h	15.9 ± 0.08 ^h	2.55 ± 0.05 ^b
	10:10	3.58 ± 0.04 ^d	11.4 ± 0.05 ^e	11.9 ± 0.04 ^e	11.0 ± 0.09 ^d	12.2 ± 0.07 ^g	13.4 ± 0.12 ^g	2.07 ± 0.03 ^b
JCR-2110	10:07	8.87 ± 0.03 ^h	17.5 ± 0.23 ^f	12.8 ± 0.06 ^e	15.0 ± 0.24 ^f	12.2 ± 0.08 ^g	13.1 ± 0.05 ^g	2.64 ± 0.06 ^b
	10:08	6.36 ± 0.07 ^f	12.3 ± 0.14 ^e	9.18 ± 0.06 ^d	11.2 ± 0.07 ^d	8.80 ± 0.10 ^d	10.2 ± 0.06 ^f	0.11 ± 0.05 ^a
	10:09	1.11 ± 0.01 ^b	9.16 ± 0.19 ^d	5.00 ± 0.11 ^c	4.86 ± 0.05 ^b	6.29 ± 0.07 ^c	7.55 ± 0.04 ^d	1.36 ± 0.03 ^a
	10:10	1.42 ± 0.04 ^b	5.16 ± 0.06 ^c	2.31 ± 0.03 ^a	2.81 ± 0.04 ^a	5.04 ± 0.06 ^b	4.47 ± 0.05 ^b	0.44 ± 0.02 ^a
WAXY	10:07	1.38 ± 0.05 ^b	17.2 ± 0.05 ^f	9.93 ± 0.06 ^d	11.2 ± 0.08 ^d	11.3 ± 0.05 ^f	13.6 ± 0.05 ^g	14.6 ± 0.09 ^g
	10:08	1.52 ± 0.03 ^b	12.3 ± 0.09 ^e	8.63 ± 0.07 ^d	10.4 ± 0.02 ^d	7.46 ± 0.02 ^d	8.18 ± 0.06 ^d	9.49 ± 0.05 ^f
	10:09	1.44 ± 0.04 ^b	10.1 ± 0.06 ^e	5.73 ± 0.02 ^c	7.97 ± 0.07 ^c	5.34 ± 0.07 ^b	6.34 ± 0.02 ^c	7.09 ± 0.07 ^e
	10:10	0.30 ± 0.01 ^a	5.55 ± 0.03 ^c	3.21 ± 0.04 ^b	2.12 ± 0.04 ^a	4.16 ± 0.02 ^b	4.52 ± 0.05 ^b	4.30 ± 0.04 ^d

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

MPT mixograph peak time; MPW mixograph peak width; LPV left peak value; LPW left peak width; RPV right peak value; RPW right peak width; WS weakening slope

1995). Salehifar et al. (2010) reported that the flours with more protein content required more water for stronger dough development. WS for dough development of other corn varieties was significantly lower than that of waxy corn and a less significant difference in WS among different water levels was recorded.

The dough made from waxy corn meal had the highest WS and the lowest MPT when compared with other varieties at a particular water level. This indicated that dough from waxy corn meal showed the high breakdown and short mixing time, hence development of weak dough.

Dynamic rheology

The dynamic rheological parameters (G' , G'' and $\tan \delta$) of dough from different corn varieties at different water levels

were measured (Table 5). The storage modulus (G') and viscous modulus (G'') ranged from 17,660 to 254,900 and 3923 to 61,423 Pa, respectively for dough from different corn varieties. The highest G' was recorded for JCR-2105 at lower water level (10:7), which decreased with increase in water. G' was higher for YP/JCR-1 and HQPM1 than African tall and JCR-2067 at lower water level. G' of dough from all corn varieties was higher than G'' which implied that the dough had more elasticity (Singh et al. 2011a). Similarly, higher G' than G'' of wheat starch pastes was reported by Kaur et al. (2016). A significant decrease in G' and G'' was recorded with increase in water level for meal from each corn type. This might be due to dilution of lipid and proteins as well as weakening of starch protein interactions that resulted into a decrease in viscoelastic behaviour. The absence of a binding agent in corn meal

