Diversity and relationship among grain, flour and starch characteristics of Indian Himalayan colored corn accessions

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Abstract The present study examined the diversification and relationship among grain, flour and starch characteristics of thirty eight differently coloured corn accessions. The differences among accessions were more pronounced due to heterogeneity in genetic traits than color. Colour properties were positively related with phenolics and antioxidant activity. K, Ca, Zn, Mg, Na, Cu, Fe and Mn were the prominent minerals present in accessions. Accumulation of 10 polypeptides, ranging from 10 to 95 kDa was also evaluated. HPLC analysis showed the presence of gallic acid, Catechin, caffeic acid, chlorogenic acid, protocatechuic acid, *p*-coumaric acid, vanillic acid, quercetin, sinapic acid, ferulic acid, resveratrol and luteolin in flours. Accessions had higher proportions of amino acids, citrulline, arginine, GABA, phenylalanine, isoleucine, tyrosine, threonine, glycine. Starch granules with different particle size showed angular structure. Final viscosity, set back viscosity and crystallinity positively related to amylose content of starch. Starches with A-type crystalline pattern showed variability in thermal properties. The results of this study showed significant relationship between DPPH and total phenolic content, thermal properties, amylose content and crystallinity among various corn germplasm. These will be helpful for selection of appropriate accessions having required characteristics not only for food applications but also for non-food ones.

Keywords Corn accessions · Amino acids · Protein profile · Polyphenols · Differential scanning calorimetry (DSC) · Minerals

Abbreviations

TPC	Total phenolics content
FV	Final viscosity
SEM	Scanning electron microscope
SBV	Setback viscosity
PT	Pasting temperature
PV	Peak viscosity
BDV	Breakdown viscosity
PP	Polypeptides
HMW	High molecular weight
MMW	Medium molecular weight
LMW	Low molecular weight
AA	Amino acids
GABA	Gamma-amino butyric acid
PCA	Principal component analysis
ANOVA	Analysis of variance

Introduction

Corn/Maize (*Zea mays*) is world's highest growing cereal crop and consumed globally next to rice and wheat. It's utility as a food and feed resources make it acceptable for consumption. The composition of corn includes starch (70–75%), protein (8–10%), lipid (4–5%), sugar (1–3%) and ash (1–4%) (Narpinder et al. 2014). Corn has physicochemical characteristics that include having large content of starch, low α -gliadin fraction in protein, lipids, flavonoids and microelements which make it vital source of human consumption (Wojtowicz et al. 2013). Phytochemical compounds may act as nutraceutical in the form of

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enzymes, antioxidants and its cofactors and therefore having health benefits in promoting effects such as anti-carcinogenic and vasodilatory effects (H€ansch and Mendel 2009). Phytosterols present in it, help in reducing the cholesterol levels and can be utilized for manufacturing of various food items of domestic and industrial use such as flour, tortilla, snacks, porridge, gruel, beverages and corn flakes (Bello-Pérez et al. 2015). The pigmented corn (mainly blue) has received the most interest for the development due to the presence of phenolic compounds prominently anthocyanins (Del Pozo-Insfran et al. 2006). The three classes in which it can be categorized are: (1) high amylose corn containing higher amylose content between 40 and 70%; (2) waxy corn with 100% amylopectin; and (3) sugary corn containing higher level of sucrose with low starch content (Nelson and Pan 1995). On the basis of different proportions of horny (vitreous) and floury endosperm corn has classified into different types viz. dent, flint, floury, waxy, popcorn and sweet corn (Knott et al. 1995). Gluten free products are being developed for the population suffering from coeliac disease as they cannot tolerate some peptides found in wheat, rye and barley (de la Hera et al. 2013). The characteristic feature of corn amylose such as resistant starch content has many health benefits while other properties; degree of polymerization, film formation characteristics supports it in the formation of biodegradable films and electronic chips (Guan et al. 2011). Although corn is widely grown and researched in India, yet the analyses of grain, flour and starches of Himalayan corn genetic pool needs further exploration. In particular, the relationship between various corn germplasm will be helpful by selection of appropriate accession having required characteristics not only for food applications but also for non food ones. Therefore, this investigation was done to characterise the corn accessions grown in India Himalayan based on their physicochemical, thermal, pasting, polyphenolic, amino acid profile and morphological properties of grain, flour and starch.

Materials and methods

Materials

Germplasm of Thirty eight (38) corn accessions varying in color i.e. yellow (IC-347386, IC-427129, IC-397828, IC-397956, IC-397957, IC-397958, IC-361709, IC-362129, IC-362130, IC-361726, IC-447627, IC-447645, IC-447646, IC-447641, IC-447648) white (IC-447511, IC-447638, IC-447632, IC-447660, IC-447639, IC-447328, IC-550370, IC-550365, IC-447626, IC-447501, IC-447509, IC-361712, IC-361714, IC-447632, IC-361719) and purple (IC-361727, IC-447636, IC-447648, IC-447649, IC-447667,

IC-447647, IC-447643, IC-447644) were procured from NBPGR, Regional Station, Pagli, Shimla (India) and were harvest of 2012–2013.

Grain color

Color characteristics (L^* , a^* and b^*) of corn grains from various accessions were measured using a colorimeter (Hunter Labs, USA) as described by Trehan et al. (2018).

Flour characteristics

Physicochemical and pasting properties of flours

50 g of grains of different corn accessions were ground to pass through sieve no. 72 (BSS) in order to get uniform particle sized flour that was kept in airtight PET jars for future analyses. Flours were examined for proximate composition using the AOAC standard methods (1990). Pasting properties of the flour were ascertained by the method adopted by Trehan et al. (2018).

Total phenolic content and antioxidant activity of flours

Total phenolic content (TPC) and antioxidant activity was determined as described earlier (Trehan et al. 2018) with minor changes. The results obtained were described as $\mu\text{g GAE/g}$ and $\mu\text{M trolox/mg}$, respectively.

Mineral composition

Mineral content of flours was examined with the help of an Atomic Absorption Spectrometer (Agilent Technologies) as described earlier (Ghumman et al. 2017).

Amino acid (AA) determination

The amino acids (AAs) were characterized using the method described in our previous report (Ghumman et al. 2017).

SDS-PAGE analysis

Total proteins present in corn flour (milled whole grain) were separated and SDS-PAGE analyses were performed as described earlier by Thakur et al. (2015).

HPLC analysis of flours

Extraction of phenolics was done from defatted twice with hexane. HPLC analysis of corn accessions as described earlier by Thakur et al. (2017). The identification and quantification of phenolic compounds was done by

comparison of the retention time with a known standard. The calibration curve equations, coefficient of determination of linearity, limits of detection and quantitation obtained for different polyphenols are provided in (Supplementary Table S2).

Starch characteristics

Physicochemical characteristics of starch

Starches from selected corn accessions were obtained as described earlier by Thakur et al. (2015). Amylose content and Blue value of corn starch was measured using the method described by Thakur et al. (2015). The iodine-absorption spectra (λ_{max}) were ascertained by determining the maximum absorbing wavelength in the visible region.

Granule size distribution and morphology

Morphological characteristics of corn starch were studied using scanning electron microscope (ZEISS, Germany) using methodology of Bajaj et al. (2018). Granule size of starch was determined using particle size analyzer, (Microtac S3500 Ins. Ltd., USA).

X-ray diffraction (XRD), Fourier transform infra-red (FTIR) spectroscopy

X-ray diffractograms of fully saturated (100% RH) starch samples were developed by an analytical diffractometer (XRD-7000; X-Ray Diffractometer Shimadzu, Japan) as described earlier by Bajaj et al. (2018). The crystalline structures of starches (dried to constant weights) were ascertained using a FTIR (Vertex70, Bruker, Germany) by analysing average Spectra of 200 scans. Absorbance intensity of the bands at 1047 cm^{-1} , one thousand thirty five, and 1022 cm^{-1} were used to evaluate relative crystallinity.

