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ORIGINAL ARTICLE

Physicochemical and rheological properties of starch and flour from different durum wheat varieties and their relationships with noodle quality

Amritpal Kaur[1] · Khetan Shevkani[1] · Mehak Katyal[1] · Narpinder Singh[1] · Arvind Kumar Ahlawat[2] · Anju Mahendru Singh[2]

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Abstract Starch and flour properties of different Indian durum wheat varieties were evaluated and related to noodle-making properties. Flours were evaluated for pasting properties, protein characteristics (extractable as well as unextractable monomeric and polymeric proteins) and dough rheology (farinographic properties), while starches were evaluated for granule size, thermal, pasting, and rheological properties. Flour peak and final viscosities related negatively to the proportion of monomeric proteins but positively to that of polymeric proteins whereas opposite relations were observed for dough rheological properties (dough-development time and stability). Starches from varieties with higher proportion of large granules showed the presence of less stable amylose-lipids and had more swelling power, peak viscosity and breakdown viscosity than those with greater proportion of small granules. Noodle-cooking time related positively to the proportion of monomeric proteins and starch gelatinization temperatures but negatively to that of polymeric proteins and amylose content. Varieties with more proteins resulted in firmer noodles. Noodle-cohesiveness related positively to the proportion of polymeric proteins and amylose-lipids complexes whereas springiness correlated negatively to amylose content and retrogradation tendency of starches.

Keywords Durum wheat · HPLC · Noodles · Proteins · Rheology · Starches

Research highlights • Different durum wheat varieties were evaluated for starch, flour and noodle-making properties
• Flour properties related to protein composition while starch properties depended on granule size, amylose and amylose-lipid
• Noodle-making properties of different durum wheat varieties depended on both starch and flour characteristics

✉ Amritpal Kaur
amritft33@yahoo.co.in

1 Department of Food Science and Technology, Guru Nanak Dev University, Amritsar 143005, India

2 Division of Genetics, Indian Agricultural Research Institute, New Delhi 110012, India

Introduction

Noodles are one of the many convenience foods which are prepared mostly from wheat flour. These are popular on the account of sensory appeal, palatable taste, low cost, convenience of preparation and storage stability (Kaur et al. 2015a). Noodles are indispensible in the diets of several Asian countries where around 20 to 50 % of the total wheat flour is consumed in this form (Hou 2010; Ma et al. 2014). Durum wheat flour/semolina is preferred for preparation of noodles owing to its high protein content and attractive bright yellow colour which is due to high content of xanthophylls and carotenoids. Although durum wheat comprises a small proportion of total wheat production in India, its popularity is increasing amongst Indian farmers owing to higher yield potential and resistance to rusts and Karnal bunt than common wheat.

Starch and proteins are the major constituents of wheat flour and their content and characteristics influence rheological properties of dough, consequently, quality of the finished products. Most of the durum wheat crops are used for the production of semolina involved in pasta/noodle production, as the quality attributes of durum gluten makes it preferably desirable for this use, but rather less suitable for bread making (Halversan and Zeleny 1988). Traditionally, gluten proteins have been divided into gliadins and glutenins, wherein the former contribute to the extensibility while the later to the elasticity of the wheat dough. In addition, a certain amount of proteins remain unextractable in various extracting systems (e.g. acetic acid solution or SDS-phosphate buffer) is known as unextractable polymeric proteins. Gliadin to glutenin ratio, quantity of monomeric and polymeric gluten proteins as well as the amount of unextractable polymeric protein have been reported to influence rheology and strength of wheat dough (Singh and Khatkar 2005; Singh et al. 2011) as well as have been applied as quality markers in bread-making (Khatkar and Schofield 1997; Khatkar 2006). The differences in composition and characteristics of wheat proteins have been attributed to the variations in noodle-making properties of different durum flours (Novaro et al. 1993; Kaur et al. 2015b). Starch is major constituent of wheat as it constitutes about 80 % of the durum flour. Therefore, quality of flour noodles would also depend on the characteristics of starches. Starch comprises mainly of two types of glucose polymers, amylose and amylopectin, among which amylose is a linear polymer and greatly influences the characteristics of cooked starch/flour pastes. Sasaki et al. (2008) determined viscoelastic properties of wheat flours, starch and gluten-starch mixture with varying amylose content and reported that the amylose content strongly affected rheological properties of flour gels. Seib (2000) reported that the elastic response of starch gels increased with increase in amylose content in the continuous phase, the volume fraction of swollen granules, rigidity of dispersed granules and adhesion between dispersed and continuous phases. Wheat cultivars with high-amylose have been used to increase resistant starch in breads (Hung et al. 2005) and to improve the texture of noodles (Morita et al. 2003). In addition, Blazek and Copeland (2008) and Singh et al. (2011) reported that non-starch constituents, e.g. proteins, lipids and non-starch polysaccharides also influence rheological/viscoelastic properties of wheat flours. The objective of the present study was to determine flours (physicochemical, protein composition, pasting and dough rheological) and starches characteristics (physicochemical, thermal and rheological properties) of different Indian durum wheat varieties and to investigate the relationship of these characteristics with their noodle-making properties.

Materials and methods

Materials

Thirteen durum wheat varieties (HI8663, VD06–06, PDW233, UP2782, HD4672, KLM1005, MASS499, WSM24, HI8627, HI8691, HI8638, GW07–112 and PDW291) were procured from Indian Agriculture Research Institute, PUSA, New Delhi, India. The grains of different varieties were cleaned and conditioned for 48 h at 14 % moisture and milled in the Quadrumat Senior mill (Barbender, Germany).

Flour characteristics

Physicochemical properties

Colour parameters (L^*, a^* and b^* values) of flours from different durum varieties were determined using Ultra Scan VIS Hunter Lab (Hunter Associates Laboratory Inc., Reston, VA, USA). Protein, ash, and YPC of the flours were determined employing standard methods (AACC 2000).

Protein composition

Sodium dodecyl sulphate (SDS) extractable and un-extractable monomeric (Ex-MP and UnEx-MP, respectively) and polymeric proteins (Ex-PP and UnEx-PP, respectively) were determined following the method of Gupta et al. (1993). Flour (10 mg) was suspended in 1 ml 1 % SDS and 0.1 M sodium phosphate buffer (pH 6.9) and stirred for 5 min using a vortex mixer. The mixture was centrifuged for 20 min at 12,000×g. The extractable protein was dissolved in supernatant and filtered through a 0.2 μm filter. The un-extractable protein was obtained from the residue. The residues were sonicated for 60 s with 1 ml of extraction buffer. Then the mixture was centrifuged for 20 min at 12,000×g and the supernatant was filtered and 20 μl of fiterate was injected to a HPLC (Agilent Technologies 1260 Infinity, USA) for analysis. SDS extractable and un-extractable protein fractions were separated by a narrow bore column PROSEC 300S (300 × 7.5 mm). Eluting solution was 50 % acetonitrile in water with 0.1 % trifluroacetic acid at a flow rate of 0.5 ml/min. Solutes were detected at 214 nm using a photodiode array detector.

