Comparison of physiochemical properties and colour of wheat flour: Effect of milling speed, packaging and storage

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Abstract: The present work was planned to investigate the influence of milling speed, packaging material and variety on quality parameters of wheat flour during storage. The wheat grains of two varieties (HD3086 and PBW725) were milled at different speeds of 80, 125 and 1440 rpm and the flours were analyzed for milling parameters and proximate composition. Thesamples were packed in high density polyethylene, low density polyethylene, ethylene vinyl alcohol/polyethylene multilayer bags, vacuum packaged in laminated aluminium bags and storedat ambient conditions for 90 days. Free fatty acid, moisture and colour parameters were recorded during storage. The proximate composition of samples decreased significantly ($p \leq 0.05$) during milling, but this decrease was more pronounced at commercial milling speed of 1440 rpm as compared to milling in domestic mill at 80 and 125 rpm. The change in moisture, free fatty acid and colour was observed to be significantly lower in flour obtained from HD3086 wheat variety at 80 rpm, vacuum packed in laminated aluminium bags after 90 days of storage. Thus, low speed milling and vacuum packaging or ordinary packaging in multilayer bags can be suggested as a suitable solution tomaintain quality of wheat flour for longer duration.

Keywords: milling parameters, packaging material, proximate composition, storage period, wheat flour quality

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1 Introduction

Wheat (*Triticum aestivum*L.) is an important cereal crop for the most of world's population. It is the main staple food of about two billion people (36% of the world population).The total production of wheat in the world is 771.7 MT. India ranks third in wheat production with a harvest of 98.5 MT during theyear 2017. Different varieties like Bread wheat (*Triticum aestivum*), Club wheat (*Triticum compactum*), and Drum wheat (*Triticum durum*) are grown in India. Wheat flour is rich in manganese, phosphorus, magnesium, and selenium in extremely high amounts. Additionally, it contains zinc, copper, iron, potassium, vitamin B6, niacin, thiamine, foliate, and riboflavin. Wheat maintains a healthy metabolism; preventscarcinoma, gallstones, and heart risks (Bakshi and Sharma 1993; Caddick and Shelton,2020).

Whole wheat flour, commonly known as *atta* in Indian subcontinent, is a coarse product obtained by milling wheat and it is used to prepare *chapatti* an Indian flatbread. Whole wheat flour (*atta*) is prepared by a variety of techniques, which causes a large influence on the quality of flour (Kang et al., 2019).The different techniques of milling such as

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hammer, disc, pin,and stone significantly affect the fineness, colour, functional characteristics of flour, quality of flour, and shelf life (Inamdar et al.,2015; Sidhu et al.,2016). As wheat flour is very hygroscopic in nature, therefore its moisture changes as the temperature and humidity of the storage environments change. These alterations lead to acidic conditions caused by enzymatic activities (Peña et al., 2006; Rizkalla et al., 2002; Kent and Evers, 1993). During long term storage, whole wheat flour undergoes several biochemical changes, which are mainly contributed by the unstable lipids due to temperature rise during milling (Sidhu et al., 2016). Also, hydrolytic rancidity in whole wheat flour can lead to a decrease in sensory quality and functional properties.

Traditionally, Indian families in villages process a smaller quantity of flourin a domestic mill, mostly located at every house hold and consume fresh flour, but due to busy lifestyles, consumers are opting for packagedflour. Packaged flourindustry is witnessing a growth of around 25% annually (Inamdar et al., 2015). For the storage of flourat the household level, generally steel drums or jars are used. On the other hand, at the commercial level, it is stored in large polyethylene bags by stacking the bags one above the other or in silos. The low-density polyethylene, high density polyethylene, aluminium coated/laminated polyethylene packages are used for the packaging of flour.laminated polyethylene package is most preferred for the packaging of whole grain wheat flour at commercial level. Hermetic storage technology using multilayer bags is an alternative method that minimizes post-harvest losses by depleting oxygen and increasing carbon dioxide levels within the package through the metabolic respiration of the product (Likhayo et al., 2018). Now a day, vacuum packaging is also used to pack food material at the industrial level. It does not allow the packaged material to interact with the surrounding environment physically. With the use of a good quality packaging material, its shelf life can be increased by almost 50% which is the major aspect of storage. So, keeping in view the above aspects, the present study was undertaken to study the effect of milling speed and packaging material on the quality andshelf-life of wheat flour.

2 Materials and methods

Whole wheat grains of two varieties viz., PBW725 and HD3086 were procured from Punjab Agricultural University farms, Ludhiana, India. The clean and healthy grains were selected for the study. Both varieties were identified as genus: *Triticum* and family: *aestivum.* All the chemicals and reagents used in the study were of analytical grade. Triplicate analysis was carried out with each sample.