Pasting characteristics

Pasting characteristics of corn starches were measured using rheometer (Anton Paar Rheo Plus/32 Model MCR-301) as described earlier by Thakur et al. (2015).

Thermal properties

Thermal characteristics of starches were examined with a differential scanning calorimeter (DSC-822e, Mettler Toledo, Greinfense, Switzerland) as described earlier by Bajaj et al. (2018).

Statistical analysis

Results were observed as mean of triplicate readings $\pm$ standard deviation. Data was subjected to one way ANOVA using Minitab Statistical Software (MINITAB 14.12.0, USA). PCA loading plot (Supplementary Figure S1) gave an outline of the relationships among different evaluated parameters.

Results and discussion

Grain color

Various corn accessions showed significant differences in grain colour characteristics. Hunter color characteristics of grains from different colored corn accessions are given in Table 1. The results of ANOVA showed a significant difference in L^* , a^* and b^* values owing to both accessions and colour, where the differences were more pronounced due to accessions than colour (Supplementary Table S1). Among the various accessions the highest L^* (indicative of lightness) value was recorded for IC 550370 (74.24) and the lowest for IC 447647 (43.72). IC 361719 had the lowest a^* value and IC 361727 showed the highest value of a^* while b^* values varied from 32.33 (IC 447646) to 7.04 (IC 447647). IC 550370, IC 447328, IC 447511, IC 447501 and IC 361719 showed significantly higher L^* than other accessions indicating a higher degree of lightness. Thakur et al. (2015) reported high L^* value of grit and flour from corn. IC 447644, IC 447667, IC 447649, IC 447647, IC 361727 and IC 447641 had comparatively higher a^* , indicating presence of higher redness as compared to other accessions. IC 361714, IC 347386, IC 427129, IC 447646 and IC 447645 showed higher b^* value than other accessions indicating presence of more yellow pigment. Sandhu et al. (2007) documented the larger b^* values for flour, which may be owing to high levels of carotenoid present in it. Shevkani et al. (2014) also witnessed these results for various fractions produced from corn dry milling. PCA revealed a positive relation between L^* and DPPH and the same was observed for a^* and TPC (Supplementary Figure S1).

Flour characteristics

Physicochemical characteristics of flours

ANOVA showed a considerable difference in the flour proximate content (Table 2). These were primarily owing to the accessions than colour. This suggested that amongst the flours there were differences within the genotypes (Supplementary Table S1). Protein, fat, moisture and ash

Table 1 Color characteristics of grains from different colored corn accessions

S. no	Colour	Accessions	L^*	a^*	b^*
1	White	IC 447511	70.19 ± 2.54de	2.52 ± 0.72ab	19.06 ± 0.95c
2	White	IC 447638	65.70 ± 0.98cd	4.15 ± 0.47bc	20.15 ± 0.40cd
3	White	IC 447632	68.68 ± 1.92d	2.97 ± 0.24b	19.63 ± 1.03c
4	White	IC 447660	68.23 ± 2.00d	3.11 ± 0.31b	21.59 ± 0.52de
5	White	IC 447639	69.15 ± 0.98de	4.78 ± 0.34c	22.68 ± 0.42de
6	White	IC 447328	71.82 ± 0.69de	3.07 ± 0.09b	20.25 ± 1.20bc
7	White	IC 550370	74.24 ± 1.90e	1.98 ± 0.16ab	17.72 ± 0.14c
8	White	IC 550365	70.16 ± 1.88de	3.23 ± 0.03b	19.13 ± 0.92c
9	White	IC 447626	70.51 ± 0.71de	2.38 ± 0.13ab	19.23 ± 0.15c
10	White	IC 447501	73.68 ± 1.93e	1.92 ± 0.13ab	20.19 ± 0.62cd
11	White	IC 447509	65.25 ± 0.82cd	3.18 ± 0.19b	19.40 ± 0.70c
12	White	IC 361712	70.74 ± 1.75de	2.56 ± 0.23ab	18.95 ± 1.09c
13	White	IC 361714	67.99 ± 0.80d	5.32 ± 0.57c	25.01 ± 1.08e
14	White	IC 447632	66.65 ± 1.61d	4.44 ± 0.22bc	21.02 ± 1.00d
15	White	IC 361719	72.46 ± 1.54e	1.68 ± 0.25a	17.05 ± 0.84b
16	Yellow	IC 347386	62.26 ± 0.73c	12.15 ± 1.07f	24.45 ± 0.90e
17	Yellow	IC 427129	62.50 ± 1.17c	12.78 ± 0.45fg	24.34 ± 0.78e
18	Yellow	IC 397828	58.35 ± 0.83bc	13.25 ± 0.15fg	23.43 ± 0.65de
19	Yellow	IC 397956	64.57 ± 0.89cd	12.46 ± 0.13f	24.28 ± 0.42e
20	Yellow	IC 397957	63.84 ± 1.82c	14.69 ± 1.45g	29.67 ± 1.17g
21	Yellow	IC 397958	63.12 ± 0.79c	10.62 ± 0.91f	26.83 ± 0.60f
22	Yellow	IC 361709	68.29 ± 1.20d	9.67 ± 0.36ef	23.97 ± 0.49e
23	Yellow	IC 362129	68.28 ± 1.20d	9.38 ± 0.28e	23.78 ± 0.92e
24	Yellow	IC 362130	61.38 ± 1.04c	10.78 ± 1.33ef	22.26 ± 1.60d
25	Yellow	IC 361726	63.28 ± 1.36c	7.68 ± 0.43de	20.67 ± 0.67cd
26	Yellow	IC 447627	67.78 ± 0.52d	9.10 ± 0.66e	26.37 ± 1.09f
27	Yellow	IC 447645	68.11 ± 0.55d	11.42 ± 0.41ef	29.02 ± 0.68g
28	Yellow	IC 447646	66.96 ± 0.59d	11.96 ± 0.82f	32.33 ± 0.57f
29	Yellow	IC 447641	63.72 ± 0.65c	14.05 ± 0.30g	27.72 ± 0.79fg
30	Yellow	IC 447648	66.13 ± 1.80cd	12.05 ± 0.92f	27.64 ± 0.70fg
31	Purple	IC 361727	60.71 ± 0.33bc	16.15 ± 0.16h	26.73 ± 0.25f
32	Purple	IC 447636	58.78 ± 4.73bc	11.74 ± 1.49f	19.55 ± 1.80c
33	Purple	IC 447648	67.35 ± 1.93d	6.44 ± 1.14d	18.82 ± 0.81c
34	Purple	IC 447649	62.17 ± 0.28c	9.65 ± 0.67ef	21.92 ± 0.71d
35	Purple	IC 447667	45.65 ± 1.91a	9.93 ± 1.13ef	7.05 ± 1.21a
36	Purple	IC 447647	43.72 ± 0.72a	9.66 ± 0.19ef	7.04 ± 0.68a
37	Purple	IC 447643	67.00 ± 1.02d	8.85 ± 0.41e	22.65 ± 0.91de
38	Purple	IC 447644	56.93 ± 1.93b	12.03 ± 0.85f	16.18 ± 0.70b

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($P \leq 0.05$)

contents ranged from 6.18 to 11.83%, 1.67 to 7.06%, 9.17 to 11.96% and 0.67 to 2.29%, respectively (Table 2). The results observed proved that flour moisture contents in various accessions were in the range of safe storage limits. IC 447644 purple corn showed the lowest and IC 397957 yellow corn presented the largest moisture content. IC 447645 with yellow colour had the largest protein level,

while the smallest was observed for IC 347386 yellow corn. IC 361714 white corn showed the smallest, while IC 447648 purple corn showed the largest ash content. Fat levels were the smallest for IC 447648 purple corn against IC 397956 yellow corn which showed the lowest value. IC 447644 purple corn showed the lowest and IC 397957 yellow corn presented the largest moisture content.

