Morphological, pasting, and textural characterization of starches and their sub fractions of good and poor cookie making wheat varieties

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Revised: 14 November 2018 / Accepted: 5 December 2018 / Published online: 18 December 2018
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Abstract Starch and its sub-fractions of good and poor cookie quality wheat varieties were examined. Scanning electron microscopy images demonstrated that A-type starch granules were lenticular shape with larger diameter of 18.80–21.50 μm , whereas B-type starch granules displayed spherical shape with smaller diameter of 3.93–5.10 μm . Rapid Visco Analyzer pasting profiles of starch and its fractions of poor cookie quality displayed greater peak, trough, final, and setback viscosity compared the starch of good cookie quality wheat variety. On the contrary, the starch of good cookie quality wheat exhibited higher pasting temperature than the starch of poor cookie quality variety. Texture Analyzer results revealed that starch gel hardness, gumminess, and chewiness were found higher for poor cookie quality wheat variety as compared to starch of good cookie quality wheat.

Keywords Starch granules · Pasting profile · Textural properties · Morphology · Cookie quality

Introduction

Starch is a major component in wheat flour. Wheat flour is processed into varieties of baked products like cakes, cookies, pita bread, bread and chapatti (Khatkar and Schofield 1997; Singh and Khatkar 2005). The products made from cereals such as bread, noodles, and cookies were influenced by the nature and contents of their starch

(Khatkar and Panghal 2009). Starches in wheat are deposited in two sizes of granules. Wheat starch granules form two important size fractions. The granule size affects gelatinization and pasting properties (Kulp 1973), baking characteristics (Soulaka and Morrison 1985).

Starch granules majorly comprise of two glucose polymers amylopectin and amylose molecules held together by hydrogen bonds, either directly or by means of hydrate bridges. Amylose refers to a linear polymer, whereas amylopectin is a highly branched polysaccharide. Viscosity is widely affected by the granule shape, swelling power, amylopectin-amylose entrapment. The characteristics of many foods result from the specific pasting, gelatinization and retrogradation properties of starch (Copeland et al. 2009).

The functionality of starch in food system affects consistency, volume, moisture holding, texture and shelf life of the food. Physicochemical and functional properties of play important role in understanding their cooking and processing properties (Sindhu and Khatkar 2016). The pasting behavior of wheat starches is primarily responsible for textural and structural properties of food products. Pasting behavior differs extensively among wheat varieties that probably due to variations in their starch constituents. Transformations in starch while gelatinization are the prime determinants of pasting behaviour that evaluated by viscosity changes using RVA.

Manley (2000) claimed that lesser degree of starch gelatinization delivers softer cookies. Variation in morphological, pasting, and textural properties of starch and granules could be attributed to differences in cookie making quality of wheat cultivars. Therefore, this research work aims on the comparison of good cookie quality wheat variety (HS 490) and poor cookie quality variety (HD

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2967) starches and their fractions in terms of their pasting, textural and morphological properties.

Materials and methods

Materials

The pure samples of two commercial wheat varieties HD 2967 and HS 490 were obtained from the DWR, Karnal, India. These varieties were chosen chiefly on the premise of their extensive physicochemical attributes, protein amount, quality, and *Glu-1* scores. All samples were analyzed for protein content (AACC 2000). SDS sedimentation volume was examined according to the method described by Axford et al. (1979). The damaged starch content of wheat flour was estimated using SDmatic. The enzyme activity (α -amylase) of the wheat flour was determined using Falling Number Apparatus according to AACC method (2000).

Separation of starch and A- and B-type starch granule

Pure starch was isolated from wheat flour samples of different wheat varieties by the method portrayed by Singh et al. (2010a, b). The pure starch procured followed by the drying step evenly ground utilizing pestle and mortar. Isolated pure starch sample was used for further separation of starch granules by centrifugation method as explained by Peng et al. (1999) with minor variations. The solution was made by adding 10 ml of 80% (w/v) sucrose and 5 ml of distilled water (0.1 g/ml) in starch. This solution was centrifuged for 10 min at 430 rpm. The small starch granules were present in the supernatants which were collected in separate tube and centrifuged for 5 min at 8000 rpm. The fresh 80% sucrose solution was used for centrifugation of starch pellets for four times where the starch pellets were suspended in 5 ml of distilled water. The large starch granules were present in the starch pellets.