2.1 Milling of wheat grain

The clean and healthy wheat grains were processed in a domestic stone mill at two speeds viz., 80 and 125 rpm and in a commercial flour mill at 1440 rpm for the production of whole wheat flour (*atta).*The domestic stone mill had a capacity of 50kgh^{-1} with diameter and thickness of grinding stones being 500 mm and 60 mm respectively. The clearance between the stones was varied between 2.60 to 4.15 mm.The speed of flour mill could be adjusted at 80 and 125 rpm by adjusting the pulley settings. A batch of 5 kg each was selected and milling was carried out at three different speeds of 80, 125, and 1440 rpm using domestic mill (A.S.S &Agri. Work Pvt. Ltd., Amritsar (Punjab)) and commercial mill respectively. The initial temperature of grains and of wheat flour coming out of the millwas noted over a regular period of time using an infrared temperature thermometer. The gap between the stones was adjusted and coarse flour was fed repeatedly to hopper for milling till finely ground flour was obtained. Total time taken for milling was noted using a stop watch.

2.2 Particle size distribution of wheat flour

The particle size analysis of flour prepared at different speeds was done using sieve analysis. Average particle size and particle size distributions were determined by differential sieve analysis using a vibratory sieve shaker (Make: Nihal Engineering Corporation, New Delhi, India) with a set of sieves ranging from US standard sieves Nos. 10 (2.00 mm) to 325 (0.044 mm). About 500 g of ground sample in a batch was screened for 20 min. The ground material retained on each sieve was accurately weighed using a digital balance having a least count of 0.001 g. Weight fraction was calculated as the ratio of the weight of material retained on each sieve to the sum of all the fractions. The fineness modulus, average particle sizes the recovery of flour, and milling efficiency was determined by the following relationships:

$$Fineness\ modulus (F.M.) = \frac{Total\ of\ Fineness\ number}{100} \quad (1)$$

$$Average\ particle\ size = 0.0104 \times 2^{F.M.} \quad (2)$$

$$Milling\ efficiency\ (\%) = \frac{Weight\ of\ milled\ sample\ (kg)}{Weight\ of\ input\ sample\ (kg)} \times 100 \quad (3)$$

$$The\ flour\ Recovery\ (\%) = \frac{Weight\ of\ flour\ obtained\ (kg)}{Weight\ of\ input\ sample\ (kg)} \times 100 \quad (4)$$

2.3 Proximate composition of wheat grain and flour samples

Proximate analysis was carried out for whole wheat grains, as well as flour obtained after milling at different milling speeds and during storage. The moisture, protein, ash, fat, crude fibre, and carbohydrate content were determined using standard methods (AOAC, 2000).

Moisture content: The moisture content of flour samples was measured by the standard hot air oven method (AOAC, 2000). The flour samples were kept in an oven at 130 ℃ for 4 hr. The loss in weight was noted down.

Fatcontent: Moisture free 5 g sample was taken in a thimble and oil was extracted in a preweighed beaker using petroleum ether in Soxhlet apparatus for - 2.5 to 3 hours and the crude fat content of sample was estimated by (AOAC, 2000).

Protein content: Protein content was determined by available nitrogen in the sample by Micro Kjeldhal method (AOAC, 2000).

Fibre content: Fibre content was determined by Hennerberg, Stohmann, and Rauterberg method (Maynard, 1970),in which acid and subsequent alkali treatment weregiven to wheat samples to cause oxidative hydrolytic degradation of the native cellulose and considerable degradation of lignin. The residue obtained after final filtration was weighed, incinerated, cooled, and weighed again. The loss in weight provided the crude fibre estimation.

Ash content: About 5 g sample were taken in crucibles. These were burnt on a hot plate and then placed in an electric muffle furnace at 600 ℃ for 6 hours (AOAC, 2000). Weight of remaining ash divided by original weight of sample provided the ash content.

Carbohydrate content: Carbohydrate content was calculated by subtraction method in which the protein content, fat content, moisture content, and ash content are subtracted from 100 to get the percentage of carbohydrates present in wheat.

2.4 Packaging and storage

The flour samples prepared from both varieties were packaged in four different types of packaging materials viz. T1: ordinary packaging in 150 gauge high density polyethylene (HDPE) bags, T2: ordinary packaging in 200 gauge low density polyethylene (LDPE) bags, T3: improved triple layer crop storage bags made of low density polyethylene with ethylene vinyl alcohollayer (EVOH/PE) T4: vacuum packaging in vacuum bags (VAP). About 500 gm sample of each treatment was packed and stored under ambient conditions. The temperature and humidity of storage environment weremeasured at regular interval.The properties of packaging materials were presented in Table 1.

2.5 Physiochemical properties of wheat flour

Different quality parameters viz. moisture content, free fatty acids and colour of the flour samples weredetermined at a regular interval of 10 days during 60 days of storage period using standard methods as discussed below:

Free fatty acids: About 5g of wheat flour sample was weighed into a flask, 30 mLof neutralised ethanol and a few drops of phenolphthalein indicator were added and the mixture was warmed to promote dissolving according to method AOAC (2000). The free fatty acid value is determined by the following formula:

$$Free\ fatty\ acid\ (\%) = \frac{Titrated\ volume\ (ml)}{2} \times 100 \quad (5)$$