Table 2 Proximate composition, total phenolic content (TPC) and antioxidant activity of flour from different colored corn accessions

S. no	Colour	Accessions	Fat (%)	Ash (%)	DPPH inhibition (μg trolox/g)	TPC (μg GAE/g)	Moisture (%)	Protein (%)
1	White	IC 447511	3.88 $\pm$ 0.02de	1.57 $\pm$ 0.05fg	555.94 $\pm$ 10.38hi	1083 $\pm$ 12c	11.21 $\pm$ 0.43d	7.75 $\pm$ 0.13b
2	White	IC 447638	4.15 $\pm$ 0.05e	1.50 $\pm$ 0.06f	582.22 $\pm$ 1.49i	1087 $\pm$ 17c	11.08 $\pm$ 0.08d	11.82 $\pm$ 1.31e
3	White	IC 447632	5.76 $\pm$ 0.16h	1.70 $\pm$ 0.03g	607.94 $\pm$ 9.57j	1551.3 $\pm$ 32.5ef	10.10 $\pm$ 0.47bc	8.31 $\pm$ 0.44bc
4	White	IC 447660	3.42 $\pm$ 0.02d	0.82 $\pm$ 0.03b	568.62 $\pm$ 0.68hi	1343 $\pm$ 72.0de	10.73 $\pm$ 0.11cd	8.06 $\pm$ 0.19bc
5	White	IC 447639	5.56 $\pm$ 0.02gh	1.91 $\pm$ 0.13hi	671.00 $\pm$ 22.80k	1207 $\pm$ 37cd	11.76 $\pm$ 0.18de	10.06 $\pm$ 2.19d
6	White	IC 447328	3.98 $\pm$ 0.07de	1.91 $\pm$ 0.04hi	543.52 $\pm$ 6.52h	1151.7 $\pm$ 27.5cd	10.76 $\pm$ 0.31cd	8.31 $\pm$ 0.44bc
7	White	IC 550370	5.27 $\pm$ 0.09gh	1.22 $\pm$ 0.02de	536.68 $\pm$ 11.37h	772.3 $\pm$ 6.5a	10.79 $\pm$ 0.21cd	10.94 $\pm$ 0.44de
8	White	IC 550365	5.27 $\pm$ 0.15gh	1.36 $\pm$ 0.01ef	517.18 $\pm$ 9.51gh	1060.3 $\pm$ 5.5c	11.61 $\pm$ 0.05de	8.75 $\pm$ 0.00cd
9	White	IC 447626	4.44 $\pm$ 0.23ef	1.31 $\pm$ 0.06e	369.44 $\pm$ 6.40cd	1129.7 $\pm$ 89.5cd	11.67 $\pm$ 0.19de	9.63 $\pm$ 1.75cd
10	White	IC 447501	4.55 $\pm$ 0.08f	1.13 $\pm$ 0.24d	311.10 $\pm$ 2.61b	1246.0 $\pm$ 91.0d	9.53 $\pm$ 0.70ab	8.30 $\pm$ 0.45bc
11	White	IC 447509	2.04 $\pm$ 0.45b	1.72 $\pm$ 0.03g	401.50 $\pm$ 35.85d	880.7 $\pm$ 75.5b	11.71 $\pm$ 0.03de	10.60 $\pm$ 0.10de
12	White	IC 361712	4.95 $\pm$ 0.59fg	1.40 $\pm$ 0.05ef	331.04 $\pm$ 10.62b	1338.3 $\pm$ 59.5de	9.42 $\pm$ 0.12ab	8.35 $\pm$ 0.38bc
13	White	IC 361714	2.62 $\pm$ 0.14c	0.67 $\pm$ 0.08a	328.19 $\pm$ 11.37b	1518.0 $\pm$ 29.0ef	9.73 $\pm$ 0.24ab	10.77 $\pm$ 0.08de
14	White	IC 447632	5.77 $\pm$ 0.12h	1.24 $\pm$ 0.04de	355.33 $\pm$ 17.52c	1693.7 $\pm$ 62.5fg	9.37 $\pm$ 0.29ab	8.75 $\pm$ 0.00bc
15	White	IC 361719	2.88 $\pm$ 0.09c	1.44 $\pm$ 0.04f	328.37 $\pm$ 7.46b	1123.0 $\pm$ 69.0cd	10.40 $\pm$ 0c	9.59 $\pm$ 0.3cd
16	Yellow	IC 347386	5.11 $\pm$ 0.20fg	1.55 $\pm$ 0.03f	351.79 $\pm$ 0.43c	938 $\pm$ 96b	11.68 $\pm$ 0.10de	6.18 $\pm$ 0.05a
17	Yellow	IC 427129	3.74 $\pm$ 0.22de	1.12 $\pm$ 0.02d	347.01 $\pm$ 0.62c	1563.7 $\pm$ 24.5ef	9.79 $\pm$ 0.25b	11.82 $\pm$ 0.43e
18	Yellow	IC 397828	2.83 $\pm$ 0.09c	1.39 $\pm$ 0.05ef	353.84 $\pm$ 0.75c	1059 $\pm$ 167c	10.48 $\pm$ 0.27cd	8.62 $\pm$ 0.04bc
19	yellow	IC 397956	1.67 $\pm$ 0.18a	1.65 $\pm$ 0.03fg	355.65 $\pm$ 1.93c	1332 $\pm$ 80.0de	9.43 $\pm$ 0.05ab	8.36 $\pm$ 0.14bc
20	yellow	IC 397957	6.98 $\pm$ 0.53i	1.73 $\pm$ 0.02g	258.04 $\pm$ 2.11a	1163.7 $\pm$ 39.0cd	11.96 $\pm$ 0.05e	8.85 $\pm$ 0.01bc
21	yellow	IC 397958	4.65 $\pm$ 0.10f	1.56 $\pm$ 0.03f	429.45 $\pm$ 8.51e	769.3 $\pm$ 76.5a	11.64 $\pm$ 0.30de	8.27 $\pm$ 0.05bc
22	yellow	IC 361709	2.86 $\pm$ 0.11c	1.43 $\pm$ 0.04ef	389.01 $\pm$ 1.37d	1623.7 $\pm$ 104.5f	10.24 $\pm$ 0.06bc	8.45 $\pm$ 0.03cd
23	yellow	IC 362129	4.38 $\pm$ 0.13ef	0.89 $\pm$ 0.50bc	407.40 $\pm$ 6.59d	1401 $\pm$ 243e	9.72 $\pm$ 0.01ab	9.41 $\pm$ 0.22cd
24	yellow	IC 362130	3.57 $\pm$ 0.12d	1.03 $\pm$ 0.05c	455.79 $\pm$ 2.30f	1438.7 $\pm$ 10.5e	10.63 $\pm$ 0.40cd	8.94 $\pm$ 0.02cd
25	yellow	IC 361726	3.63 $\pm$ 0.18d	2.16 $\pm$ 0.08i	488.54 $\pm$ 4.72g	1221.7 $\pm$ 63.5cd	11.76 $\pm$ 0.18de	9.80 $\pm$ 0.00cd
26	yellow	IC 447627	3.83 $\pm$ 0.12de	1.92 $\pm$ 0.03h	494.25 $\pm$ 1.49g	1106.7 $\pm$ 117.5e	9.77 $\pm$ 0.05b	9.50 $\pm$ 0.05cd
27	yellow	IC 447645	4.52 $\pm$ 0.18f	1.61 $\pm$ 0.10fg	506.18 $\pm$ 2.36g	1694 $\pm$ 10fg	10.69 $\pm$ 0.11cd	11.83 $\pm$ 0.02e
28	yellow	IC 447646	4.10 $\pm$ 0.20e	1.58 $\pm$ 0.03f	501.46 $\pm$ 14.79g	1275 $\pm$ 55.5d	9.84 $\pm$ 0.32bc	9.06 $\pm$ 0.05cd
29	Yellow	IC 447641	4.27 $\pm$ 0.19ef	2.08 $\pm$ 0.14i	529.04 $\pm$ 1.12h	1176 $\pm$ 10.5cd	10.60 $\pm$ 0.01cd	8.44 $\pm$ 0.13bc
30	Yellow	IC 447648	5.23 $\pm$ 0.13g	1.31 $\pm$ 0.04e	258.04 $\pm$ 2.11a	1608 $\pm$ 84f	11.28 $\pm$ 0.15de	8.70 $\pm$ 0.14bc
31	Purple	IC 361727	5.70 $\pm$ 0.22gh	1.85 $\pm$ 0.05gh	471.58 $\pm$ 13.36f	995 $\pm$ 37bc	10.38 $\pm$ 0.35c	7.92 $\pm$ 0.05b
32	Purple	IC 447636	4.35 $\pm$ 0.26ef	1.41 $\pm$ 0.15ef	535.63 $\pm$ 20.50h	1531 $\pm$ 9.0ef	10.23 $\pm$ 0.46bc	9.74 $\pm$ 0.11cd
33	Purple	IC 447648	7.06 $\pm$ 0.63i	2.29 $\pm$ 0.09ij	496.43 $\pm$ 1.55g	1467.7 $\pm$ 39.5e	9.23 $\pm$ 0.05a	8.70 $\pm$ 0.05cd
34	Purple	IC 447649	4.71 $\pm$ 0.15f	1.56 $\pm$ 0.03f	517.55 $\pm$ 10.38gh	1603 $\pm$ 102f	10.39 $\pm$ 0.44c	9.01 $\pm$ 0.09cd
35	Purple	IC 447667	3.77 $\pm$ 0.21de	1.71 $\pm$ 0.03g	505.19 $\pm$ 1.24g	1884 $\pm$ 24g	10.06 $\pm$ 0.23a	9.88 $\pm$ 0.08d
36	Purple	IC 447647	4.61 $\pm$ 0.09f	1.54 $\pm$ 0.05f	518.73 $\pm$ 7.58gh	1226 $\pm$ 14d	9.21 $\pm$ 0.56a	9.54 $\pm$ 0.27d
37	Purple	IC 447643	1.70 $\pm$ 0.11a	1.58 $\pm$ 0.03f	516.62 $\pm$ 5.96gh	1830 $\pm$ 63.5g	10.72 $\pm$ 0.37cd	9.54 $\pm$ 0.08d
38	Purple	IC 447644	4.53 $\pm$ 0.16f	1.06 $\pm$ 0.07c	509.41 $\pm$ 1.99g	1616 $\pm$ 83f	9.17 $\pm$ 0.07a	9.88 $\pm$ 0.08d