Pasting properties

Pasting properties of flours from different durum wheat varieties were determined using a rheometer (MCR-301, Anton Paar, Austria) equipped with starch cell (C-ETD 160). Flour suspensions (10 %) were held at 50 °C for 1 min then heated from 50 to 95 °C at a rate of 12.16 °C/min, held at 95 °C for 2.5 min, cooled from 95 to 50 °C at a rate of 11.84 °C/min, and held at 50 °C for 2 min (Kaur et al. 2015a). Parameters recorded were pasting temperature (PT), peak viscosity (PV), breakdown viscosity (BDV), final viscosity (FV), and setback viscosity (SBV).

Farinographic characteristics

Dough properties were determined using a farinograph (Brabender, Germany) according to AACC (2000) methods. Water absorption (WA) was determined as the amount of water required to center the farinograph curve at 500 BU. Dough development time (DDT) was determined as the time between the first addition of the water and the development of the dough's maximum consistency. Dough stability (DS) was the difference in time between the point at which the top of the curve first intercepts 500 BU and the point at which the top of the curves leaves the 500 BU. Degree of softening (DOS) was determined as the difference in BU, between the height of the center of the curve at the peak and the center of the curve after 12 min (Singh et al. 2011).

Starch isolation

Starch was isolated from different durum wheat varieties following the method elaborated elsewhere (Singh et al. 2010).

Starch characteristics

Physicochemical characteristics

Amylose content of the starches was determined following the method of Williams et al. (1970). Particle (granular) size was determined using laser-light particle size analyzer (S3550, Microtrac Inc., USA) equipped with delivery system for wet samples (Microtrac SDC, Microtrac Inc., USA). Swelling power was determined by the method of Leach et al. (1959). Transmittance (%) of starches was measured using UV-VIS spectrophotometer (Lambda 25, Perkin-Elmer, USA). Two percent aqueous suspension of starch was heated at 90 °C for 30 min with constant stirring followed by cooling for 1 h at 30 °C. The samples were stored for five days at 4 °C, and % transmittance was measured every 24 h at 640 nm against a water blank (Singh et al. 2014).

Thermal properties

Thermal properties were analysed using DSC-822^e (Mettler Toledo, Greifense, Switzerland) equipped with a thermal analysis data station as described earlier (Singh et al. 2010). Onset, peak, and endset transition temperatures (To, Tp, and Tc, respectively) and enthalpy of gelatinization were calculated using Star^e Software for thermal analysis (Mettler Toledo).

Pasting properties

Pasting properties of starch suspensions (10 %) were determined following the method described in Pasting properties section.

Dynamic rheological properties

The changes in viscoelastic properties of starch pastes for retrogradation were determined using aforementioned rheometer equipped with parallel-plate geometry (PP-40) following the method of Shevkani et al. (2011) with a slight modification. Gap, stress and frequency were 1.0 mm, 1 Pa and 1.0 rad/s, respectively. These values were within linear viscoelastic range. For preparation of starch pastes, starch suspensions (20 %) were stirred for 1 h in sealed vials at room temperature and then cooked in water bath set at 95 °C for 30 min with vortex shaking (10 s) at an interval of 2 min. The cooked starch pastes were immediately transferred between the plates of the rheometer preheated to 90 °C. The pastes were cooled from 90 to 10 °C at a rate of 2.5 °C/min and then held at 10 °C for 30 min. Storage and loss modulus (G and G, respectively) of the cooked starch pastes were recorded.

Noodle-making properties

Noodles were prepared following the method described earlier (Kaur et al. 2015a). Cooking time (CT) was determined by cooking 5 g noodles in 100 ml boiling distilled water till the disappearance of white core as judged by squeezing between two glass slides. Water absorption (WA) by noodles was measured as the difference in the weight of cooked and uncooked noodles. For WA determination, cooked noodles were rinsed with cold water and drained for 30 s then weighed to determine the cooking gain (Galvez and Resurreccion 1992). For gruel solid loss (GSL) determination, cooked noodles were drained and rinsed with distilled water (50 ml). GSL was determined by evaporating to dryness the cooking and rinse water in a pre-weighed petri-plate in an oven at 110 °C for about 12 h (Galvez and Resurreccion 1992). Textural properties of cooked noodles were determined using a TA-XT2 plus Texture Analyzer (Stable Micro Systems, England) within 5 min after cooking. A set of five strands of cooked noodles was placed parallel on a flat heavy duty metal platform and compressed 70 % of their original height at a speed of 1.0 mm/s. Firmness, cohesiveness and springiness were calculated from force-time curves.

Statistical analysis

The data reported is mean of triplicate observations. The data was subjected to analysis of variance (ANOVA) by Duncan's test ($P < 0.05$) and principal component analysis (PCA) using Minitab Statistical Software (State College, PA, USA). PCA was carried out to draw loading plot (Fig. 1) which provided an overview of the relationships between the measured parameters. The parameters whose curves lie close to one another on the loading plot were positively related, while those whose curves ran in opposite directions were negatively related.