Swelling power and solubility

Swelling power (g/g) and solubility (%) were estimated using the method of Leach et al. (1959). Aqueous starch suspension (2% w/w) was heated at 90 °C for 30 min with constant stirring and cooled to room temperature. Samples were transferred to pre-weighed centrifuge tubes and centrifuged at 3000 rpm for 15 min. Supernatant and sediments were separated. Sediment obtained was weighed, and the supernatant was poured into pre-weighed moisture dishes, which were then dried at 110 °C for 24 h. All

measurements were taken in triplicates. Swelling power and solubility is determined using following formula:

$$\text{Swelling power (g/g)} = \frac{\text{weight of sediments}}{\text{weight of sample}}$$

$$\text{Solubility \%} = \frac{(\text{Dried supernatant weight} / \text{Initial weight of starch}) \times 100}{\times 100}$$

Amylose and amylopectin content

The iodine binding procedure accounted by Williams et al. (1970) was used to compute the amylose content of the separated starch samples. 20 mg of starch powder was dispersed in 10 ml KOH followed by 5 min vortexed. Distilled water was added to make the sample volume 100 ml. Out of this 100 ml solution, 10 ml fraction was taken to make the 50 ml solution by adding 5 ml of HCl, 0.5 ml of iodine reagent and distilled water. The graph obtained from amylose and amylopectin blends was used to determine the amylose contents. Absorbance was evaluated on three replications at 625 nm.

Pasting profile

The pasting properties of starch and its sub-fractions were determined using a Rapid Visco Analyzer- TechMaster (Perten Instruments). Base sample (3.0 g, 14% mb) was weighed in the canister, and distilled water was added to obtain a sample weight of 28.0 g. The temperature–time conditions included a heating step from 50 to 95 °C at 6 °C/min (after an equilibration time of 1 min at 50 °C), a holding phase at 95 °C for 1.5 min, a cooling step from 95 to 50 °C at 6 °C/min, and a holding phase at 50 °C for 2 min. The deliberated parameters were pasting temperature, peak viscosity, peak time, trough, final viscosity, breakdown, and setback.

Texture profile analysis

The mixture in the canister, after the RVA measurement, starch and fractions samples were sealed with paraffin film to prevent moisture loss and kept at 4 °C temperature for 24 h to allow gelation. The gel was then subjected to texture profile analysis using Texture Analyzer (TA-XT 2i), Stable Micro Systems, U.K. following the method of Wu et al. (2006) and the textural properties such as hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness were enumerated from the graph obtained.

Scanning electron microscopy

Scanning microscope (Jeol, UK) using 5 kV of acceleration potential was used for scanning electron micrographs

of starch and granules. The double sided tape was used to fix starch samples on aluminium stubs then coated with gold.

Cookie preparation and evaluation

Cookies were prepared with slight modification to standard method 10-50D of AACC (2000). The spread ratio was calculated by dividing diameter (mm) by the thickness (mm). Texture Analyzer (TA-XT2i) was used in compression mode using the three-point bending test to calculate the breaking force needed for rupturing cookies.

Statistical analysis

For statistical analysis over three sets of experimental data the mean $\pm$ standard deviation and the analysis of variance (ANOVA) along with the correlation analysis were performed using SPSS 16.0 software.

Results and discussion

Flour characteristics

The outcomes of the flour quality analysis of good (HS 490) and poor (HD 2967) cookie making wheat varieties are summarized in Table 1. HD 2967 displayed higher protein content (12.88%), while HS 490 indicated lower protein content (10.02%). The HD 2967 had higher SDS sedimentation volume (68 ml), falling number and damaged starch (6.7 g/100 g). Results were in agreement with Farrand (1972). According to Donelson and Gaines (1998), soft wheat flour produced larger sugar-snap cookies diameter than flour of hard wheat owing to less amount of damaged starch. Alkaline water retention capacity values

(AWRC) ranged from 186.94% in HS 490 to 202.46% in HD 2967. Excellent cookie flours would have less AWRC values and would offer cookies having higher diameters.