Values are mean $\pm$ SD. Means with similar superscript in a column did not differ significantly ($P \leq 0.05$). All values are reported on dry weight basis

Shevkani et al. (2014) also documented similar results for various corn fractions. PCA illustrated a positive relation among ash and fat levels for flours, suggesting that flours having larger amounts of lipids also contained large amounts of inorganic material (Supplementary Figure S1).

Pasting properties of flours

Pasting characteristics of flours in various corn accessions had considerable differences, which ranged from 461.7 to 1938 cP, 722 to 2932 cP, 5.17 to 1346 cP, 259.3 to

Fig. 1 Pasting curves of flours from different corn accessions

2918 cP, 72.55 to 81.95 °C, respectively for PV, FV, BDV, SBV and PT (Supplementary Table S3, Fig. 1). When the heating process was going on, the starch granule gelatinization took place where these granules had undergone swelling, which led to their crystalline structure breakage and leaching of amylose. Pasting temperature (PT), indicating the lowest temperature for cooking of flours. It was the highest for IC 362130 yellow corn, while the lowest value was observed for IC 361714 white corn. On the other hand, highest PV (where granule swelling rate equals its breakdown rate) for IC 447645 yellow corn and the lowest was for IC 361714 white corn (Supplementary Table S3). BDV of IC 447639, IC 447511, IC 447649 and IC 447328 was considerably lower (5–40 cP) than the other ones which indicated their larger thermal stability. BDV represented granular disintegration after swelling. Sandhu et al. (2007) reported the lowest Breakdown viscosity (BDV) for Pb sathi flour indicated its paste stability. The enhancement in viscosity upon cooling was probably by the aggregation of amylose molecules led to final viscosity (FV). IC 361712 and IC 447511 presented significantly smaller FV (722.5–757.9 cP) than other lines. Singh et al. (2014) also documented similar results for corn starches. Setback viscosity (SBV) indicated the amount of retrogradation present in starch pastes while the cooling process was going on. The smallest SBV value was for IC 447511 white corn, whereas the largest for IC 447646 yellow corn. Lowest SBV values showed lower retrogradation tendencies of starch granules upon cooling. PCA gave information that PT had a positive relation with ash and fat levels (Supplementary Figure S1). Shevkani et al. (2014) documented that lipids might enhance the integrity of starch granules that would delay gelatinization initiation, thereby increasing the PT of corn fractions.

Total phenolic content and antioxidant activity of flours

ANOVA presented considerable differences in DPPH inhibition and TPC due to accessions and colour; however, colour had lower effect than accessions (Supplementary Table S1). The highest TPC was observed for IC 447667 purple corn, while the lowest was observed for IC 550370 white corn (Table 2). Purple corn showed high TPC which could be due to greater accumulation of anthocyanins (Singh et al. 2014). IC 447639 white corn showed the highest DPPH inhibition, while IC 447648 yellow corn showed the lowest (Table 2). Previous results also reported similar results for antioxidant activity (Adom et al. 2005). DPPH inhibition could be contributed to the presence of greater amounts of lutein and zeaxanthin (de la Parra et al. 2007). PCA revealed that TPC was related positively to a^* and b^* values, but negatively to L^* value, suggesting that dark coloured accessions had higher amounts of phenolic compounds as compared to the light coloured ones (Supplementary Figure S1). Moreover, there was a positive relation between DPPH and TPC for flours (Supplementary Figure S1).

Mineral analysis

Mineral content of corn flour from different accessions is given in Table 3. ANOVA demonstrated significant differences in accumulation of minerals due to accessions and colour. Conversely, accessions had a larger impact than colour (Supplementary Table S1). The macroelements Na, K, Ca and Mg content ranged from 97.49 to 19.50 mg/kg, 21 to 1677 mg/kg, 0.87 to 89.30 mg/kg and 48 to 621 mg/kg, respectively. The microelements Cu, Mn, Fe, and Zn ranged from 0.02 to 2.94 mg/kg, 0.09 to 1.32 mg/kg, 3.10 to 9.40 mg/kg and 1.63 to 7.42 mg/kg, respectively.