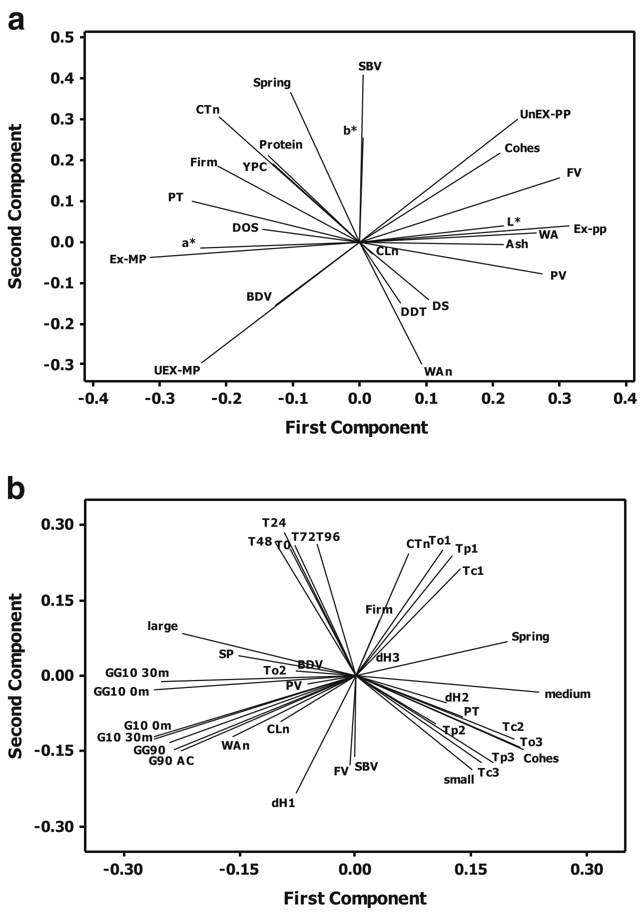

Fig. 1 a. PCA loading plot representing relationships of flour characteristics with noodle-making properties of Indian durum wheat varieties. CLn = noodle gruel solid loss; CTn = noodle cooking time; WAn = water absorption by noodles; PT = pasting temperature; PV = peak viscosity; BDV = breakdown viscosity; FV = final viscosity; SBV = setback viscosity; YPC = yellow pigment content; Cohes = cohesiveness; Firm = firmness; Spring = springiness; WA = dough water absorption; DDT = dough development time; DS = dough stability; DOS = degree of softening Ex-MP = extractable monomeric proteins; Ex-PP = extractable polymeric proteins; UnEx-MP = unextractable monomeric proteins; UnEx-PP = unextractable polymeric proteins. **b.** PCA loading plot representing relationships of starch characteristics with noodle-making properties of Indian durum wheat varieties. AC = amylose content; SP = swelling power; large = A-granules; medium = B-granules; small = C-granules; CLn = noodle gruel solid loss; CTn = noodle cooking time; WAn = water absorption by noodles; PT = pasting temperature; PV = peak viscosity; BDV = breakdown viscosity; FV = final viscosity; SBV = setback viscosity; Cohes = cohesiveness; Firm = firmness; Spring = springiness; G90 = *G* of starch paste at 90 °C; G10 0 m and G10 30 m = *G* of starch paste at 10 °C after 0 min and 30 min, respectively; GG90 = *G* of starch paste at 90 °C; GG10 0 m and GG10 30 m = *G* of starch paste at 10 °C after 0 min and 30 min, respectively; T0, T24, T48, T72 and T96 = percent transmittance of starch gels after 0 h, 24 h, 48 h, 72 h and 96 h, respectively. To1, Tp1 and Tc1 = onset, peak and endset transition temperatures, respectively of starch gelatinization/melting; To2, Tp2 and Tc2 = onset, peak and endset transition temperatures, respectively of amylose-lipids dissociation; To3, Tp3 and Tc3 = onset, peak and endset transition temperatures, respectively of amylose-lipids re-association; dH1, dH2 and dH3 = enthalpies for starch gelatinization, amylose-lipids dissociation and re-association, respectively

Result and discussion

Flour characteristics

Physicochemical properties

*L**, *a** and *b** values of flours from different varieties ranged from 88.85 to 92.03, 0.40 to 0.91, and 11.03 to 18.04, respectively (Table 1). PDW291 showed the highest *L** value and the lowest *a** value indicating the highest brightness and lowest redness. HI8663 and MASS499 flour had higher *b** values (more yellowness) which might be due to the presence of higher amount of carotenoids and xanthophylls. Kaur et al. (2015b) reported *L**, *a** and *b** values in the range from 90.92 to 92.25, 0.30 to 0.73 and 13.66 to 17.50, respectively for different durum wheat flours. Protein content of flours varied between 11.6 % and 16.0 %. Singh et al. (2011) reported lower protein content between 8.26 % and 12.85 % in flours from different common Indian wheat varieties. The content of proteins had been reported to be influenced by genetic as well as by non-genetic factors (Subda 1991). Ash content of the flours varied between 0.55 % and 1.0 % amongst different varieties. Ash and protein content in the range from 1.66 to 2.32 % and 13.1 to 16.5 %, respectively has been reported for durum wheat (Rharrabti et al. 2003). Amount of ash in flours determines their contamination with bran particles during milling. It also indicates degree of separation of bran and germ from endosperm during milling. PCA revealed that protein content related positively to *a** and *b** values but negatively to *L** value (Fig. 1a). A positive correlation of *a** and *b** value with protein content has been reported previously for different corn fractions (Shevkani et al. 2014). YPC of flours from different varieties varied between 3.39 and 5.63 ppm. PDW291, HI8627, and HI8691 had the lowest YPC while UP2782 had the highest. PCA revealed that YPC related negatively to *L** value but positively with protein content, *a** and *b** values, indicating that the flours with lower lightness and greater proteins had higher YPC. YPC between 3.33 and 6.64 ppm has been reported earlier for Indian durum wheat varieties (Kaur et al. 2015b). The ash content located on the opposite side of *a** and *b** values on the PCA loading plot (Fig. 1a) which indicated that the difference in yellowness and redness was attributed by YPC content rather than contamination of brany layers.

Protein composition

The proportion of Ex-PP and Ex-MP ranged from 18.15 to 52.57 % and 47.43 to 81.85 %, respectively (Table 1). The proportion of Ex-PP, Ex-MP, UnEx-PP and UnEx-MP on average basis had been reported to be 46 %, 54 %, 62 % and 38 %, respectively for bread wheat (Gupta et al. 1993). The proportion of UnEx-PP and UnEx-MP ranged from 45.46 to

Table 1 Physicochemical properties and protein composition of flours from different durum wheat varieties