Colour parameters: Colour was determined using Hunter lab Miniscan XE plus Colorimeter. The colour is described by tristimulus valuesof L, a, b with positive value of a, b indicating red and yellow colour and negative values indicating green and blue colour respectively. Value a, b closer to zero indicates grey colour. L indicates the intensity of colour i.e. lightness which varies from L=100 for perfect white to L=0 for black. The colour change, hue, chroma was determined using the formula:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (6)$$

$$Hue\ angle = \tan^{-1}(\frac{b}{a}) \quad (7)$$

$$Chroma = (a^2 + b^2)^{1/2} \quad (8)$$

Table 1 Properties of packaging materials

Parameters	T1	T2	T3	T4
Density (gcc^{-1})	0.945-0.967	0.91-0.925	1.14-1.19	2.7
WVTR gm^2day^{-1} at 38 ℃ & 90% RH gradient	5-7	14-18	20-50	<0.01
Oxygen permeability (gm^2day^{-1}. atm 25 ℃)	3.70	12.5	80	<0.006
Light transmission (%)	80	80	90	-

2.6 Statistical analysis

The data is represented as mean±standard deviation of three observations. The experimental data for all parameters was subjected to analysis of variance to determine significant effect of various factors using Graph pad prism (version 8.3.1 software). Multiple comparisons were done using Tukey’s test.

3 Results and discussion

3.1 Effect of milling speed and wheat variety on milling parameters

Effect of milling speed and wheat variety on various milling parameters, milling efficiency, flour recovery, and particle size distribution is presented in Table 2. A rise in temperature of the flour was observed with the increase in milling speed regardless of the varieties. The flour temperature varied between 12.24 ℃ to 31.12 ℃ for HD 3086 and 12.31 ℃ to 31.19 ℃ for PBW 725 variety respectively. The rise in temperature during milling was lesser at 80 rpm speed due to slow milling in large time duration, whereas it was highest at 1440 rpm with short time interval. Similar results were reported for the effect of speed on milling parameters for preparation of maize and pearl millet flour by Sidhu and Sharma et al. (2016), Sidhu and Singh et al.(2016). Similar indications of temperature rise have been observed for flours by various scientists (Saleh and Meullenet, 2015;Yu et al.,2018). This may be attributed to the fact that damage of proteins, starch, and fatty acid components within the wheat flour due to excessive heat generation by friction.

Table 2 Effect of milling speed on milling parameters

S. No.	Variety	HD 3086			PBW725		
	Milling speed (rpm)	80	125	1440	80	125	1440
1.	Flour temperature rise (℃)	12.24	18.26	31.12	12.31	18.32	31.19
2	Milling time (min)	15.00	12.20	7.40	15.50	13.30	8.50
3	Milling efficiency (%)	93.64	91.89	89.68	98.64	95.89	94.68
4	Flour recovery (%)	91.37	88.38	84.45	94.37	91.38	85.45
5	Fineness modulus	2.05	2.00	1.99	2.08	2.03	1.97
6	Average particle size (mm)	0.043	0.041	0.040	0.044	0.042	0.041

The recovery of flour was highest at low speed and decreased with increase in speed. Reduced flour recovery could be attributed to the lesser milling efficiency of 89.68% for HD3086 and 85.45% for PBW725. The overall flour recovery for sieve size 1.4 mm, average particle size and fineness modulus were found to be higher at 80 rpm milling speed followed by 125 rpm and 1440 rpm for both the varieties.

3.2 Comparative proximate composition of whole grain and milled flour

The whole wheat grains of two varieties viz.HD3086 and PBW725 were milled in a domestic stone mill (*atta chakki*) at two speeds viz. 80 and 125 rpm and in a commercial flour mill at 1440 rpm. Proximate composition of whole grains and milled flour obtained is presented in Figure 1.

3.2.1 Moisture content

Moisture content of flour is very important for its shelf life, lower the moisture content better its storage life (Kadam et al., 2012). Significant difference in moisture content was observed for whole wheat and milled flour in both the varieties (Figure 1). With increase in milling speed, moisture content was found to decrease significantly ($p\leq$ 0.05). This may be attributed to higher heat generation with an increase in speed. Similar results have been reported by Butt et al. (2004) and Barnwal et al. (2013). Owing to this fact, the percentage decrease in moisture content was highest (6.43%) for 1440 rpm speed and lowest for 80 rpm speed (2.61%) for HD3086. Similarly in case of PBW725 decrease was highest (8.47%) at 1440 rpm speed and lowest for 80 rpm speed (3.80%).

3.2.2 Fat content

More amount of fat content in the flour leads to rapid degradation resulting poor keeping quality, so crude fat content of the product is also limiting factor for good shelf life of flour. The results of crude fat content were presented in Figure 1 and values showed the significance difference ($p\leq$ 0.05) between whole wheat and wheat flour for PBW 725 variety, whereas, milling speed showed non-significant affect on fat content of HD3086 variety. Fat content showed a decline in values with the increase in milling speed for both the varieties. The decreasing order may be attributed due to the lipolytic activity of enzymes and similar effects were observed by Kadam et al. (2012). Significantly different values were noticed for samples milled at 1440 rpm as compared with samples milled at 80 rpm speed for both the varieties. Overall, decrease in fat content of wheat flour was less observed in HD3086 as compared to PBW725variety.