Table 3 Mineral composition of flour from different colored corn accessions (in ppm)

S. no	Colour	Accessions	Cu (ppm)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Mg (ppm)	Ca (ppm)	K (ppm)	Na (ppm)
1	White	IC 447511	2.94 ± 0.15l	1.22 ± 0.03ij	9.40 ± 0.20h	4.92 ± 0.33e	394 ± 31de	89.30 ± 5.20bc	565.7 ± 9.5bc	61.04 ± 2.49ef
2	White	IC 447638	1.02 ± 0.01i	0.83 ± 0.05fg	5.87 ± 0.38ef	3.21 ± 0.11cd	444 ± 12ef	84.50 ± 2.50bc	339.3 ± 5.5b	58.19 ± 0.44e
3	White	IC 447632	0.56 ± 0.02e	0.60 ± 0.05d	5.00 ± 0.52d	2.16 ± 0.33ab	332 ± 18cd	84.07 ± 1.55bc	661 ± 11c	97.49 ± 2.14h
4	White	IC 447660	0.45 ± 0.2de	0.70 ± 0.02e	5.33 ± 0.18e	2.93 ± 0.27c	294.27 ± 32cd	61.50 ± 3.50abc	385 ± 40b	47.73 ± 5.28d
5	White	IC 447639	0.39 ± 0.01cd	0.76 ± 0.01ef	5.27 ± 0.23e	3.13 ± 0.36c	426.77 ± 29.25e	49 ± 3ab	319.7 ± 5.5b	50.97 ± 5.27de
6	White	IC 447328	0.62 ± 0.15f	0.96 ± 0.06g	7.06 ± 0.17g	3.34 ± 0.17cd	439 ± 14ef	48.50 ± 3.50ab	713 ± 10c	53.25 ± 2.35de
7	White	IC 550370	0.83 ± 0.35h	0.95 ± 0.03fg	5.3 ± 0.25e	3.12 ± 0.39c	350.27 ± 5.75de	54.50 ± 1.50ab	350 ± 6b	61.66 ± 1.91ef
8	White	IC 550365	0.53 ± 0.02ef	0.82 ± 0.02fg	5.00 ± 0.25de	3.01 ± 0.51c	705.50 ± 19.50h	58.77 ± 1.25ab	607.7 ± 17.5bc	77.95 ± 2.50fg
9	White	IC 447626	0.93 ± 0.04j	0.87 ± 0.03fg	4.28 ± 0.27cd	3.00 ± 0.25bc	265.50 ± 26cd	60 ± 5bc	512.3 ± 12.5bc	57.48 ± 2.13e
10	White	IC 447501	0.46 ± 0.04e	0.90 ± 0.05fg	5.89 ± 0.07ef	2.51 ± 0.13bc	606.77 ± 18.25fg	57 ± 5bc	508.7 ± 36.5bc	59.67 ± 0.57ef
11	White	IC 447509	0.43 ± 0.04e	0.93 ± 0.02fg	5.50 ± 0.06ef	7.42 ± 0.08f	302 ± 23cd	51.50 ± 4.50abc	249.7 ± 6.5ab	74.11 ± 0.46f
12	White	IC 361712	0.78 ± 0.07g	1.32 ± 1.75j	5.90 ± 0.34ef	5.10 ± 0.15e	314.27 ± 10.75cd	48.87 ± 1.35abc	30.17 ± 23.5b	48.71 ± 1.86d
13	White	IC 361714	0.33 ± 0.45d	0.80 ± 0.05ef	4.36 ± 0.14cd	3.22 ± 0.28cd	241 ± 9bc	41 ± 4ab	267 ± 9ab	49.83 ± 2.53de
14	White	IC 447632	0.49 ± 0.06e	0.92 ± 0.03fg	4.01 ± 0.23c	3.30 ± 0.54cd	263.50 ± 11.50cd	39.77 ± 5.25ab	250 ± 6ab	57.28 ± 0.73e
15	White	IC 361719	0.37 ± 0.05de	0.99 ± 0.65g	5.99 ± 0.25f	3.17 ± 0.39c	293.50 ± 31.50cd	39.50 ± 5.50ab	216.7 ± 36.5ab	51.23 ± 4.03de
16	Yellow	IC 347386	0.42 ± 0.35de	0.92 ± 0.35fg	5.11 ± 0.14de	2.35 ± 0.21b	258.50 ± 16.50bc	231.50 ± 146d	219 ± 4ab	41.10 ± 3.90cd
17	Yellow	IC 427129	0.42 ± 0.04de	0.82 ± 0.03ef	5.01 ± 0.49de	3.06 ± 0.19c	234 ± 16bc	24.27 ± 0.75ab	162.7 ± 12.5a	37.68 ± 7.33c
18	Yellow	IC 397828	0.40 ± 0.05de	0.82 ± 0.03ef	5.57 ± 0.17ef	3.18 ± 0.18cd	286 ± 14cd	15.50 ± 12.50ab	1677 ± 7.5d	32.95 ± 2.05bc
19	Yellow	IC 397956	0.78 ± 0.04g	0.88 ± 0.06fg	4.70 ± 0.04d	3.29 ± 0.35cd	248.50 ± 7.50bc	46.77 ± 5.25ab	551.3 ± 45c	41.40 ± 3.60cd
20	Yellow	IC 397957	0.40 ± 0.60de	0.88 ± 0.06fg	5.89 ± 0.35ef	3.23 ± 0.26cd	244 ± 6bc	38 ± 8ab	170.7 ± 4.5a	39.33 ± 3.48cd
21	Yellow	IC 397958	0.40 ± 0.60de	0.89 ± 0.02fg	5.57 ± 0.17ef	3.41 ± 0.24cd	244 ± 12bc	58.50 ± 6.50bc	264 ± 11ab	47.50 ± 2.50d
22	Yellow	IC 361709	0.36 ± 0.02d	0.90 ± 0.05fg	5.30 ± 0.21e	3.11 ± 0.14c	262.27 ± 12.75cd	52.50 ± 3.50abc	239 ± 11ab	59.30 ± 2.70ef
23	Yellow	IC 362129	0.35 ± 0.03d	0.90 ± 0.03fg	4.97 ± 0.52de	3.46 ± 0.18cd	281.77 ± 7.25cd	40.87 ± 4.35ab	4182.7 ± 52.5	49.60 ± 2.40de
24	Yellow	IC 362130	0.39 ± 0.35de	1.15 ± 0.09h	5.31 ± 0.18e	3.29 ± 0.27cd	300.27 ± 24.75cd	46.27 ± 5.75ab	216.7 ± 8.5b	62.83 ± 2.18ef
25	Yellow	IC 361726	0.81 ± 0.04g	0.48 ± 0.08cd	4.68 ± 0.07d	3.13 ± 0.43c	119.27 ± 5.75ab	11.50 ± 3.50ab	306.3 ± 18.5bc	29 ± 6.60b
26	Yellow	IC 447627	1.30 ± 0.05j	0.54 ± 0.4d	4.46 ± 0.04cd	3.07 ± 0.15c	101 ± 4ab	11 ± 4ab	196.7 ± 59.5b	23.95 ± 8.05ab
27	Yellow	IC 447645	0.48 ± 0.75e	0.32 ± 0.35b	3.10 ± 0.14b	2.16 ± 0.08ab	64.77 ± 3.25ab	0.87 ± 0.35a	21 ± 4a	21.20 ± 3.80a
28	Yellow	IC 447646	0.40 ± 0.03de	0.41 ± 0.15bc	4.08 ± 0.17c	2.26 ± 0.23b	433 ± 5e	47 ± 5ab	80 ± 5ab	50.98 ± 4.23de
29	Yellow	IC 447641	0.13 ± 0.03b	0.36 ± 0.06bc	4.10 ± 0.10c	2.34 ± 0.18b	177.50 ± 7.50b	42.50 ± 0.50ab	39.7 ± 2.5a	28.35 ± 2.15ab
30	Yellow	IC 447648	0.02 ± 0.01a	0.31 ± 0.04b	3.12 ± 0.13a	2.24 ± 0.29b	92.50 ± 7.50ab	22 ± 3ab	415 ± 10c	88 ± 7g
31	Purple	IC 361727	0.51 ± 0.04e	0.09 ± 0.01a	2.95 ± 0.54a	2.05 ± 0.48ab	48 ± 7a	0.87 ± 0.35a	31 ± 11a	62.49 ± 2.74ef
32	Purple	IC 447636	0.46 ± 0.06e	0.35 ± 0.35bc	4.09 ± 0.15c	2.00 ± 0.25ab	110.50 ± 14.50ab	7.77 ± 0.75a	112.3 ± 10.5ab	21.50 ± 4.10a
33	Purple	IC 447648	0.58 ± 0.04f	0.42 ± 0.35bc	3.93 ± 0.31c	1.98 ± 0.04ab	88.50 ± 6.50ab	8.50 ± 1ab	82.7 ± 2.5ab	32.90 ± 2.70bc
34	Purple	IC 447649	0.50 ± 0.02e	0.45 ± 0.05cd	4.02 ± 0.20	2.46 ± 0.09bc	123.77 ± 6.25ab	12.37 ± 2.85ab	262.7 ± 12.5b	46.78 ± 5.23d
35	Purple	IC 447667	1.69 ± 0.06k	0.56 ± 0.003d	4.39 ± 0.11cd	3.60 ± 0.15cd	88.50 ± 2.00ab	3.17 ± 0.65a	33 ± 2a	21.03 ± 3.98a
36	Purple	IC 447647	0.28 ± 0.05c	0.39 ± 0.06bc	3.31 ± 0.19b	1.63 ± 0.21a	70.77 ± 4.25ab	1.50 ± 0.50a	28 ± 4a	23.78 ± 8.23ab