Varieties	*L**	*a**	*b**	Protein content (%)	Ash content (%)	Yellow pigment content (ppm)	Ex-pp. (%)	Ex-MP (%)	UEX-PP (%)	UEX-MP (%)
HI8663	90.30[c]	0.91[d]	17.90[i]	13.3[c]	0.99[c]	3.71[a]	26.87[c]	73.13[c]	60.36[bc]	39.64[e]
VD06–06	90.30[c]	0.77[c]	12.43[c]	11.9[ab]	0.65[a]	3.72[a]	30.56[e]	69.44[b]	60.41[bc]	39.59[e]
PDW233	90.16[c]	0.87[d]	16.57[h]	13.7[c]	0.65[a]	4.24[b]	25.91[bc]	74.09[c]	56.84[b]	43.88[g]
UP2782	89.50[b]	0.73[c]	11.79[b]	12.3[b]	0.64[a]	5.63[d]	18.15[a]	81.85[d]	45.46[a]	54.55[h]
HD4672	88.85[a]	0.82[cd]	15.16[g]	11.9[ab]	0.55[a]	4.63[c]	30.41[e]	69.59[b]	65.14[d]	34.86[c]
KLM1005	91.46[f]	0.62[b]	11.03[a]	13.8[c]	0.56[a]	4.73[c]	30.54[e]	69.46[b]	62.23[c]	37.76[d]
MASS 499	90.84[d]	0.74[c]	18.04[i]	16.0[e]	0.62[a]	7.32[e]	25.39[b]	74.61[c]	68.82[e]	31.18[b]
WSM 24	88.85[a]	0.84[cd]	13.11[d]	15.5[e]	0.67[a]	4.31[b]	28.58[d]	71.42[bc]	58.88[b]	41.12[f]
HI8627	91.28[ef]	0.66[b]	16.74[h]	13.9[c]	0.90[bc]	3.41[a]	26.71[c]	73.29[c]	62.56[c]	37.43[d]
HI8691	91.07[e]	0.69[bc]	13.40[d]	15.9[e]	0.56[a]	3.44[a]	25.32[b]	74.68[c]	60.19[bc]	39.82[e]
HI8638	91.09[e]	0.76[c]	16.97[h]	15.9[e]	0.79[b]	4.70[c]	25.39[b]	74.61[c]	67.09[de]	32.91[bc]
GW07–112	91.07[e]	0.64[b]	14.09[f]	14.8[d]	0.59[a]	5.21[d]	28.77[d]	71.23[bc]	60.30[bc]	39.69[e]
PDW291	92.03[g]	0.40[a]	13.66[e]	11.6[a]	1.00[c]	3.39[a]	52.57[f]	47.43[a]	73.99[f]	26.01[a]

Values with similar superscript do not differ significantly ($P > 0.05$). Ex-pp. = extractable polymeric proteins; Ex-MP = extractable monomeric proteins; UEX-PP = unextractable polymeric proteins; UEX-MP = unextractable monomeric proteins

73.99 % and 26.01 to 54.55 %, respectively. The proportion of Ex-PP, Ex-MP, UnEx-PP and UnEx-MP in the range from 44.01 to 52.47 %, 47.43 to 56.07 %, 73.14 to 80.73 % and 19.27 to 26.86 % has been reported previously for Indian durum wheat varieties (Kaur et al. 2015b). The differences in proportion of extractable and unextractable polymeric as well as monomeric proteins may be attributed to the differences in inherited characteristics of the varieties. Differences in extractability of polymeric proteins in the dough from different varieties were attributed to the differences in degree of polymerization that resulted in the availability of varied amount of cysteine residues. An increase in availability of cysteine residues result into polymerization of proteins, increasing the size and decreasing the solubility (Don et al. 2005).

Pasting properties

Pasting properties (PV, BDV, FV, SBV, and PT) of flours from different varieties ranged from 893 to 2469 cP, 477 to 741 cP, 1846 to 3403 cP, 1214 to 1885 cP and 63.65 to 66.95 °C, respectively (Table 2). PDW291 showed the highest values of PV and FV. HI8638 showed the lowest BV value indicating the highest resistance to shearing at high temperature. PCA revealed that PV and FV related negatively to the content of proteins as well as the proportion of both extractable and unextractable monomeric proteins but positively to that of polymeric proteins in flours (Fig. 1a). PT, on the other hand, related positively to protein content and proportion of monomeric proteins. Higher PT of rice flours in the presence of greater amounts of protein isolate was reported previously (Shevkani et al. 2015). Proteins have been reported to affect pasting properties of cereal flours/starches. Recently, Singh et al. (2016a) attributed the variations in paste viscosities of different wheat flours to the difference in proportion of polymeric or monomeric proteins. Singh et al. (2014) reported that paste viscosities of corn starches decreased in the presence of more proteins due to the protective effect of proteins on granular integrity. Similarly, Shevkani et al. (2015) demonstrated that more proteins incorporated to rice flours decreased their paste viscosities depending on the water absorption capacities of the proteins.

Farinographic characteristics

Water absorption of the flours varied between 64.6 and 73.1 %, being the lowest for WSM24 and the highest for PDW291 (Table 2). DDT ranged between 2.2 and 15.0 min, HI8627 showed the lowest value while HI8663, HI8638 and VD06–06 showed higher values as compared to other varieties. DS varied widely between 2.2 and 12.7 min, UP2782 showed the lowest DS value while VD06–06 and PDW233 showed the highest values. DOS ranged from 5 to 115 FU. PCA revealed that DDT and DS related negatively to Ex-MP and UEx-MP but positively to Ex-PP and UEx-PP (Fig. 1a). A positive correlation of DDT and DS with UEx-PP has been reported earlier (Gupta et al. 1993; Zhang et al. 2008; Singh et al. 2011). The results reflected that the variations in pasting properties and dough strength of the flours from different durum varieties were due to the differences in both content and characteristic of flour proteins. PCA also revealed that DDT and DS did not relate positively to protein content of the flours (Fig. 1a). Therefore, it can be inferred that it is not

Table 2 Pasting and farinographic properties of flours from different durum wheat varieties

Varieties	Pasting temperature (°C)	Peak viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Water absorption (%)	Dough development time (min)	Dough stability (min)	Degree of softening (FU)
HI8663	66.11^{c}	967^{ab}	516^{a}	1936^{ab}	1485^{c}	70.6^{f}	15.0^{f}	12.5^{g}	19^{b}
VD06–06	64.99^{b}	1199^{d}	599^{b}	2020^{b}	1420^{bc}	66.8^{c}	14.7^{f}	12.7^{g}	5^{a}
PDW233	66.69^{cd}	1081^{c}	547^{ab}	1896^{a}	1362^{b}	66.6^{c}	6.2^{e}	12.7^{g}	11^{a}
UP2782	65.26^{bc}	1373^{e}	741^{d}	1846^{a}	1214^{a}	65.8^{b}	3.5^{c}	2.2^{a}	115^{f}
HD4672	66.09^{c}	996^{b}	568^{b}	2090^{b}	1662^{e}	66.9^{c}	2.8^{b}	4.0^{c}	77^{e}
KLM1005	66.06^{c}	1177^{d}	676^{c}	2067^{b}	1566^{cd}	68.1^{e}	4.7^{d}	4.6^{cd}	41^{c}
MASS 499	65.71^{c}	1157^{cd}	637^{bc}	2355^{d}	1835^{f}	70.6^{f}	4.0^{c}	4.3^{c}	35^{c}
WSM 24	66.75^{d}	1124^{cd}	650^{c}	2048^{b}	1574^{d}	64.6^{a}	2.9^{b}	3.2^{b}	59^{d}
HI8627	66.29^{cd}	1018^{bc}	496^{a}	2319^{d}	1797^{f}	65.3^{b}	2.2^{a}	5.2^{d}	62^{d}
HI8691	66.95^{d}	1145^{cd}	632^{bc}	1918^{a}	1405^{b}	68.2^{e}	6.0^{e}	12.1^{g}	5^{a}
HI8638	66.74^{d}	893^{a}	477^{a}	2301^{d}	1885^{f}	66.3^{c}	15.0^{f}	12.5^{g}	28^{b}
GW07–112	66.22^{cd}	1373^{e}	741^{d}	2224^{c}	1592^{d}	67.4^{d}	5.9^{e}	6.1^{e}	39^{c}
PDW291	63.65^{a}	2469^{f}	539^{ab}	3403^{e}	1473^{c}	73.1^{g}	5.5^{de}	9.0^{f}	21^{b}