3.2.3 Carbohydrate content

The carbohydrates of whole wheat samples were also found to be significantly different from milled samples of both the varieties. Considering the variation in milling speeds, carbohydrate content declined significantly ($p\leq$ 0.05) as speed changed from 80 to 1440 rpm (Figure 1). These observations may be indications of variation in starch as a result of endogenous amylase activity as observed by Rehman and Shah (1999) for wheat. The maximum decrease in carbohydrates of wheat flour samples was 12.5% in HD3086 and 11.5% in PBW725 variety,as compared with whole wheat samples.

3.2.4 Protein content

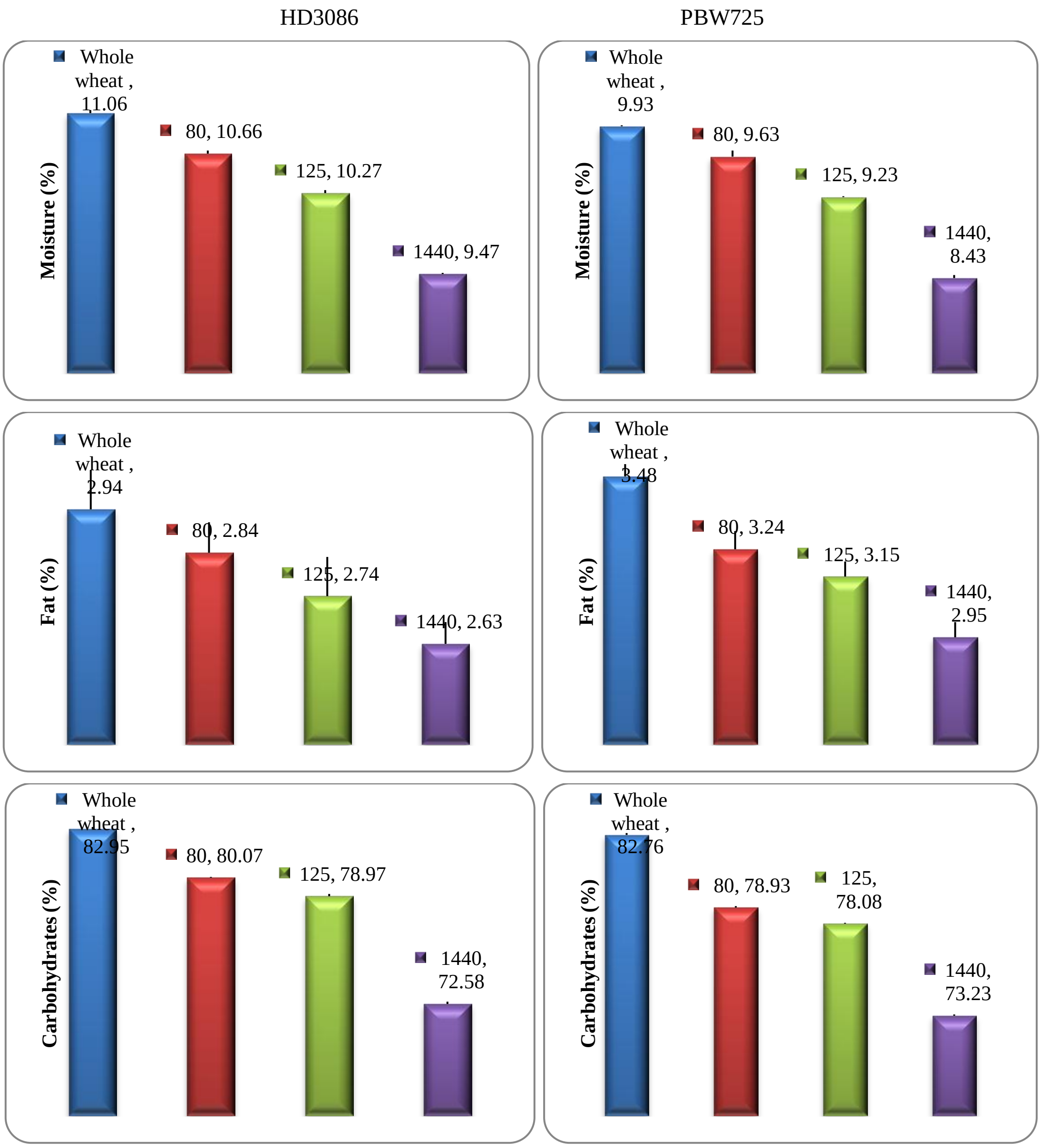
The observations in Figure 1 indicate that the protein content of whole wheat grains of both the varieties were non-significantly different from flour samples. The percentage decrease in protein content was lowest at 80 rpm (0.65%) and highest at 1440 rpm speed (17.11%) for HD3086 variety. Similarly, for PBW725, it was 1.56% at 80 rpm and 12.62% for 1440 rpm speed. This trend may be due to the fact that flour at high milling temperature cause instability in the biochemical properties as compared to flour obtained at lower rpm. Prabhasankar and Haridas (2001) observed a loss of amino acids with rise in temperature due to reaction of these amino acids resulted in formation of covalent bonds as wheat flour was prepared by different mills. The HD3086 variety had more stable and high values of protein initially i.e. 12.33% as compared to PBW725 having 12.12% protein content.