Table 3 continued

S. no	Colour	Accessions	Cu (ppm)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Mg (ppm)	Ca (ppm)	K (ppm)	Na (ppm)
37	Purple	IC 447643	0.58 ± 0.04f	0.58 ± 0.75d	4.09 ± 0.16c	3.01 ± 0.25c	88.50 ± 2ab	4 ± 0.50a	23 ± 3a	19.50 ± 5.50a
38	Purple	IC 447644	0.15 ± 0.03b	0.43 ± 0.13c	4.34 ± 0.15cd	2.85 ± 0.39c	621.77 ± 3.25g	78.77 ± 6.25bc	100 ± 5ab	28.38 ± 3.63ab

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($P \leq 0.05$). All values are reported on dry weight basis
Cu Copper, Mn Manganese, Fe Iron, Zn Zinc, Mg Magnesium, Ca Calcium, K Potassium, Na Sodium

(Table 3). K, Mg, Ca Zn, Na, Cu, Mn, and Fe were in high concentration in IC 447511 (89.30 mg/kg), IC 362129 (4182.7 mg/kg), IC 447644 (621.77 mg/kg), IC 447509 (7.42 mg/kg), IC 447632 (97.49 mg/kg), IC 447511 (2.94 mg/kg), IC 361712 (1.32 mg/kg) and IC 447511 (9.40 mg/kg), respectively, while the lowest accumulation of Cu, K, Mg, Zn, Na, Ca, Mn, and Fe was observed for IC 361727 (0.87 mg/kg), IC 447645 (21 mg/kg), IC 361727 (48 mg/kg), IC 447647 (1.63 mg/kg), IC 447643 (19.50 mg/kg), IC 447648 (0.02 mg/kg), IC 361727 (0.09 mg/kg) and IC 447645 (3.10 mg/kg), respectively. The variation in mineral composition among different coloured corn accessions may be due to environmental factors and soil nutrients as well as variation in the use of fertilizers (Ahmadi et al. 1993). Minerals act as body regulators and play major role in metabolic and cellular functions of the body. The accessions having large or small amounts of minerals can be considered to differentiate the genetic and physiological mechanisms that were reported to be responsible for development of seeds by regulating mineral transport (Wang et al. 2003). A marked variation in mineral concentration of grains among different corn accessions was also reported earlier by Menkir et al. (2008). Nuss and Tanumihardjo (2010) reported that Mg and K were the most prevalent minerals present in corn.

SDS-PAGE analysis

Different corn accessions showed the presence of different molecular weight storage proteins of 15–20 polypeptide (PP) subunits that ranged from 9.7 to 95 kDa [Supplementary Figure S3(a), (b)]. Major PP subunits observed in coloured corn accessions were 97, 86, 60, 45, 30, 27, 22, 19 and 13 kDa. Low molecular weight (LMW) PP subunits (20 to > 10 kDa) were highly accumulated in different coloured corn varieties. Zein (alcohol soluble protein) was present in corn as LMW PPs. Esen (1986) termed zein proteins of 19 and 22 kDa, 14 kDa, and 16 and 27 kDa PP as α , β and γ -zein, respectively. Yellow corn accessions did not show variation among high molecular weight (HMW) protein subunits, whereas small variations were observed for medium molecular weight (MMW) PP subunits. All accessions showed higher accumulation of 23–28 kDa PPs, while absence of 23 kDa PP in IC 447509 accessions was remarkable. This might be due to more proportion of hard endosperm in corn. Dombrink-Kurtzman and Bietz (1993) reported that hard endosperm had lesser amount of γ -zeins, while soft endosperm of same genotype showed the reverse trend. Thakur et al. (2015) reported that γ -zein (27 kDa) was present in very small amount in corn varieties with soft endosperm texture. Major polymorphism was found in MMW PPs. 15.6 kDa PP was highly accumulated in yellow coloured accessions, whereas 12 kDa PP was present

in white coloured accessions. Shewry and Tatham (1990) reported 15 kDa PP as β -zein. Higher accumulation of 23, 25, 27 and 28 kDa PP subunits was observed in yellow corn accessions. HMW 95 kDa PP was present in all accessions, whereas LMW 10, 11, 12, 13, 14, 15, 17 and 19 kDa PPs were observed in corn accessions. Polymorphism in different MW PPs was found among white and red-pigmented corn accessions, where IC 447509 white accession showed the absence of MMW 23, 24 kDa PPs. IC 447649 showed the accumulation of MMW except 20–24 kDa PPs among purple accessions. Dombrink-Kurtzman and Bietz (1993) reported that α -zein (22 kDa) was present in higher amount in hard endosperm fractions and was not uniformly distributed throughout the endosperm.

Amino acid analyses

Amino acids (essential and non essential) content in different corn accessions are shown in Supplementary Table S7a, b. Higher proportions of citrulline, arginine, GABA, phenylalanine, isoleucine, tyrosine, threonine, glycine in relation to other amino acids were observed in different corn accessions. According to NRC (2012), corn contains minute quantity of crude protein (CP) and amino acids (AA) as compared to other plant protein sources. IC 550370, IC 447639, IC 447638, IC 447644, IC 550365, IC 447509, IC 447648, IC 361727, IC 397958, IC 397957, IC 447501, IC 447649, IC 447511, IC 427129, IC 447636, IC 447645 showed higher relative proportion of glutamic acid, tryptophan and GABA, asparagine and lysine, glutamine and threonine, histidine, citrulline, arginine, phenylalanine, isoleucine, proline, leucine, tyrosine, cystine, valine, methionine, alanine and glycine respectively. Similar trends were also observed by Mouhamad et al. (2016) in the nine and 39 corn cultivars. Corn sources from different origins varied in CP and AA content especially in lysine and tryptophan (Kil et al. 2014). Factors such as corn genotype, soil condition, precipitation and other environmental conditions resulted in considerable variation in CP and AA concentrations among corn sources produced in various regions of The United States (Cowieson and Adeola 2005).