Results showed that dry gluten contents varied considerably in wheat varieties. HS 490 displayed lesser dry gluten content (8.7 g/100 g) and HD 2967 had fairly higher dry gluten (11.6 g/100 g). HD 2967 demonstrated superior gluten index (95.23 g/100 g) whereas, HS 490 had inferior gluten index (80.01 g/100 g). Gluten index is a measure of the flour strength. The lower amount or gluten dilution enhances the spread and extensibility of dough while baking (Cauvain and Young 2006). Spread ratio (SR), the most significant quality attribute of cookie (Devi and Khatkar 2016). SR of cookies prepared using HS 490 and HD 2967 varieties was found 10.36 and 9.86, respectively. Whereas, breaking strength, which indicates cookie hardness was found 3.04 and 5.13 kg f for HS 490 and HD 2967 wheat varieties, correspondingly. Results were in accordance with Devi and Khatkar (2018). Based on the chemical analysis, gluten quality and cookie quality parameters, HS 490 and HD 2967 were considered suitable for this study, HS 490 characterizing superior quality and HD 2967 inferior quality cookie making wheat variety.

Physical properties of starch and its fractions

The physical properties of starch and fractions are presented in Table 2. Variations in the bond strengths in starch fractions resulted into differences in swelling power of starch and its fractions. Jane et al. (1999) investigated that swelling power of the starches also influenced by their sub fractions characteristics and amylose content. The swelling power decreased linearly with amylose content. More amylose content in starches results into poor swelling, signifying a powerful intermolecular association (Toyokawa et al. 1989). Mean swelling power of starch from good cookie quality wheat variety HS 490 and poor cookie quality wheat variety HD 2967 was 7.51 and 10.86 g/g, respectively. Results shown in Table 2 suggest that the swelling power of starches varied from 7.12 to 13.56 g/g. Analogous results were laid out by Shevkani et al. (2011). A-type starch granules exhibited poor swelling power, whereas the B-type starch granules had greater swelling power. B-type starch granules of poor cookie quality wheat variety (HD 2967) displayed the higher value of swelling power, i.e., 13.56 g/g, while A-type starch granules of good cookie quality wheat variety (HS 490) showed the lower value (7.12 g/g). The solubility of starches ranged from 4.06 to 7.49%. Solubility followed the similar trend with swelling power. Starch samples of wheat variety HD 2967 exhibited the higher solubility, while HS 490 starch had the lower solubility. Solubility was also found to be negatively

Table 1 Chemical analysis of wheat flour

Chemical analysis of flour	Wheat varieties	
	HS 490	HD 2967
Protein Content (g/100 g)	10.02 $\pm$ 0.1	12.88 $\pm$ 0.2
Sedimentation volume (ml)	32 $\pm$ 0.4	68 $\pm$ 0.3
Falling number (s)	331 $\pm$ 3	388 $\pm$ 4
Damaged starch (%)	4.3 $\pm$ 0.2	6.7 $\pm$ 0.2
AWRC (%)	186.94 $\pm$ 0.2	202.46 $\pm$ 0.3
Dry gluten (g/100 g)	8.7 $\pm$ 0.2	11.6 $\pm$ 0.3
Wet gluten (g/100 g)	25.35 $\pm$ 0.4	36.41 $\pm$ 0.2
Gluten Index (g/100 g)	80.01 $\pm$ 0.2	95.32 $\pm$ 0.2
Spread ratio	10.36 $\pm$ 0.2	9.86 $\pm$ 0.4
Breaking strength (kg f)	3.04 $\pm$ 0.2	5.13 $\pm$ 0.4