3.2.5 Crude fibre content

The perusal of Figure 1 showed that the crude fibre content of wheat grain samples of PBW725 was more as compared to HD3086 variety and were non-significantly different from samples milled at 80 rpm ($p\leq$ 0.05) in both these varieties. During milling, crude fibre content decreased with increased in milling speeds. For milled samples of HD3086 variety had significant effect on crude fibre content values with increase in milling speed. The percent decrease in fibre content of PBW725 was 12.97% and 13.13% for HD3086 varietyat 1440 rpm speed as comparison with value of raw wheat grains.

3.2.6 Ash content

A non-significant difference was observed between ash content of whole wheat grain and milled flour samples for both the varieties. A glimpse of Figure1 showed that milling speeds also had non-significant effects on milled samples ($p \leq 0.05$). The highest ash content (1.69%) was found in whole wheat grains of variety HD3086, whereas, PBW 725 variety showed the lowest ash content (1.62%).The decline in ash content after milling was lowest (0.59%) at 80 rpm and highest (2.95%) at 1440 rpm for HD3086 variety, whereas for PBW725, ash content decrease was (0.60%) at 80 rpm and (2.46%) at 1440 rpm respectively, indicating loss of minerals as milling speed increases. The possible reasons for such results may be minor mineral destruction due to heat generation as milling speed increased. Similar observations have been reported by Shahzadi et al. (2005),Kadam et al. (2012) for wheat and maize flour respectively.