Table 5 Rheological properties of dough made from different corn varieties at varied water level

Variety	Moisture level	G' (Pa)	G'' (Pa)	Tan δ
HQPM1	10:07	230,121 $\pm$ 85 ^h	44,551 $\pm$ 45 ^{gh}	0.194 $\pm$ 0.02 ^f
	10:08	209,600 $\pm$ 69 ^h	39,664 $\pm$ 36 ^g	0.189 $\pm$ 0.05 ^e
	10:09	73,820 $\pm$ 58 ^d	13,460 $\pm$ 49 ^c	0.182 $\pm$ 0.08 ^e
	10:10	63,160 $\pm$ 48 ^d	10,322 $\pm$ 57 ^b	0.163 $\pm$ 0.01 ^c
JCR-2067	10:07	213,540 $\pm$ 87 ^h	55,324 $\pm$ 59 ⁱ	0.259 $\pm$ 0.02 ^g
	10:08	197,100 $\pm$ 98 ^h	47,790 $\pm$ 78 ^h	0.242 $\pm$ 0.06 ^g
	10:09	89,280 $\pm$ 85 ^d	17,610 $\pm$ 29 ^d	0.197 $\pm$ 0.08 ^f
	10:10	78,420 $\pm$ 49 ^d	11,285 $\pm$ 65 ^{bc}	0.144 $\pm$ 0.05 ^b
African tall	10:07	214,520 $\pm$ 59 ^h	49,852 $\pm$ 87 ^h	0.232 $\pm$ 0.06 ^g
	10:08	163,100 $\pm$ 58 ^g	32,590 $\pm$ 73 ^f	0.200 $\pm$ 0.08 ^f
	10:09	160,000 $\pm$ 75 ^g	29,710 $\pm$ 54 ^{ef}	0.186 $\pm$ 0.09 ^e
	10:10	150,730 $\pm$ 72 ^g	14,448 $\pm$ 59 ^{cd}	0.096 $\pm$ 0.04 ^a
YP/JCR-1	10:07	242,140 $\pm$ 51 ⁱ	61,423 $\pm$ 29 ^j	0.254 $\pm$ 0.08 ^g
	10:08	201,400 $\pm$ 45 ^h	50,800 $\pm$ 62 ^{hi}	0.252 $\pm$ 0.03 ^g
	10:09	116,020 $\pm$ 65 ^f	26,900 $\pm$ 39 ^e	0.232 $\pm$ 0.09 ^g
	10:10	87,870 $\pm$ 84 ^d	15,600 $\pm$ 56 ^d	0.178 $\pm$ 0.02 ^d
JCR-2105	10:07	254,900 $\pm$ 77 ⁱ	48,711 $\pm$ 41 ^h	0.191 $\pm$ 0.08 ^f
	10:08	158,690 $\pm$ 49 ^g	29,500 $\pm$ 26 ^{ef}	0.186 $\pm$ 0.06 ^e
	10:09	105,220 $\pm$ 46 ^e	19,319 $\pm$ 31 ^d	0.184 $\pm$ 0.08 ^e
	10:10	101,204 $\pm$ 89 ^e	18,670 $\pm$ 85 ^d	0.184 $\pm$ 0.03 ^e
JCR-2110	10:07	124,950 $\pm$ 41 ^f	24,670 $\pm$ 42 ^e	0.197 $\pm$ 0.02 ^f
	10:08	75,120 $\pm$ 76 ^d	14,420 $\pm$ 29 ^{cd}	0.192 $\pm$ 0.09 ^f
	10:09	59,180 $\pm$ 71 ^c	10,144 $\pm$ 49 ^b	0.171 $\pm$ 0.07 ^d
	10:10	49,650 $\pm$ 79 ^c	8459 $\pm$ 29 ^{ab}	0.170 $\pm$ 0.08 ^d
WAXY	10:07	83,640 $\pm$ 81 ^d	25,480 $\pm$ 42 ^e	0.305 $\pm$ 0.02 ^h
	10:08	46,420 $\pm$ 73 ^c	13,570 $\pm$ 35 ^c	0.292 $\pm$ 0.09 ^h
	10:09	28,750 $\pm$ 55 ^b	7584 $\pm$ 31 ^a	0.264 $\pm$ 0.02 ^g
	10:10	17,660 $\pm$ 39 ^a	3923 $\pm$ 25 ^a	0.222 $\pm$ 0.11 ^g