Values with similar superscript do not differ significantly ($P > 0.05$). FU: Farinograph Unit

necessary that flours with higher protein content will have higher dough strength.

Starch characteristics

Physicochemical characteristics

Amylose content of starches from different Indian durum wheat varieties varied between 17.5 and 28.4 %. WSM24 had the lowest amylose content while HI8663 and VD06–06 had the highest (Table 3). Amylose content of durum wheat starches was quite comparable to that of common wheat starches (18.2 % to 28.8 %) as reported previously by Singh et al. (2010).

Starches from different durum wheat varieties showed tri-modal granular size distribution indicating the presence of large (A), medium (B) and small granules (C) of >15 μm, 5–15 μm and <5 μm, respectively. The proportion (volume %) of A-, B- and C-granules varied significantly amongst the varieties (Table 3). A-granules were present in the highest proportion (69.9 to 85.4 %); followed by B-granules (9.4 to 20.1 %), whereas C-granules contributed to the least proportion (4.7 to 10.0 %). The proportion of A-, B- and C-granules in the range from 45.6 to 73.2 %, 14.0 to 37.0 % and 10.5 to 17.5 %, respectively had been reported for starches from different common Indian wheat varieties (Singh et al. 2010).

Swelling power of the starches ranged from 7.5 to 12.4 g/g. UP2782 showed the highest value of swelling power while PDW291 showed the least (Table 3). The differences in swelling power of starches may be attributed to the differences in structural properties of starches as this parameter provide the evidence of strength of interaction between starch chains within amorphous and crystalline domains (Ratnayake et al. 2002). Swelling power in the range of 8.3 to 10.1 g/g had been reported earlier for starches from different Indian wheat lines (Shevkani et al. 2011). PCA revealed that swelling power of starches related positively to the proportion of A-granules and negatively to that of B- and C-granules (Fig. 1b), suggesting that starches with greater proportion of large granules had higher tendency to swell than those with high proportion of small granules and the probable reason might be the differences in starch structure amongst the granules of varying sizes.

Transmittance values of cooked starch suspensions from different varieties during the storage up to 96 h at 4 °C are presented in Fig. 2. Transmittance values of the starch suspensions ranged from 0.56 to 1.61 %, 0.32 to 1.00 %, 0.22 to 0.85 %, 0.19 to 0.63 % and 0.10 to 0.41 %, respectively after storage of 0, 24, 48, 72 and 96 h. HI8691 and WSM24 showed higher values of transmittance than other varieties (Fig. 2). The starch suspensions from all varieties showed gradual decrease in transmittance values with increasing storage duration. This may be attributed to the interaction of amylose and

Table 3 Amylose content, particle (granule) size, and swelling power of starches from different durum wheat varieties

Varieties	Swelling power (g/g)	Amylose content (%)	A-granules (volume %, >15 μm)	B-granules (volume %, 5–10 μm)	C-granules (volume %,<5 μm)
HI8663	9.3^{bc}	28.2^{g}	82.0^{f}	10.8^{b}	7.1^{c}
VD06–06	10.0^{c}	28.4^{g}	84.3^{g}	10.1^{ab}	5.7^{b}
PDW233	11.3^{e}	21.0^{c}	82.7^{f}	11.6^{bc}	5.7^{b}
UP2782	12.4^{f}	22.0^{d}	85.4^{h}	9.4^{a}	5.3^{a}
HD4672	9.1^{b}	21.9^{d}	72.9^{b}	19.3^{g}	7.7^{c}
KLM1005	10.4^{d}	20.4^{c}	78.0^{d}	16.0^{f}	5.9^{b}
MASS 499	8.7^{b}	19.2^{b}	76.3^{c}	16.1^{f}	7.7^{c}
WSM 24	9.4^{bc}	17.5^{a}	80.9^{e}	14.5^{e}	4.7^{a}
HI8627	9.9^{c}	18.2^{a}	82.9^{f}	11.7^{bc}	5.4^{ab}
HI8691	9.8^{c}	26.3^{f}	80.8^{e}	13.4^{d}	5.8^{b}
HI8638	10.4^{d}	20.9^{c}	82.3^{f}	12.2^{c}	5.5^{ab}
GW07–112	9.9^{c}	23.4^{e}	85.0^{h}	9.8^{a}	5.2^{a}
PDW291	7.5^{a}	22.2^{d}	69.9^{a}	20.1^{h}	10.0^{d}

Values with similar superscript do not differ significantly ($P > 0.05$)

amylopectin chains during storage, as a result of retrogradation, which formed functional zones that reflected or scattered significant amount of light (Perera and Hoover 1999). The variations in swelling power of granules, leached amylose and amylopectin, amylose and amylopectin chain lengths, etc. have been reported to be attributable for differences in optical properties of starch gels (Jacobson et al. 1997).