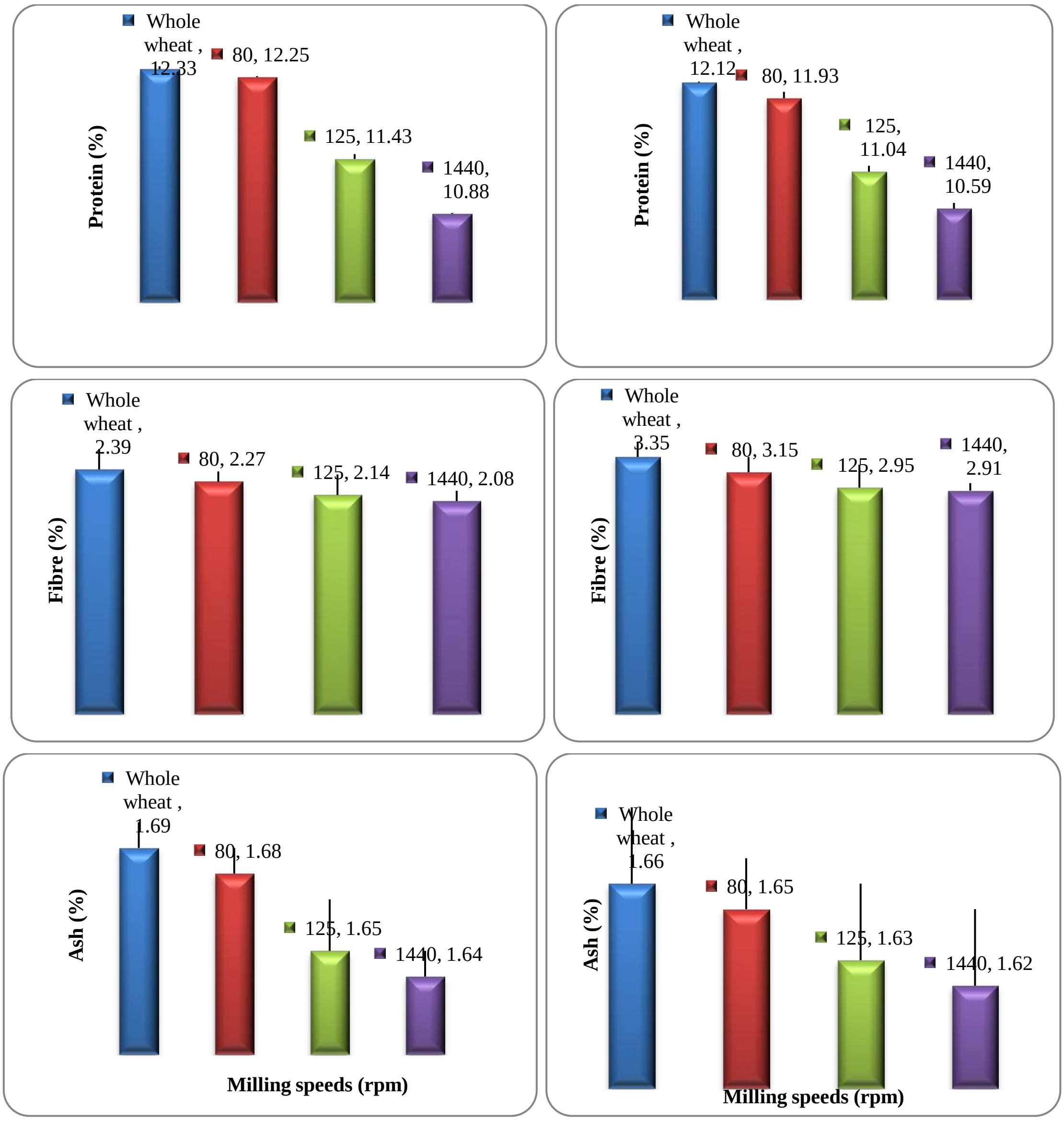


Figure 1 Proximate composition of whole wheat and wheat flour

3.3 Physiochemical properties of wheat flour during storage

3.3.1 Free fatty acids

Free fatty acid content of wheat flour samples increased with increase in storage period for all the milling speeds and for both the varieties (Table 3). The effects of packaging material, storage period and their interaction were found to be significant for all quality parameters (Table 3 p<0.005). This effect of storage resulted in the minimum increase in FFA (3.64%) for flour sample milled at 80 rpm, stored in T4 for HD3086 variety, whereas maximum increase in FFA (10.12%) for PBW725 variety milled at 1440 rpm and packed in T1. On the whole, the variation in free fatty acids was lower in HD3086 as compared to PBW725 variety. Agrahar-murugkar and Jha (2011) reported that storage period leads to increase in free fatty acid contents of soy flour which may be due to temperature and relative humidity variations during storage. This alteration in free fatty acid content was least in T4 and highest in T1, showing vacuum packaging providing promising conditions for better shelf-life retention. In addition to this, aluminium laminated packaging is more promising to maintain free fatty acid levels. For samples milled at 80 and 1440 rpm, free fatty acid values for samples packed in T1 were significantly different from the other packaged samples for HD3086variety, but in case of PBW725variety, similar trend was observed for samples obtained from 80 and 125 rpm milling speeds. A general observation of non-significant results was recorded for T2 and T3 packaging materials for all the milling speeds.

Table 3 Effect of packaging material on physicochemical properties of flour during storage

Variety			HD3086PBW725							
Parameter	Milling speed (rpm)	Storage period (days)	T1	T2	T3	T4	T1	T2	T3	T4
Free fatty acid	80	0	9.7 ± 0.07^{AZ}	9.7 ± 0.0^{AZ}	9.7 ± 0.0^{AZ}	9.7 ± 0.07^{AZ}	9.5 ± 0.0^{AZ}	9.5 ± 0.0^{AZ}	9.5 ± 0.0^{AZ}	9.5 ± 0.06^{AZ}
		90	18.00 ± 0.0^{AY}	16.31 ± 0.06^{BY}	16.12 ± 0.08^{BY}	13.34 ± 0.08^{CY}	18.38 ± 0.07^{AY}	16.39 ± 0.07^{BY}	16.25 ± 0.06^{BY}	13.42 ± 0.05^{CY}
	125	0	9.7 ± 0.07^{AZ}	9.7 ± 0.07^{AZ}	9.7 ± 0.0^{AZ}	9.7 ± 0.07^{AZ}	9.5 ± 0.0^{AZ}	9.5 ± 0.0^{AZ}	9.5 ± 0.0^{AZ}	9.5 ± 0.06^{AZ}
		90	17.81 ± 0.011^{AY}	17.71 ± 0.08^{AX}	17.67 ± 0.08^{AX}	14.33 ± 0.09^{BX}	18.94 ± 0.05^{AX}	18.32 ± 0.05^{BX}	18.37 ± 0.06^{BX}	14.63 ± 0.05^{CX}
	1440	0	9.7 ± 0.07^{AZ}	9.7 ± 0.07^{AZ}	9.7 ± 0.07^{AZ}	9.7 ± 0.07^{AZ}	9.5 ± 0.06^{AZ}	9.5 ± 0.06^{AZ}	9.5 ± 0.06^{AZ}	9.5 ± 0.06^{AZ}
		90	19.09 ± 0.0^{AX}	17.89 ± 0.08^{BX}	17.81 ± 0.09^{BX}	15.26 ± 0.07^{CX}	19.62 ± 0.07^{AW}	18.58 ± 0.07^{BX}	18.87 ± 0.06^{BW}	16.05 ± 0.06^{BW}
Moisture content	80	0	13.01 ± 0.05^{AZ}	13.01 ± 0.05^{AZ}	13.01 ± 0.05^{AZ}	13.01 ± 0.05^{AZ}	13.40 ± 0.07^{AZ}	13.40 ± 0.07^{AZ}	13.40 ± 0.07^{AZ}	13.40 ± 0.07^{AZ}
		90	19.73 ± 0.0^{AY}	17.23 ± 0.05^{BY}	17.09 ± 0.05^{BY}	16.55 ± 0.06^{BY}	19.85 ± 0.06^{AY}	17.93 ± 0.05^{BY}	15.87 ± 0.06^{CY}	15.76 ± 0.07^{CY}
	125	0	12.90 ± 0.09^{AZ}	12.90 ± 0.09^{AZ}	12.90 ± 0.09^{AZ}	12.90 ± 0.09^{AZ}	13.01 ± 0.08^{AZ}	13.01 ± 0.08^{AZ}	13.01 ± 0.08^{AZ}	13.01 ± 0.08^{AZ}
		90	19.67 ± 0.0^{AY}	16.09 ± 0.08^{BY}	17.13 ± 0.08^{BY}	16.05 ± 0.08^{BY}	18.62 ± 0.08^{AX}	16.33 ± 0.08^{BX}	16.66 ± 0.08^{BY}	15.90 ± 0.08^{BY}
	1440	0	12.50 ± 0.07^{AZ}	12.50 ± 0.07^{AZ}	12.50 ± 0.07^{AZ}	12.50 ± 0.07^{AZ}	12.75 ± 0.06^{AZ}	12.75 ± 0.06^{AZ}	12.75 ± 0.06^{AZ}	12.75 ± 0.06^{AZ}
		90	18.50 ± 0.0^{AY}	17.10 ± 0.06^{AY}	17.43 ± 0.08^{AY}	15.02 ± 0.05^{BY}	19.82 ± 0.05^{AY}	17.80 ± 0.05^{BY}	15.92 ± 0.06^{CY}	15.82 ± 0.06^{CY}