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

G' elastic modulus; G'' viscous modulus

might cause non-significant absorption of water; hence the repulsive forces between starch granules inhibited the formation of defined structural system with increase in water content during dough formation (Sivaramakrishnan et al. 2004). The decrease in rheological properties with increase in water level was reported earlier by Rouille et al. (2005) and Navickis (1989). The dough made from waxy corn meal had the lowest G' and G'' at each water level, when compared to other varieties. Singh et al. (2006) reported higher G' and G'' of normal corn than waxy corn. This might be due to high protein content and negligible amylose content of waxy corn, resulting into weak starch-protein network and hence formation of less viscoelastic doughs. The high protein content of malanga flour resulting in lower G' and G'' of dough upon addition in corn flour was reported earlier (Chel-Guerrero et al. 2015). Tan δ (G''/G') values of dough samples from different varieties decreased with increase in water level. This indicated the

formation of weaker dough at high water level when compared with the dough made at lower water levels. Fevzioglu et al. (2012) observed that the moduli of dough samples decreased with increase in water level. Chel-Guerrero et al. (2015) reported that the lower tan δ for corn dough made the tortilla preparation difficult. Mejia et al. (2007) compared the effect of wheat gluten with corn zein proteins on rheological properties and reported the role of zein protein in the formation of viscoelastic system at zein's transition temperature (35 °C).

FTIR analysis

FTIR spectra of dough prepared from corn at different water levels is illustrated in Fig. 1. Corn proteins present in dough made from different varieties showed major bands in amide-I region between 1600 to 1700 cm⁻¹ (C=O stretching of amide carbonyl). Five peaks were observed

◀**Fig. 1** FTIR [peak and second-derivative (SD)] spectra of dough made at different water level **a** 7 ml **b** 8 ml **c** 9 ml **d** 10 ml from JCR-2105 corn variety

between 1610 and 1650 cm^{-1} region. A low frequency peak at 1613 cm^{-1} and another peak at 1619 cm^{-1} was observed that correspondent to β -structure (β -sheets + β -edges) (Georget and Belton 2006). The bands present between 1610 and 1620 cm^{-1} in amide-I region were corresponded to zein proteins of corn (Singh et al. 2009). The zein showed the viscoelastic behaviour similar to that of wheat gluten dough but the extensibility was observed to be lost over time (Oom et al. 2008). Schober et al. (2008) reported the role of zein in dough cohesiveness, viscoelasticity and extensibility on macroscopic level that provided physical stability. The region between 1623 and 1638 cm^{-1} determined low frequency bands, where a peak at 1623 cm^{-1} was for intermolecular (IM) β -sheets (Khurana and Fink 2000). Two peaks of lower intensity at 1629 and 1635 cm^{-1} were reported at low water level, indicative of IM β -sheets and antiparallel (AP) β -sheets structure, respectively. A shoulder at approximately 1635 cm^{-1} was reported by Duodu et al. (2001). The peak shifting of three peaks viz. 1623, 1629 and 1635 cm^{-1} to 1625 (antiparallel intermolecular β -sheet), 1632 and 1637 cm^{-1} , respectively, was observed. The peak shifting indicated that the amount of protein-water hydrogen bonds increased and, hence, protein backbone exposed to water considerably (Wang et al. 2001). Khurana and Fink (2000) reported that these peaks determined the β -sheets conformations in globular proteins along with the small absorbance bands in 1685–1695 cm^{-1} range. A peak at 1646 and 1673 cm^{-1} determined the extended chains and turns, respectively, in an unusual environment. The most prominent peak in the amide-I region was at about 1652 cm^{-1} followed by a less intense peak at 1659 cm^{-1} , both originates from α -helical structures. The amide-I band of corn was reported to display their maxima at 1650 cm^{-1} by Cremer and Kaletunc (2003). Duodu et al. (2001) reported that amide-I components located between 1650 and 1660 cm^{-1} represented α -helical structures. Amide-I band with frequency range of 1650–1658 cm^{-1} corresponded to α -helix, 1620–1635 cm^{-1} determined β -sheet and 1640–1650 cm^{-1} was assigned to random structures (Fabian and Schultz 2000). This variation in spectral behaviour providing the information regarding secondary structure of proteins may be due to structural deformation and domain interactions (Cremer and Kaletunc 2003). A large increase in intensity of peak at 1652 cm^{-1} was observed as the water content in