Values are mean $\pm$ standard deviations of triplicate samples

Table 2 Physical properties of starch and its fractions

Wheat varieties	Sample	Swelling power (g/g)	Solubility (%)	Amylose (%)	Amylopectin (%)	Amylopectin/amylose	Granule size (μm)
HS 490	ST	7.51 $\pm$ 0.01b	4.24 $\pm$ 0.02b	25.94 $\pm$ 0.23c	74.06 $\pm$ 0.30c	2.86 $\pm$ 0.02b	15.41 $\pm$ 0.13c
	A-G	7.12 $\pm$ 0.04a	4.06 $\pm$ 0.01a	28.05 $\pm$ 0.41e	71.95 $\pm$ 0.33a	2.57 $\pm$ 0.01a	21.50 $\pm$ 0.11f
	B-G	11.24 $\pm$ 0.02e	6.88 $\pm$ 0.01e	19.12 $\pm$ 0.13b	80.88 $\pm$ 0.11d	4.23 $\pm$ 0.01d	5.10 $\pm$ 0.15b
HD 2967	ST	10.86 $\pm$ 0.01d	5.16 $\pm$ 0.2d	25.38 $\pm$ 0.8c	74.62 $\pm$ 0.23c	2.94 $\pm$ 0.02c	16.47 $\pm$ 0.51d
	A-G	9.76 $\pm$ 0.04c	4.85 $\pm$ 0.04c	26.16 $\pm$ 0.24d	73.84 $\pm$ 0.44b	2.82 $\pm$ 0.04b	18.80 $\pm$ 0.16e
	B-G	13.56 $\pm$ 0.02f	7.49 $\pm$ 0.01f	18.49 $\pm$ 0.16a	81.51 $\pm$ 0.16e	4.40 $\pm$ 0.02e	3.93 $\pm$ 0.12a

Values are mean $\pm$ standard deviations of duplicate samples; values followed by the same letters in the same column are not significantly different at $p < 0.05$

ST, unfractionated starch; A-G, A-granules; B-G, B-granules

related to amylose content, i.e., starches having higher amylose content had less solubility.

Amylose content is associated with the size of starch granules. Amylose content varied from 28.05 to 18.49%. Mean amylose content of starch from HS 490 and HD 2967 wheat varieties was 25.94 and 25.38%, respectively. The amylose content of A-type starch granules (28.05% and 26.16%) was much higher when compared to un-fractionated starch (25.94% and 25.38%) and B-granules (19.12% and 18.49%) for HS 490 and HD 2967, correspondingly. According to Khatkar and Panghal (2009), amylose content was found higher in the larger A-granules and lower in the smaller B-granules. Similar results were confirmed in this study. The granules of good cookie quality wheat variety contained higher amylose content when compared to granules of poor cookie quality variety. It offered consistent results with earlier reports (Bertolini et al. 2003; Ao and Jane 2007; Kumar et al. 2016). The amylopectin content values and the ratio of amylopectin to amylose in A-granules were much lesser compared to starch and B-granules in wheat varieties. B-granules possessed higher amylopectin content and amylopectin to amylose value. The ratio of amylose to amylopectin ratio of the unfractionated starches was found 25.38:74.62 for variety (HD 2967) and 25.94:74.06 for variety (HS 490). The quantity of amylopectin and amylose in the granule strongly influence the physical, chemical, and functional characteristics of fractions and starch.

Morphological analysis of starch and its fractions

SEM images of unfractionated starch, A and B-type starch granules of both wheat lines are displayed in Fig. 1a–f. Sizes of unfractionated starch and fractions are mentioned in Table 2. Starches from both wheat varieties displayed remarkable variation in the size distribution. Wheat starch granules showed bimodal size distributions (Fig. 1a, d),

having the mean particle size measuring 15.41 to 16.47 μm (Table 1). Granules of A-type showed mean diameters measuring from 18.8 to 21.5 μm , while granules of B-type had diameters measuring an average of 3.93 to 5.1 μm (Table 2). Such values are in line with the inference of Kim and Huber (2010) that showed the diameter of mean granule right from 6.2 to 6.3 μm and 20.9 to 21.9 μm for B- and A-type granules, respectively. Jane et al. (1994) and Salman et al. (2009) reported that functional and physicochemical characteristics of wheat starches are affected by variations in shape or size of granules.

The bigger A-granules had a smooth look and showed lenticular, or disk like shape (Fig. 1b, e) with diameter ranging from 15.8 to 27.3 μm . Mean values for the size of A-type starch granules were 21.50 μm for good cookie making variety HS 490 and 18.80 μm for poor cookie making wheat variety HD 2967. The B-granules revealed polygonal or spherical shape (Fig. 1c, f) measuring the diameter of 3.36 to 8.42 μm , with mean values of 5.10 μm for HS 490 and 3.93 μm for HD 2967 wheat variety. Singh et al. (2010a, b) also accounted similar inference. Also, it is evident through SEM micrographs that starch granules of A-type are contaminated at a low degree of B-granules. However, some disc shaped A-granules contaminated B-granules.