Note: Letters A, B.. show difference in mean for each storage period and speed due to packaging material and letters Y, Z.. show difference in mean for each storage period due to speed

3.3.2 Moisture content

The effect of packaging material and storage on moisture content of wheat flour during storage is presented in Table 3. Significant difference in moisture content of wheat flour samples was observed for storage period, packaging types and their interaction ($p<0.005$).On comparing both varieties, it was observed that the shelf life of HD3086 was superior to PBW725 as the variation in moisture content was lower during storage of wheat flour for period of 90 days. Nagiet al. (2012) observed similar fluctuations for cereal bran incorporated packaged biscuits. The increase in moisture content may also be attributed due to hygroscopic properties of flour, transmission through package and atmospheric conditions. During storage, while comparing packaging material for both varieties, samples milled at 80 and 125 rpm and packaged in T2 showed significant values of moisture content on comparison with other packaging materials. Moreover, all other packaging materials had non-significant results for moisture content of milled samples from variety HD3086. While evaluating effect of storage and packaging material on flour samples prepared at 1440 rpm for the same variety, T4 samples were significantly different from rest all the samples. However, for PBW725 variety significant results were observed for all samples packaged in different packaging materials with an exception of T3 and T4 as shown in Table 5.

3.3.3 Colour parameters

The colour characteristics of wheat flour i.e. L-value, hue angle and chroma packaged in different materials showed significant ($p\leq 0.05$) results during storage for both wheat varieties. The effects of packaging material, storage period and their interaction were found to be significant for all quality parameters (Table 4 and Table 5).

The samples milled at 80 rpm were more whitish and showed high *L* values as compared to other samples obtained at 125 and 1440 rpm milling speeds. This may be due to breakage of excessive portion of endosperm with minimum part of bran and germ at lower speed, which were later on mixed with each other to large extent during milling at higher speeds (Prabhasankar et al., 2000). While comparing effect of various packaging materials on

L-value of samples milled at different speeds, T2 packages showed more lightness in colour of flour as compared to that in T1, T3 and T4. A perusal of Table 5 shows that there was a significant decline in hue angle of wheat flours of two varieties milled at different speeds during storage in different packaging materials. Considering the milling speeds, lowest values were observed at 80 rpm followed by 125 and 1440 rpm. In addition to this percentage decrease during storage also increased as milling speed increased. Findings reveal that deviation in hue angle may be attributed due to increase in lightness depending upon the properties of packaging material as lower values were found in T2 and higher values in T4. From observations for chroma, the intensity of colour increased with storage of wheat flour samples in different packaging materials with maximum values for T2 packages. However, for speed 80 rpm, T1 and T3 were non-significantly different from T2 and T4 respectively for variety HD3086 (Table 4 and Table 5). But for variety PBW725, T1 was non-significantly different from T3.

Table 4 Effect of packaging material on the colour of flour during storage for each packaging material