HPLC analysis

Significant variation in concentration of base-hydrolysed bound phenolic compounds of different coloured corn accessions was observed (Supplementary Table S6). Calibration curve equations, limits of detection, coefficient of determination of linearity and quantification collected for different phenolics are given in Supplementary Table S2. The major phenolics in corn flours were associated with

cell wall components in bound form, while absent in free form. HPLC analysis showed the presence of gallic acid, catechin, caffeic acid, chlorogenic acid, protocatechuic acid, vanillic acid, *p*-coumaric acid, quercetin, ferulic acid, sinapic acid, resveratrol and luteolin in the range of 0.76–27.02, 0.19–17.62, 0.01–1, 0.11–11.54, 0.63–27.22, 0.01–2.28, 2.17–3.64, 0.11–9.66, 0.23–18.43, 0.04–22.74, 0.01–2.49 and 9.36–15.38 mg/g, respectively. Similar results were reported earlier in corn by Ramos-Escudero et al. (2012). Primarily all corn accessions contained ferulic acid but white accessions had exceptionally large amounts of this phenolic acid. Lopez-Martinez et al. (2009) observed ferulic acid present in eighteen strains of Mexican corn. IC 447632 presented the largest concentration of ferulic acid, while IC 397828 showed the lowest. Base-hydrolyzed bound gallic acid, protocatechuic acid, *p*-coumaric acid, sinapic acid, quercetin and luteolin content showed a significant variation among different coloured corn accessions. Gallic acid content of yellow coloured corn accessions was significantly lower as compared to other accessions except IC 347386. White coloured corn accessions showed significantly high gallic acid content than purple coloured corn accessions. Slightly lower concentration of protocatechuic acid was observed in yellow accessions in comparison with white and purple coloured corn accessions. A significantly higher sinapic acid and luteolin content in different corn accessions were observed. Sinapic acid ($r = 0.318$, $P \leq 0.05$), catechin ($r = 0.440$, $P \leq 0.005$), *p*-coumaric acid ($r = 0.388$, $P \leq 0.05$) and luteolin ($r = 0.502$, $P \leq 0.005$) correlated significantly with Mg and TPC respectively. Zhao and Moghadasian (2008) reported some phenolic compounds chelates metal ions thus exhibit antioxidant activity. Phenolic acids have wide range of variation in their effectiveness as antioxidant (Robards et al. 1999). The highest content of quercetin was observed for IC 427129, while the lowest was for IC 447643.

Starch characteristics

Physico-chemical characteristics

The amylose content, blue value and $\lambda_{\max}$ of different corn starches varied significantly and differences in the characteristics were highly prominent due to accessions than colour (Supplementary Table S1). Amylose content of starches from various corn accessions ranged widely from 7.64 (IC 550365) to 20.90% (IC 447645) (Supplementary Table S5). Similar results for amylose content of different corn starches were reported by Thakur et al. (2015). Blue value of starches from various corn accessions ranged from 0.099 (IC 550365) to 0.22 (IC 447627). Higher number of long chains in amylopectin was responsible for high iodine

Fig. 2 Scanning electron microscope of starches from different corn accessions

binding capacity (Lu et al. 2008). $\lambda_{\max}$ of starches from different corn accessions ranged from 570.46 (IC 550365) to 598.49 (IC 361726).

Granule size distribution and morphology

SEM micrographs of starches from various corn accessions are shown in Fig. 2. Starch granules showed a characteristic angular (polygonal) shape with smooth surfaces. Some starch granules were irregular in shape having the presence of grooves or furrows or pores on the surface. Bajaj et al. (2018) suggested that the pores and differences in granule morphology of starches were associated with botanical source and physiology of the plant. Similar results were seen in corn, sorghum and millet starch granules by (Fannon et al. 1992) SEM confirmed the granule size distribution which ranged from 10 to 100 μm . The average granule size of starches varied significantly. The differences were higher due to accessions than colour (Supplementary Table S1). The size of the starch granules ranged from 13.49 μm (IC 447636) to 48 μm (IC 361714) (Supplementary Table S5). All starches from different corn

accessions showed unimodal distribution for granule size. Bajaj et al. (2018) reported the diameter of corn starch granule ranging from 6 to 30 μm .

Thermal characteristics

Thermal characteristics of starches among various corn accessions are given in Supplementary Table S4. Significant variation in transition temperatures; onset (T_o), peak (T_p), conclusion (T_c) and enthalpy of gelatinization (ΔH_{gel}) among starches from various corn accessions was observed. ANOVA presented considerable differences in thermal properties due to accessions and colour but accessions had a greater effect than colour (Supplementary Table S1). T_o , T_p , T_c and ΔH_{gel} ranged from 62.84 (IC 447638) to 68.33 $^{\circ}\text{C}$ (IC 447643), 66.35 (IC 361726) to 71.44 $^{\circ}\text{C}$ (IC 347386), 70.01 (IC 361712) to 75.78 $^{\circ}\text{C}$ (IC 447643) and 6.10 (IC 447648) to 11.64 J/g (IC 362130). Bajaj et al. (2018) reported the DSC values in the similar trend for starches. Differences in the degree of crystallinity were responsible for the variation in the transition temperatures among starches from different corn accessions

Table 4 Pasting characteristics of starches from different colored corn accessions