Thermal properties

Durum wheat starches were characterized to have two endotherms during heating and one exotherm during cooling. The first endotherm with Tp between 60.9 and 67.1 °C corresponded to the gelatinization of starches while the second endotherm with higher values of Tp (between 97.1 and 99.6 °C) represented melting/dissociation of amylose-lipids complexes (Singh et al. 2010; Shevkani et al. 2011). Exotherms with Tp in the range from 84.5 to 87.4 °C indicated subsequent re-association of amylose-lipids complexes during cooling of the gelatinized starches. Transition temperatures (To, Tp and Tc) and enthalpies for starch gelatinization (first endotherm) varied in the range from 57.4 to 64.2 °C, 60.9 to 67.1 °C, 64.3 to 70.1 °C and 3.2 to 8.4 J/g, respectively amongst different varieties (Table 4). Transition temperatures and enthalpies of starch gelatinization in the range from 55.6 to 57.3 °C, 60.6 to 62.1 °C, 65.3 to 67.5 °C and 8.0 to 10.8 J/g, respectively had been reported for different common wheat starches (Singh et al. 2010). Higher transition temperatures have been reported for starches with high crystallinity which is attributed mainly to the content and structure of amylopectin

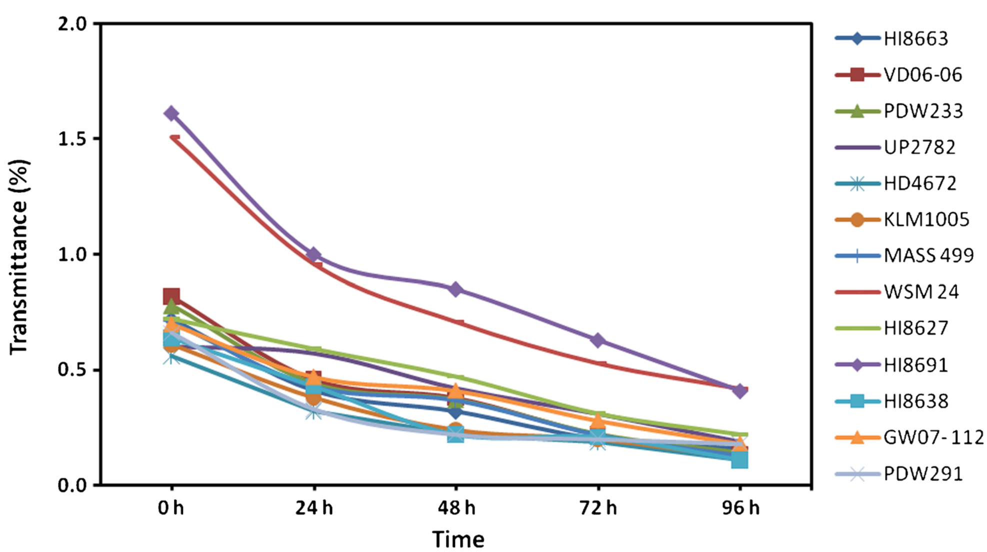

Fig. 2 Transmittance values of starches from different durum wheat varieties

Table 4 Thermal properties of starches from different durum wheat varieties

Varieties	To1	Tp1	Tc1	dH1	To2	Tp2	Tc2	dH2	To3	Tp3	Tc3	dH3
HI8663	57.8^{ab}	60.9^{a}	64.5^{ab}	6.3^{e}	93.5^{bc}	97.2^{ab}	99.7^{a}	0.1^{a}	85.9^{a}	84.5^{a}	82.2^{ab}	0.9^{b}
VD06–06	59.4^{c}	63.1^{c}	66.3^{cd}	5.3^{c}	93.7^{c}	97.4^{ab}	100.8^{b}	0.3^{c}	85.9^{a}	84.6^{ab}	82.0^{a}	0.8^{b}
PDW233	58.2^{b}	61.6^{b}	66.5^{cd}	7.7^{g}	92.8^{b}	97.1^{a}	100.9^{b}	0.4^{d}	86.4^{ab}	85.0^{ab}	82.4^{ab}	1.0^{bc}
UP2782	57.4^{a}	61.6^{b}	65.6^{bc}	8.1^{h}	94.8^{de}	98.7^{cd}	101.6^{bc}	0.2^{b}	86.6^{b}	85.1^{ab}	82.7^{b}	0.7^{ab}
HD4672	59.7^{cd}	63.6^{c}	67.4^{d}	6.5^{e}	91.8^{a}	99.6^{d}	103.5^{e}	0.4^{d}	87.9^{cd}	86.3^{c}	83.7^{c}	0.8^{b}
KLM1005	60.0^{cd}	63.2^{c}	67.1^{d}	6.2^{e}	94.6^{d}	98.2^{bc}	101.8^{c}	0.2^{b}	87.5^{c}	86.1^{c}	83.7^{c}	0.5^{a}
MASS 499	60.2^{cd}	63.2^{c}	66.1^{c}	4.8^{b}	93.8^{c}	97.7^{b}	101.9^{c}	0.4^{d}	87.4^{c}	85.9^{bc}	84.2^{cd}	0.5^{a}
WSM 24	64.2^{e}	66.8^{d}	69.8^{e}	3.2^{a}	93.1^{b}	97.7^{b}	101.1^{b}	0.2^{b}	86.6^{b}	84.8^{ab}	82.0^{a}	1.2^{c}
HI8627	64.2^{e}	67.1^{d}	70.1^{e}	3.5^{a}	93.1^{b}	97.6^{ab}	101.5^{bc}	0.4^{d}	87.2^{bc}	85.3^{b}	82.8^{b}	0.9^{b}
HI8691	57.7^{ab}	60.9^{a}	64.3^{a}	7.2^{f}	91.4^{a}	99.2^{d}	102.1^{c}	0.2^{b}	86.9^{bc}	85.5^{bc}	82.3^{ab}	1.0^{bc}
HI8638	60.5^{d}	63.4^{c}	67.2^{d}	5.8^{d}	95.3^{e}	98.5^{c}	101.5^{bc}	0.1^{a}	87.8^{c}	86.5^{cd}	84.5^{d}	0.7a^{b}
GW07–112	57.7^{ab}	61.1^{ab}	64.8^{ab}	8.4^{h}	93.2^{b}	98.4^{c}	103.0^{d}	0.6^{e}	88.5^{d}	87.1^{d}	84.5^{d}	1.2^{c}
PDW291	57.6^{ab}	61.3^{b}	65.3^{b}	7.3^{f}	91.6^{a}	99.6^{d}	105.2^{f}	0.3^{c}	89.7^{e}	87.4^{d}	83.9^{cd}	1.3^{c}

Values with similar superscript do not differ significantly ($P > 0.05$)

To1, Tp1 and Tc1 = onset, peak and endset transition temperatures, respectively of starch gelatinization/melting; To2, Tp2 and Tc2 = onset, peak and endset transition temperatures, respectively of amylose-lipids dissociation; To3, Tp3 and Tc3 = onset, peak and endset transition temperatures, respectively of amylose-lipids re-association; dH1, dH2 and dH3 = enthalpies for starch gelatinization, amylose-lipids dissociation and re-association, respectively

while amylose is amorphous; this was also observed in the present study as To, Tp and Tc related negatively to amylose content of the starches (Fig. 1b). PCA also revealed that transition temperatures related negatively to the enthalpy of gelatinization. Starch gelatinization has been reported to be influenced with several factors including structural and granular characteristics of starches e.g. content of amylose and amylose-lipid complexes, presence of non-starch constituents (proteins and lipids), relative crystallinity and granule-shape and size distribution (Singh et al. 2010; Shevkani et al. 2011; Zhang et al. 2013; Singh et al. 2014; Singh et al. 2016b).