Pasting profile of starch and its fractions

RVA indicates the viscosity through measurement of the resistance developed through slurry with water and flour in stirring paddle. Pasting characteristics are significant and used to predict the pasting behavior of starch. The pasting profile curves of A-granule starch, unfractionated starch, and B-granule starch of wheat varieties are shown in Fig. 2, and the summary of pasting parameters is given in Table 3.

Fig. 1 Scanning Electron Micrographs of unfractionated starches (a, d), A-granule (b, e) and B-granules (c, f) of good HS 490 and poor HD 2967 cookie quality wheat varieties, respectively

Fig. 2 Pasting properties of starch and sub fractions of good HS 490 (a) and poor HD 2967 (b) cookie quality wheat varieties

The RVA profiles of wheat starches revealed considerable difference among the pasting traits (Fig. 2 and Table 3). Pasting properties such as peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, and pasting temperature of starches and fractions ranged from 2161 to 3398 cP, 1549 to 2786 cP, 372 to 884 cP, 2652 to 4464 cP, 861 to 1803 cP, and 74.2 to 87.95 °C respectively. Poor cookie quality wheat variety HD 2967 showed the higher values of pasting viscosities

while good cookie quality variety HS 490 had higher pasting temperature. Singh et al. (2010a, b) also reported that starches with higher pasting temperature displayed lower pasting viscosities. The differences in the pasting properties of good and poor cookie making wheat varieties can be attributed to the variation in their amylose content as displayed in Table 2. It has been investigated that the structure of amylose and amylopectin play significant role in the pasting properties of starches.

Table 3 Pasting properties of starch and its fractions

Sample	PV (cP)		TR (cP)		BD (cP)		FV (cP)		SB (cP)		PT (°C)	
	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967
ST	3050	3398	2343	2786	707	612	3762	4464	1419	1678	80.70	75.10
A-G	2201	3211	1549	2327	652	884	2779	4130	861	1803	84.00	74.20
B-G	2161	2753	1648	2381	513	372	2652	3832	1004	1451	87.95	75.90

All above results are the mean value of three independent observations

PV, peak viscosity; TR, trough viscosity; BD, breakdown viscosity; FV, final viscosity; SB, setback viscosity; PT, pasting temperature; ST, unfractionated starch, A-G, A-granules; B-G, B-granules

Peak viscosity of starches from HS 490 and HD 2967 was 3050 and 3398 cP, respectively. The starch and fractions with low peak viscosity in good cookie quality variety HS 490 could be correlated to the high amylose content. Amylose content was observed to suppress swelling of starch granule. The higher swelling power in varieties has been genetically associated with granule bound starch synthase (GBSS-4A) null mutation which is believed to confer lower amylose content in the variety along with a slight change inside starch structure which imparts greater peak viscosity to starch pastes (Zhao et al. 1998). It may also because of higher amount of damaged starch in poor cookie quality wheat variety HD 2967 as compared to good cookie quality variety HS 490. Singh et al. (2017) also reported similar results for peak viscosity of starch from soft and hard wheat cultivars.

For good cookie quality variety HS 490, A-granules showed significantly higher final viscosity (2779 cP) and peak viscosity (2201 cP) when compared to B-granule fraction. B-granule starch showed higher trough viscosity (1648 cP) and pasting temperature (87.95 °C) when compared to starch counterparts with A-granule. Higher peak viscosity of A-granules can be attributed to large granule size, having loosely packed efficiency and attracting huge volume of water when compared with B-granules having an identical concentration (Singh et al. 2010a, b). Breakdown viscosity (BD) refers to starch paste's stability while shearing in top temperatures. Mean BD of starch from HS 490 and HD 2967 was 707 and 612 cP, respectively. BD was reported higher for starch of good cookie quality variety HS 490 signifying better paste stability. The setback viscosity occurs when there is a rise in viscosity owing to amylose molecules rearrangement that is leached through the swollen starch while cooling and is utilized as gelling ability measure or starch's retrogradation ability. Comparatively higher values of setback viscosity were notice for starch and fractionated starch granules of HD 2967 variety and A-granule fraction exhibited the highest setback viscosity (1803 cP) that indicates the maximum retrogradation ability. Lesser setback viscosity or

retrogradation was expected in poor cookie quality wheat variety starch and its fractions due to lower amylose content than good cookie quality wheat variety starch. But factors including chain length of amylopectin, presence of other components and size of granules also affect the retrogradation of gelatinized starches as concluded by Shevkani et al. (2017) and that could be the reason for higher setback viscosity of starch from poor cookie quality wheat variety.