dough increased. This might be due to dilution of protein as well as starch of meal in the presence of excessive amount of water. Oom et al. (2008) reported that the addition of water for resin formation may hydrate the protein and caused the changes in protein secondary structure that facilitated the further disulphide bond formation. A weak C–O–H starch glucose ring deformation might cause a change in intensity of 1652 cm^{-1} . The intensity of this peak in waxy dough remained same at 10:7 and 10:8 water levels, while an increase was observed at 10:9 water levels, which might be due to low starch and high protein content in waxy corn. The strong protein–protein interactions in waxy dough may require more water for distortion. Moreover, the changes in peak intensities of corn dough with variation in water level might be due to alterations in polypeptide backbone structure.

The proportion of peak area in amide-I region as IM + AP β -sheet ($1610\text{--}1640\text{ cm}^{-1}$), α -helix ($1650\text{--}1660\text{ cm}^{-1}$), β -sheet ($1680\text{--}1690\text{ cm}^{-1}$) and b -turn ($1665\text{--}1675\text{ cm}^{-1}$) was determined (Table 6). An increase in intensities in amide-I region with increase in hydration indicated the increase in IM + AP β -sheet as well as α -helix and β -sheet structures. A significant increase in IM + AP β -sheet proportion with increase in water content was recorded, while α -helix proportion decreased and b -turn increased insignificantly among different varieties with increase in water content. Duodu et al. (2001) reported that the increased IM + AP β -sheet structure might be at expense of α -helix conformations.

The area under the peak from $1732\text{ to }1752\text{ cm}^{-1}$ assigned to lipids was also calculated (Fig. 2). A band at 1748 cm^{-1} characteristic of C=O stretch, corresponding to