Transition temperature (To, Tp, and Tc) for amylose-lipids complex dissociation (second endotherm) ranged from 91.6 to 95.3 °C, 97.1 to 99.6 °C and 99.7 to 105.2 °C, respectively, and the enthalpies ranged from 0.1 to 0.6 J/g (Table 4). To, Tp and Tc for amylose-lipids complex re-association (exotherm) ranged from 85.9 to 89.7 °C, 84.5 to 87.4 °C and 82.0 to 84.5 °C, respectively, and enthalpies varied between 0.5 and 1.3 J/g. Transition temperatures (To, Tp and Tc) and enthalpies for amylose-lipids dissociation in the range from 93.28 to 96.89 °C, 98.57 to 101.41 °C, 102.12 to 104.28 °C and 0.32 to 1.00 J/g, respectively have been reported for starches from different Indian wheat lines (Shevkani et al. 2011). Amylose-lipids complexes are formed during the biosynthesis of starch granules as well as during the heating of starch suspensions at gelatinization temperature or above. Transition temperatures represent thermal stability of amylose-lipids complexes while enthalpies provide their quantitative measure. Enthalpy values for amylose-lipids re-association were higher than dissociation (Table 4), indicating that more lipids complexed with amylose in the gelatinized starches than in their native state. PCA revealed that peak transition temperatures as well as enthalpies of amylose-lipids complexes dissociation and re-association related negatively to swelling power and proportion of A-granules in the starches while positively to that of B- and C-granules (Fig. 1b). This demonstrated that large granules might have swollen to a greater degree than small granules likely due to the presence of fewer or less stable amylose-lipids complexes. Amylose-lipids complexes have been reported to influence swelling potential of granules by hindering water absorption by them and increasing their integrity (Elliasson 1994; Shevkani et al. 2011; Singh et al. 2014). Negative correlation between enthalpy of amylose-lipids dissociation and swelling power has been reported for starches from Japanese, American, Canadian and Australian wheat varieties (Wickramasinghe et al. 2005).

Pasting properties

Pasting properties (PT, PV, BDV, FV and SBV) varied in the range from 66.8 to 89.6 °C, 1010 to 3130 cP, 508 to 1676 cP, 1070 to 4148 cP and 572 to 3459 cP, respectively amongst starches from different durum wheat varieties (Table 5). PDW233 starch showed the highest PV; HI8627 starch showed the highest BDV; GW07–112 and PDW233 starches showed the highest FV while GW07–11 showed highest SBV. WSM24 showed the lowest BDV indicating the highest thermal stability. PCA revealed that starches with greater proportion of A-granules were more viscous compared to those with

Table 5 Pasting properties of starches of flours from different durum wheat varieties

Varieties	Pasting temperature (°C)	Peak viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
HI8663	68.6^{b}	1236^{b}	769^{c}	2610^{e}	2143^{f}
VD06–06	75.2^{e}	2480^{h}	1100^{f}	3120^{g}	1740^{e}
PDW233	75.7^{e}	3130^{k}	1140^{f}	4130^{h}	2140^{f}
UP2782	73.9^{d}	2910^{j}	1440^{h}	3180^{g}	1710^{e}
HD4672	66.8^{a}	1010^{a}	721^{c}	2920^{f}	2631^{h}
KLM1005	89.6^{i}	2290^{g}	880^{d}	3085^{fg}	1675de
MASS 499	75.7^{e}	1930^{f}	930^{d}	2050^{b}	1050^{b}
WSM 24	67.2^{a}	1678^{d}	508^{a}	2162^{c}	992^{b}
HI8627	82.0^{g}	1730^{d}	1676^{i}	2390^{d}	2336^{g}
HI8691	68.4^{b}	1520^{c}	1022^{e}	1070^{a}	572^{a}
HI8638	76.7^{f}	2730^{i}	1370^{g}	2940^{f}	1580^{d}
GW07–112	69.9^{c}	1716^{d}	1027^{e}	4148^{h}	3459^{i}
PDW291	85.1^{h}	1848^{e}	664^{b}	2541^{e}	1357^{c}

Values with similar superscript do not differ significantly ($P > 0.05$)

higher proportion of B- and C-granules (Fig. 1b). This might be due to loose packing ability of large A-granules in the starch pastes, leading to occupancy of relatively larger volume than smaller ones that increased viscosity to a greater extent than B- and C-granules. PCA also revealed that varieties with lower proportion of A-granules had higher transition temperatures and enthalpies of amylose-lipids dissociation and re-association and exhibited lower PV and BDV and vice-versa (Fig. 1b). This supported that A-granules swelled and disintegrated to a greater extent than B- and C-granules, possibly due to the presence of less stable amylose-lipids complexes. On cooling, the viscosity of starch pastes increased due to retrogradation. PCA revealed that FV and SBV depended on the amount of amylose as these related positively (Fig. 1b).

Dynamic rheological analysis of starch pastes

G and G of starch pastes from different varieties varied in the range from 1310 to 6110 cP and 172 to 758 cP, respectively at 90 °C (Table 6). Higher values of G than G indicated predominance of solid/elastic behaviour which was in accordance to an earlier work on wheat starch pastes (Shevkani et al. 2011). During cooling, G and G of the pastes increased to values ranging from 8190 to 21,800 cP and 477 to 2040 cP, respectively at 10 °C (no hold) and from 9020 to 24,400 cP

Table 6 Dynamic rheological analysis of starch pastes from different durum wheat varieties