S. no	Colour	Accessions	Peak viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Pasting temperature (°C)
1	White	IC 447511	3284 ± 9.0de	1505 ± 28c	3961 ± 11.5g	2182 ± 30.5fg	72.99 ± 0.02cd
2	White	IC 447638	3528 ± 26.5fg	1721 ± 45d	4293 ± 42i	2452 ± 23h	73.99 ± 0.57de
3	White	IC 447632	2773 ± 14ab	1389 ± 23bc	3639 ± 40.5f	2241 ± 64g	72.92 ± 0.46cd
4	White	IC 447660	2679 ± 32ab	2050 ± 17.5f	3679 ± 26f	3021 ± 18j	71.00 ± 0.09b
5	White	IC 447639	2846 ± 21b	1851 ± 2e	3356 ± 31.5e	2361 ± 8.5gh	69.64 ± 0.36a
6	White	IC 447328	3043 ± 13.5c	1382 ± 2.5bc	3606 ± 29f	1944 ± 17.5de	74.16 ± 1.01de
7	White	IC 550370	3232 ± 16.5de	1489 ± 37c	3805 ± 10.5fg	2212 ± 15.9ef	74.11 ± 0.09de
8	White	IC 550365	2872 ± 9.9bc	1271 ± 32.5ab	3220 ± 50.5de	1620 ± 16c	72.18 ± 0.97c
9	White	IC 447626	3029 ± 10c	1590 ± 24cd	3667 ± 7.5f	2233 ± 36.5g	72.98 ± 0.19cd
10	White	IC 447501	3139 ± 21cd	1356 ± 12b	3858 ± 29g	2075 ± 20ef	72.86 ± 0.37cd
11	White	IC 447509	3213 ± 36d	1544 ± 2c	3671 ± 48.5f	2003 ± 14e	72.70 ± 0.45cd
12	White	IC 361712	3725 ± 12.5g	2798 ± 8i	2102 ± 82a	1175 ± 49a	72.56 ± 0.09cd
13	White	IC 361714	3883 ± 38h	2691 ± 57.5h	2511 ± 3c	1319 ± 16.5b	72.07 ± 0.020c
14	White	IC 447632	2644 ± 17.5a	1913 ± 33e	3543 ± 5.5f	2812 ± 45.5i	71.33 ± 0.18bc
15	White	IC 361719	3470 ± 22ef	2377 ± 4.5g	2299 ± 28b	1206 ± 1.5a	72.27 ± 0.37c
16	Yellow	IC 347386	3245 ± 34de	1438 ± 46.5c	4057 ± 5.5gh	2251 ± 17.5g	73.86 ± 0.59de
17	Yellow	IC 427129	3345 ± 20.2e	1555 ± 98c	3990 ± 17.5gh	2200 ± 73fg	74.22 ± 1.34de
18	Yellow	IC 397828	3047 ± 19c	1297 ± 25.6b	3703 ± 41.5f	1955 ± 47.5de	73.87 ± 0.23de
19	Yellow	IC 397956	3149 ± 18cd	1199 ± 34a	4287 ± 63i	2337 ± 11gh	74.98 ± 0.86e
20	Yellow	IC 397957	3306 ± 28.5de	1632 ± 24.5d	4017 ± 22gh	2343 ± 17gh	74.66 ± 0.18e
21	Yellow	IC 397958	3144 ± 20.5de	1361 ± 8b	3928 ± 32.5g	2145 ± 20f	74.29 ± 0.04de
22	Yellow	IC 361709	2891 ± 10.8bc	1220 ± 73.5a	3560 ± 99.5f	1890 ± 64d	73.80 ± 0.28de
23	Yellow	IC 362129	3189 ± 19.5d	1572 ± 10c	3491 ± 3.5ef	1873 ± 13.5d	73.77 ± 0.47de
24	Yellow	IC 362130	2913 ± 28.5bc	1265 ± 16.9ab	3765 ± 28.7fg	2117 ± 174f	74.39 ± 1.05e
25	Yellow	IC 361726	3500 ± 35ef	1682 ± 8d	3863 ± 39g	2045 ± 11ef	73.31 ± 0.55de
26	Yellow	IC 447627	3180 ± 21de	1418 ± 32.5bc	4105 ± 45h	2343 ± 33.5gh	74.46 ± 0.24e
27	Yellow	IC 447645	2958 ± 26.5bc	1277 ± 19.5b	3782 ± 1.5fg	2102 ± 5f	74.44 ± 0.18e
28	Yellow	IC 447646	3329 ± 37.5de	1607 ± 9cd	3824 ± 27.5fg	2101 ± 19.5f	73.36 ± 0.69de
29	Yellow	IC 447641	3158 ± 49cd	1431 ± 14.5c	3892 ± 37.5g	2166 ± 3f	73.45 ± 0.89de
30	Yellow	IC 447648	3173 ± 73.5cd	1461 ± 8.5c	3715 ± 10f	2003 ± 35.5e	74.54 ± 0.24e
31	Purple	IC 361727	3431 ± 0.1ef	1895 ± 26e	3487 ± 2ef	1968 ± 8de	73.25 ± 0.72cd
32	Purple	IC 447636	3016 ± 15.8bc	1563 ± 30cd	3148 ± 19d	1894 ± 7d	70.87 ± 0.08b
33	Purple	IC 447648	3004 ± 0.2bc	1589 ± 3.5cd	3383 ± 21.6e	1876 ± 24.5d	69.85 ± 0.26a
34	Purple	IC 447649	3022 ± 15bc	1657 ± 15.5d	3775 ± 9fg	2410 ± 21.2h	73.09 ± 0.30cd
35	Purple	IC 447667	3185 ± 12d	1702 ± 36.5d	3686 ± 17.5f	2204 ± 66fg	71.91 ± 0.23c
36	Purple	IC 447647	3297 ± 13de	1580 ± 16.5cd	3927 ± 38g	2210 ± 41.5fg	73.50 ± 0.30de
37	Purple	IC 447643	2987 ± 14e	1321 ± 3b	3676 ± 27f	2010 ± 10e	74.64 ± 0.24e
38	Purple	IC 447644	3177 ± 21de	1708 ± 10.5d	3156 ± 49d	1695 ± 25cd	72.95 ± 0.16cd

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($P \leq 0.05$)

(Singh and Singh 2003). The deviation in ΔH_{gel} (indicative of melting of amylopectin crystallites) might represent the variation in bonding forces among the double helices, forming amylopectin crystallites. This led to different hydrogen bonds alignments inside starch molecules (McPherson and Jane 1999). The low ΔH_{gel} indicated the role of shape of starch granules and fraction of large and

small granules along with the presence of amylopectin (Yuan et al. 1993). Moreover, low T_o and broad range of gelatinization (R) indicated the presence of irregular shaped starch granules (Yamin et al. 1999). PCA revealed positive correlation between thermal properties and crystallinity.

X-ray diffraction (XRD) and Fourier transform infra-red (FTIR) spectroscopy

The X-ray diffraction pattern of starches from various corn accessions are illustrated in Supplementary Figure S2. Starch granule exhibited a semi-crystalline structure which was classified into A, B and C types. All starches presented a typical A-type diffraction pattern having prominent diffraction peaks around 15.02° and 23.2° and dual peak at $17\text{--}18.1^\circ$ 2θ which has been confirmed by Bajaj et al. (2018) and explained that the presence of higher content of amylose in starches led to lower degree of crystallinity possibly because of associated lower amylopectin content. Crystalline structure as well as short range order was studied by IR spectroscopy. The absorbance bands at 1047 cm^{-1} were associated with crystalline regions while absorbance at 1022 cm^{-1} was observed due to amorphous regions in starch. Ratio of absorbance of $1047/1022\text{ cm}^{-1}$ described the changes in crystallinity and $1047/1035\text{ cm}^{-1}$ ratio for short range order. The change in crystallinity (ratio of absorbance of $1047/1022\text{ cm}^{-1}$) and short range order ($1047/1035\text{ cm}^{-1}$) varied significantly for the accessions which ranged from 0.29 (IC 447648) to 1.14 (IC 362129) and 2.64 (IC 447501) to 0.01 (IC 447632), respectively. The higher ratio of band intensity of $1047/1022\text{ cm}^{-1}$ and $1047/1035\text{ cm}^{-1}$ indicated larger crystallinity and more of short range regions. The differences in crystallinity in various corn starches can be due to the differences in the amylose content and long and short chain amylopectin (Singh et al. 2006). PCA confirmed the positive relation between the crystallinity with amylose content.

Pasting properties of starches

A significant variation in pasting properties was observed amongst starches from different corn accessions. Table 4 represents the differences in pasting behaviour of starches from different corn accessions. PT, FV, PV, BDV and SBV ranged from 69.64 (IC 447639) to 74.98°C (IC 397956), 2102 (IC 361714) to 4293 cP (IC 447638), 1175 (IC 361712) to 3021 cP (IC 447660), 1199 (IC 397956) to 2798 cP (IC 361712) and 2644 (IC 447632) to 3883 cP (IC 361714), respectively. Similar results were reported by Sandhu et al. (2007). The accessions with higher PT showed resistance to swelling. Li and corke (1999) explained that low PV indicated the resistance of starch to shear thinning. PCA revealed the positive relation of amylose content with FV and SBV while negative relation with BDV of starch. The high BDV may be due to weaker rigidity of starch granules under heating and shearing in the presence of low amylose content (Lu et al. 2008). Bajaj et al (2018) reported higher SBV was associated with

amylose content of starches. The high FV of corn starches is because the amylose molecules tend to aggregate (Miles et al. 1985).

Conclusion

The present study revealed characterization of diverse range of coloured corn accessions. Grain, flour and starch characteristics were in strong correlation with each other. Significant differences were observed in grain characteristics. Flours from various corn accessions differed significantly for physicochemical, antioxidant, pasting, amino acid and polyphenolic profiles. Quercetin, Sinapic acid, protocatechuic acid, ferulic acid, and gallic acid were present in different accessions in varying concentration. Purple corn accessions showed higher antioxidant activities and polyphenolic content than yellow and white accessions may be useful to impart nutritional properties. Analyses of physicochemical, pasting, thermal and structural characteristics of starches presented considerable knowledge contributing to functional properties of starches. The production and processing of significant quality starch depends upon the desired food characteristics. The differences in composition and physical properties can be utilized in developing gluten free products. Corn being a non-glutinous, antioxidant rich cereal showed high amount of phenolics that are useful to impart resistance to several diseases.

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Compliance with ethical standards

Conflict of interest Authors declared no conflict of interest.

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