The pasting temperature signifies the temperature where the beginning of viscosity rises occurred whilst the heating process. The starch at high pasting temperatures showed better resistance to rupture and swelling. Higher pasting temperature (PT) 87.95 °C was observed for B-granule fractions of good cookie quality wheat variety HS 490. Greater PT could be responsible for softer cookies produced using HS 490 wheat variety as shown in Table 1 as at higher PT little starch get gelatinized, conferring tender cookies. Katyal et al. (2018) also observed that higher protein content delayed pasting temperature.

Textural profile of starch and its fractions

The textural properties of the poor and good cookie making wheat starch gels stored at 4 °C for 24 h after RVA test were analyzed by Texture Analyzer (TA) and results are displayed in Table 4.

Textural properties of starch gels are crucial for commercial applications of starch and depend on various factors like origin of starch, amylose and amylopectin content, rigidity of gelatinised granules, interaction between continuous and dispersed phase (Berski et al. 2011; Sandhu and Singh 2007; Sindhu and Khatkar, 2018).

During storage crystallisation of amylopectin takes place that leads to hardness of gel. The hardness of unfractionated starch gels were higher than their granules for both wheat varieties. A-granules fraction of starches from both varieties of wheat exhibited higher gel hardness values than B-granules fraction. Poor cookie quality wheat (HD 2967) had higher values of hardness for starch,

Table 4 Textural characteristics of starch and its fractions

Sample	GHD (g)		GAD (g/s)		GSP (ratio)		GCO (ratio)		GGU (g)		GCH (g)	
	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967	HS 490	HD 2967
ST	1494	2392	– 417	– 398	0.46	0.40	0.41	0.32	609	764	277	303
A-G	1474	2052	– 392	– 428	0.58	0.51	0.43	0.38	637	783	369	397
B-G	1195	1688	– 397	– 379	0.60	0.54	0.48	0.42	574	709	342	382

All above results are the mean value of three independent observations

GHD, gel hardness; GAD, gel adhesiveness; GSP, gel springiness; GCO, gel cohesiveness; GGU, gel gumminess; GCH, gel chewiness

A-granules fraction, and B-granules fraction gels than good cookie quality wheat variety HS 490. Difference in starch gel hardness of both the varieties of wheat could be due to variations in amylose to amylopectin ratio of starches. Sandhu and Singh (2007) studied corn starch from different varieties and reported higher gel hardness for higher amylose containing starches.

Gel adhesiveness indicates ability of gel to get separated from the probe during gel textural analysis and is generally undesirable in cookies. The minimum value of gel adhesiveness was noticed for B-granules (– 379 g/s) of starch from poor cookie quality wheat variety (HD 2967). Starch from good cookie wheat variety (HS 490) exhibited higher springiness and in both the varieties, B-granules showed higher values of springiness. Cohesiveness specifies the difficulty in breaking down the gel's internal structure. Comparatively higher values of gel cohesiveness were noticed for starch and starch fractions of good cookie quality wheat. Further, gel cohesiveness of B-granules was higher than A-granules and unfractionated starch in case of both varieties of wheat. In both varieties, higher values for gumminess and chewiness were exhibited by A-granule of starch. Gel gumminess and gel chewiness of poor cookie quality wheat variety were found higher than good cookie making wheat variety.

Conclusion

Morphological, pasting and textural analysis of starches and their fractions of good (HS 490) and poor (HD 2967) cookie quality wheats disclosed considerable differences. The sub fractions of both starches exhibited different compositional attributes including amylose and amylopectin content, amylopectin/amylose ratio and swelling power. SEM micrograph illustrated that B-granules of poor cookie quality wheat variety (HD 2967) had smaller size. RVA analysis revealed that B-granules fractions of good cookie quality wheat (HS 490) had higher pasting temperatures which could be responsible for tender cookies produced using HS 490 wheat variety. Texture profile

analysis depicted higher gel hardness of poor cookie quality wheat (HD 2967) starch and its fractions resulting in lower spread and stiffer cookies.

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