Varieties	G 90 °C (Pa)	G 90 °C (Pa)	G 10 °C (Pa)	G 10 °C (Pa)	G 10 °C hold (Pa)	G 10 °C hold (Pa)
HI8663	8780^{i}	710^{f}	26600^{h}	1630^{h}	28000^{h}	1590^{h}
VD06–06	4930^{g}	607^{e}	21400^{g}	1170^{f}	24600^{g}	1170^{f}
PDW233	3890^{e}	457^{c}	14800de	763^{c}	15900^{d}	752^{c}
UP2782	3470^{d}	495^{cd}	14500^{d}	983^{e}	16600^{d}	1010^{e}
HD4672	4020^{ef}	455^{c}	15600^{e}	762^{c}	16900^{d}	733^{c}
KLM1005	2050^{c}	269^{b}	11000^{c}	575^{b}	12300^{c}	572^{b}
MASS 499	1310^{a}	172^{a}	9610^{b}	538^{ab}	10500^{b}	556^{b}
WSM 24	1500^{ab}	217^{ab}	8190^{a}	504^{a}	9020^{a}	494^{ab}
HI8627	1690^{b}	222^{ab}	10300^{c}	477^{a}	10600^{b}	467^{a}
HI8691	3890^{e}	465^{c}	21500^{g}	2040^{i}	22600^{f}	2280i
HI8638	6110^{h}	758^{f}	21800^{g}	1270^{g}	24400^{g}	1310^{g}
GW07–112	4650^{f}	533^{d}	17300^{f}	868^{d}	19000^{e}	869^{d}
PDW291	1560^{ab}	178^{a}	9820^{bc}	489^{a}	10500^{b}	472^{ab}

Values with similar superscript do not differ significantly ($P > 0.05$)

G' = Elastic modulus; G" = Viscous modulus

Table 7 Noodle-making properties of flours from different durum wheat varieties

Varieties	Cooking time (min)	Water absorption (g/100 g)	Gruel solid loss (%)	Firmness (N)	Cohesiveness	Springiness
HI8663	310^{b}	175^{e}	6.48^{d}	4.56^{b}	0.83^{b}	0.81^{a}
VD06–06	319^{b}	195^{g}	7.05^{d}	5.83^{cd}	0.79^{a}	0.86^{ab}
PDW233	415^{e}	123^{c}	6.92^{d}	6.64^{de}	0.85^{b}	0.91^{bc}
UP2782	389^{d}	164^{d}	5.04^{b}	7.07^{e}	0.83^{b}	0.86^{ab}
HD4672	486^{f}	105^{a}	5.70^{c}	6.33^{d}	0.90^{c}	0.94^{c}
KLM1005	422^{e}	194^{g}	5.31^{b}	8.26^{f}	0.86^{b}	0.90^{bc}
MASS 499	547^{h}	114^{b}	5.74^{c}	8.11^{f}	0.91^{c}	0.92^{bc}
WSM 24	541^{h}	126^{c}	4.49^{a}	7.10^{e}	0.81^{ab}	0.91^{bc}
HI8627	483^{f}	106^{a}	6.48^{d}	5.35^{c}	0.81^{ab}	0.90^{bc}
HI8691	512^{g}	185^{f}	5.13^{b}	5.37^{c}	0.77^{a}	0.84^{ab}
HI8638	483^{f}	177^{e}	6.05^{cd}	8.19^{f}	0.86^{b}	0.92^{bc}
GW07–112	361^{c}	165^{d}	5.08^{b}	4.50^{b}	0.77^{a}	0.88^{b}
PDW291	270^{a}	170^{de}	5.21^{b}	3.34^{a}	0.99^{d}	0.86^{ab}

Values with similar superscript do not differ significantly ($P > 0.05$)

and 467 to 2280 cP, respectively at 10 °C after 30 min of holding. This increase in moduli may be attributed to the retrogradation in starch pastes. PCA revealed that dynamic moduli of starch pastes related positively to their amylose content (Fig. 1b) which further showed that amylose was an influential factor in starch retrogradation as it rapidly formed double-helical associations of glucose units during cooling of starch gels (Ring et al. 1987).

Noodle-making properties

Cooking properties

Cooking time of noodles prepared from flours from different durum wheat varieties ranged between 270 and 547 s. Noodles from PDW291 took lesser time while those from MASS499 and WSM24 took longer time to cook. WA of noodles ranged from 105 to 195 g/100 g. Noodles from HD4672 and HI8627 showed the lowest whereas VD06–06 and KLM1005 showed the highest WA. GSL of noodles varied between 4.49 and 7.05 g/100 g, being the lowest for WSM24 and the highest for VD06–06. CT, WA and GSL of the noodles were consistent with a recent study (Kaur et al. 2015b). CT related positively to the transition temperatures (To, Tp and Tc) of starch gelatinization and protein content of the flours (Fig. 1a and b). Earlier, it was observed that more proteins in flours might reduce swelling of starch granules thus prevent GSL (Kaur et al. 2015b). This relation was also observed in the present study (Fig. 1a and b). PCA also revealed that CT related positively to Ex-MP and UEx-MP but negatively to Ex-PP and UEx-PP while WA related positively to amylose content and negatively to protein content of flours (Fig. 1a and b).

Textural properties

Textural parameters of noodles evaluated were firmness, cohesiveness and springiness which varied significantly amongst different varieties. These parameters are the most important textural characteristics of noodles which are desirable for their acceptance by the consumers. The values of noodle-firmness, cohesiveness and springiness varied in the range from 3.34 to 8.26 N, 0.77 to 0.99 and 0.81 to 0.94, respectively. Noodles from PDW291 showed the lowest noodle firmness while those made from KLM1005, MASS499 and HI8638 showed higher values (Table 7). Firmness correlated positively to protein content of flours and transition temperatures of starch gelatinization as well as amylose lipid association and dissociation (Fig. 1a and b). Cohesiveness is another important texture property which affects the mouthfeel of noodles, as it indicates the extent of disruption of noodle structure during mastication (Tan et al. 2009). HI8691, GW07–112, and VD06–06 produced the least cohesive noodles while PDW291 produced the most cohesive noodles. Cohesiveness related positively to the proportion of Ex-PP and UEx-PP which was consistent with the recent report (Kaur et al. 2015b). Cohesiveness also related positively to transition temperatures and enthalpies of amylose-lipids complexes association as well as dissociation and proportion of B- and C- granules but negatively to swelling power and BDV of starches (Fig. 1a and b). This indicated that amylose-lipids complexes might have increased the integrity of starch granules thus prevented their excessive swelling and leaching of starch components on cooking of noodles resulting in formation of firm and cohesive noodles. Springiness was observed to be the lowest for HI8663 and the highest for HD4672. Springiness showed negative relation with amylose content and retrogradation tendency of starches. Negative correlation of amylose content and retrogradation with springiness of wheat starch gels has been reported earlier (Shevkani et al. 2011). Therefore, the results suggested that noodle-making properties of the durum flours were dependant not only on the characteristics of flour proteins but also on the characteristics of starches.

Conclusion

Noodle-making properties of flours from different durum wheat varieties influenced with both protein and starch characteristics. Noodles from varieties with high proportion of monomeric proteins and starch gelatinization temperature needed more time to cook. Polymeric proteins and amylose-lipids complexes improved cohesiveness while springiness related negatively to the content of amylose and retrogradation.

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