Table 6 Secondary structure of dough proteins from different corn varieties

Variety	Water level	1610–1640 IM + AP- β -sheet (%)	1650–1660 α -helix (%)	1665–1675 b -turn (%)	1680–1690 β -sheet (%)	Ratio (α -helix/ β -sheet)
HQPM1	10:07	36.43 ± 1.9^a	35.44 ± 3.5^e	7.20 ± 1.1^d	20.93 ± 1.8^{gh}	1.69 ± 0.08^c
	10:08	35.17 ± 2.4^a	35.52 ± 4.2^e	8.50 ± 1.5^e	20.81 ± 2.2^g	1.71 ± 0.02^d
	10:09	39.82 ± 2.9^{ab}	29.57 ± 5.1^c	9.50 ± 1.2^f	21.11 ± 2.4^h	1.40 ± 0.01^b
	10:10	42.35 ± 3.5^b	26.18 ± 2.8^b	9.96 ± 1.5^f	21.51 ± 2.0^h	1.22 ± 0.08^a
JCR-2067	10:07	38.23 ± 4.6^{ab}	33.14 ± 3.5^d	8.70 ± 1.1^e	19.93 ± 1.8^f	1.66 ± 0.07^c
	10:08	40.79 ± 5.1^b	32.15 ± 4.6^d	8.00 ± 0.9^e	19.05 ± 1.9^{ef}	1.69 ± 0.05^c
	10:09	42.23 ± 4.2^b	31.98 ± 4.2^{cd}	8.34 ± 1.6^e	17.45 ± 3.1^d	1.83 ± 0.09^e
	10:10	42.36 ± 2.8^b	31.79 ± 5.6^{cd}	8.70 ± 1.8^e	17.15 ± 2.1^d	1.85 ± 0.11^e
African tall	10:07	51.90 ± 2.2^c	27.19 ± 2.8^{bc}	5.53 ± 1.2^{ab}	15.38 ± 2.8^b	1.77 ± 0.02^d
	10:08	49.32 ± 3.4^c	27.29 ± 2.1^{bc}	7.15 ± 1.8^d	16.25 ± 1.1^c	1.68 ± 0.12^c
	10:09	52.39 ± 3.8^c	24.35 ± 3.2^{ab}	7.03 ± 1.2^{cd}	16.23 ± 2.0^c	1.50 ± 0.05^b
	10:10	53.29 ± 4.3^c	24.68 ± 3.8^{ab}	6.81 ± 1.2^c	15.21 ± 2.1^b	1.62 ± 0.07^c
YP/JCR-1	10:07	42.29 ± 6.5^b	32.59 ± 3.8^d	7.26 ± 1.1^d	17.86 ± 2.9^d	1.82 ± 0.02^c
	10:08	40.54 ± 4.9^b	32.37 ± 2.5^d	7.94 ± 1.6^{de}	19.15 ± 2.8^f	1.69 ± 0.03^c
	10:09	40.15 ± 7.2^b	32.54 ± 3.7^d	8.30 ± 1.9^e	19.01 ± 1.8^{ef}	1.71 ± 0.05^d
	10:10	43.07 ± 7.1^b	30.80 ± 5.2^c	7.81 ± 1.2^d	18.32 ± 1.9^e	1.68 ± 0.08^c
JCR-2105	10:07	52.03 ± 6.1^c	26.95 ± 4.9^b	4.94 ± 1.6^a	16.08 ± 2.1^{bc}	1.68 ± 0.02^c
	10:08	53.27 ± 5.2^c	25.86 ± 5.1^b	5.85 ± 1.0^b	15.03 ± 2.1^{ab}	1.72 ± 0.12^d
	10:09	58.84 ± 3.1^{cd}	22.78 ± 3.5^a	5.15 ± 0.9^b	13.24 ± 2.6^a	1.72 ± 0.09^d
	10:10	61.64 ± 7.5^d	21.03 ± 3.8^a	5.03 ± 0.5^a	12.30 ± 1.2^a	1.71 ± 0.05^d
JCR-2110	10:07	41.23 ± 2.9^b	32.30 ± 4.6^d	7.62 ± 1.1^d	18.85 ± 2.5^e	1.71 ± 0.03^d
	10:08	43.10 ± 3.4^b	30.41 ± 2.2^c	7.78 ± 1.8^d	18.71 ± 2.1^e	1.62 ± 0.08^c
	10:09	45.95 ± 5.9^{bc}	31.21 ± 2.9^{cd}	7.59 ± 1.2^d	15.24 ± 1.8^b	2.05 ± 0.02^f
	10:10	44.12 ± 4.3^{bc}	31.60 ± 2.6^{cd}	8.70 ± 1.8^e	15.58 ± 1.2^b	2.03 ± 0.02^f
WAXY	10:07	40.05 ± 5.1^b	33.63 ± 2.4^d	6.99 ± 1.9^{cd}	19.32 ± 2.1^f	1.74 ± 0.04^d
	10:08	40.76 ± 2.8^b	32.62 ± 2.3^d	7.42 ± 0.5^d	19.20 ± 2.2^f	1.70 ± 0.02^d
	10:09	42.38 ± 2.2^b	31.74 ± 3.1^{cd}	7.38 ± 0.8^d	18.50 ± 0.9^e	1.72 ± 0.08^d
	10:10	42.06 ± 3.9^b	31.42 ± 1.9^{cd}	7.93 ± 1.0^{de}	18.59 ± 1.2^e	1.69 ± 0.01^c

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

Fig. 2 FTIR spectra [peak and second derivative (SD)] spectra showing the behaviour of 1748 cm^{-1} band with change in water level **a** 7 ml **b** 10 ml of dough made from waxy corn

lipids was reported earlier (Georget and Belton 2006). Cremer and Kaletunc (2003) also reported carboxylic ester carbonyl band at 1744 cm^{-1} in corn flour spectra which was associated to lipids. The band at 1748 cm^{-1} showed the most intense peak in dough made from waxy corn followed by HQPM1, whereas the band intensity was the lowest for YP/JCR-1. This might be due to the highest fat content of waxy corn and the lowest for YP/JCR-1 corn. Moreover, the band intensity was observed to be decreased with increase in water level in each corn variety, which might be due to the dilution of lipids with addition of more water for making dough. The lipids interaction with water

might cause the dissolution of C=O to form weak C–O–H bond. A clear decrease in band intensity at 1748 cm^{-1} with increase in water content was obtained in the spectra of waxy dough (Fig. 2).

Chapatti making properties

The chapatti made from different corn varieties was analysed for rupture force, extensibility and water activity (Table 7). Chapatti made from HQPM1 and JCR-2110 showed the lower force to rupture and high extensibility which indicated the more soft behaviour of chapattis made from these two varieties when compared to that of other varieties. Water activity of chapattis made from yellow and red-pigmented corn meal was significantly higher as compared to that from white and waxy corn. A highly different textural behaviour of chapatti made from waxy corn meal was observed, with the highest force to rupture (7.25 N) and the lowest extensibility (1.22 mm). This might be due to presence of negligible amount amylose and high protein content in waxy corn which may restrict the complete development of starch-protein complex during dough formation, hence caused low extensibility.

The sensory analysis scores for texture, colour, mouthfeel and overall acceptability ranged from 5.5 to 7.5, 4 to 8.1, 3.5 to 8.5 and 4 to 8.2, respectively for chapattis made from different varieties (Table S1). The higher colour scores for chapattis were recorded for HQPM1 and JCR-2110. Chapatti made from HQPM1 showed highly acceptable score for texture, mouthfeel and overall acceptability. The chapatti made from waxy corn had extremely low colour scores and was disliked. Moreover, the mouthfeel of waxy corn chapatti was also not liked by the panellists.

Conclusion

Grain and meal obtained from waxy corn had higher L^* , a^* and b^* values than normal corn varieties indicating the dark colour of waxy corn meal with more redness and

Table 7 Characteristics of chapatti prepared from dough of different corn varieties

Variety	Rupture force (N)	Extensibility (mm)	Water activity (a_w)
HQPM1	4.05 ± 0.02^a	4.97 ± 0.06^c	0.9533 ± 0.001^b
JCR-2067	4.14 ± 0.04^{ab}	3.26 ± 0.01^c	0.9568 ± 0.002^{bc}
African Tall	4.54 ± 0.03^b	3.75 ± 0.03^d	0.9442 ± 0.001^{ab}
YP/JCR-1	4.12 ± 0.08^{ab}	2.61 ± 0.04^b	0.9458 ± 0.005^{ab}
JCR-2105	3.97 ± 0.01^a	3.51 ± 0.01^{cd}	0.9588 ± 0.003^{bc}
JCR-2110	3.55 ± 0.05^a	4.12 ± 0.03^{de}	0.9612 ± 0.002^c
WAXY	7.25 ± 0.04^c	1.22 ± 0.02^a	0.9313 ± 0.004^a

Values with similar superscript in a column do not differ significantly ($p \leq 0.05$)

yellowness. Protein, ash and fat content of waxy corn meal were the highest. The mixograph behaviour of corn meal from different varieties showed a decrease in dough consistency and stability with increase in water level. The elastic modulus and viscous modulus of corn dough also decreased with increase in water content. Low G' and G'' of dough developed from waxy corn indicated its less viscoelasticity due to high protein and low amylose content in waxy corn. FTIR spectra showed an increase in proportion of IM + AP β -sheet as well as α -helix and β -sheet with increase in hydration of dough made from different varieties. The chapattis made from HQPM1 dough were soft, extensive with more appealing colour, appearance and overall acceptability, while that from waxy corn were poorly acceptable on the basis of textural as well as sensory analysis.

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