Variety			HD3086				PBW725			
Parameter	Milling speed (rpm)	Storage period (days)	T1	T2	T3	T4	T1	T2	T3	T4
L-value	80	0	79.00±0.07^{Aa}	79.00±0.07^{Aa}	79.00±0.07^{Aa}	79.00±0.07^{Aa}	77.80±0.05^{Zz}	77.80±0.05^{Zz}	77.80±0.050^{Zz}	77.80±0.05^{Zz}
		90	75.70±0.09^{Bb}	74.70±0.10^{Ab}	76.80±0.10^{Cb}	76.50±0.09^{Cb}	73.70±0.11^{Yy}	72.60±0.09^{Zy}	74.90±0.08^{Xy}	75.00±0.08^{Wy}
	125	0	78.00±0.06^{Aa}	78.00±0.06^{Aa}	78.00±0.06^{Aa}	78.00±0.06^{Aa}	76.50±0.04^{Zz}	76.50±0.04^{Zz}	76.50±0.04^{Zz}	76.50±0.04^{Zz}
		90	73.50±0.03^{Bb}	72.20±0.05^{Ab}	74.60±0.04^{Cb}	74.30±0.04^{Cb}	69.60±0.05^{Yy}	68.90±0.05^{Zy}	72.70±0.04^{Xy}	72.90±0.03^{Xy}
	1440	0	74.30±0.07^{Aa}	74.30±0.07^{Aa}	74.30±0.07^{Aa}	74.30±0.07^{Aa}	74.30±0.08^{Zz}	74.30±0.08^{Zz}	74.30±0.08^{Zz}	74.30±0.08^{Zz}
		90	68.40±0.10^{Bb}	67.20±0.08^{Ab}	70.50±0.08^{Cb}	70.70±0.09^{Cb}	67.50±0.07^{Yy}	66.30±0.09^{Zy}	69.10±0.07^{Xy}	69.50±0.08^{Xy}
Hue angle	80	0	1.368±0.12^{Aa}	1.368±0.12^{Aa}	1.368±0.12 Aa	1.368±0.12^{Aa}	1.341±0.10^{Zz}	1.341±0.10^{Z} z	1.341±0.10^{Zz}	1.341±0.10^{Zz}
		90	1.262±0.11^{Bb}	1.197±0.10^{Ab}	1.327±0.12^{Cb}	1.319±0.11^{Cb}	1.219±0.13^{Zy}	1.154±0.12^{Zy}	1.257±0.11^{Xy}	1.286±0.11^{Yy}
	125	0	1.375±0.09 Aa	1.375±0.09 Aa	1.375±0. 09 Aa	1.375±0.09^{Aa}	1.341±0.11^{Zz}	1.341±0.11^{Zz}	1.341±0.11^{Zz}	1.341±0.11^{Zz}
		90	1.215±0.09^{Bb}	1.102±0.10^{Ab}	1.272±0.08^{Cb}	1.307±0.12^{Db}	1.208±0.11^{Yy}	1.103±0.09^{Zy}	1.206±0.10^{Yy}	1.257±0.11^{Xy}
	1440	0	1.438±0.12^{Aa}	1.438±0.12^{Aa}	1.438±0.12^{Aa}	1.438±0.12^{Aa}	1.520±0.10^{Zz}	1.520±0.10^{Zz}	1.520±0.10^{Zz}	1.520±0.10^{Zz}
		90	1.166±0.09^{Bb}	1.106±0.08^{Ab}	1.315±0.09^{Cb}	1.329±0.10^{Cb}	1.229±0.11^{Yy}	1.104±0.10^{Zy}	1.307±0.11^{Xy}	1.334±0.10^{Xy}
Chroma	80	0	17.87±0.04^{Aa}	17.87±0.04^{Aa}	17.87±0.04^{Aa}	17.87±0.04^{Aa}	17.15±0.05^{Zz}	17.15±0.05^{Zz}	17.15±0.05^{Zz}	17.15±0.05^{Zz}
		90	19.11±0.06^{Ab}	19.27±0.05^{Ab}	18.98±0.06^{Bb}	18.82±0.06^{Bb}	18.72±0.05^{Yy}	19.03±0.06^{Zy}	18.63±0.07^{Yy}	18.12±0.05^{Xy}
	125	0	19.00±0.03^{Aa}	19.00±0.03^{Aa}	19.00±0.03^{Aa}	19.00±0.03^{Aa}	17.20±0.04^{Zz}	17.20±0.04^{Zz}	17.20±0.04^{Zz}	17.20±0.04^{Zz}
		90	20.32±0.05^{Bb}	20.89±0.05^{Cb}	19.83±0.04^{Ab}	20.17±0.04^{Bb}	19.84±0.05^{Zy}	19.69±0.04^{Yy}	19.05±0.06^{Xy}	18.21±0.04^{Wy}
	1440	0	38.44±0.04^{Aa}	38.44±0.04^{Aa}	38.44±0.04^{Aa}	38.44±0.04^{Aa}	30.93±0.05^{Zz}	30.93±0.05^{Zz}	30.93±0.05^{Zz}	30.93±0.05^{Zz}
		90	39.91±0.7^{Ab}	40.72±0.05^{Ab}	40.11±0.04^{Ab}	39.99±0.05^{Ab}	32.63±0.06^{Yy}	33.25±0.06^{Xy}	32.67±0.07^{Yy}	31.74±0.05^{Zy}

Note: Same lowercase letters denote a non-significant difference in mean at each storage period and same uppercase letters denote a non-significant difference in mean for packaging material

Table 5 p-values for physicochemical properties of wheat flour

Variety	HD3086			PBW725		
Parameters	Packaging	Storage period	Packaging*Storage period	Packaging	Storage period	Packaging*Storage period
Free fatty acid (%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Moisture content (%)	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
L-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Hue angle (°)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chroma	0.0479	<0.0001	0.0068	0.0536	<0.0001	0.0092

A general trend was observed for colour characteristics of both varieties that maximum variation was found in T2 followed by T1, T3 and T4. Moreover, flour samples packaged in T3 and T4 showed comparable results with more favourable outcomes in case of T4 making it best packaging material for storage of flour for extended time period. Out of two varieties, HD3086 showed results close to that of fresh flour owing to less percentage of decrease in quality as compared to variety PBW725.

4 Conclusions

Wheat and different wheat products are staple food and are consumed in all parts of India. The performance analysis of flour mill, showed that recovery of flour and milling speed had an inverse relation. Milling operations significantly affect (p<0.05) the quality parameters of wheat flour. All the properties of milled flour decreased with increase in milling speed. Apart from this, packaging showed a considerable effect on storability of wheat flour. as samples packaged under vacuum retained flour quality to maximum content followed by ethylene vinyl alcohol/polyetylene bags. Hence flour obtained from wheat milling at low speeds i.e. 80 rpm and packaged into vacuum bags can be considered suitable option to prolong the storage life of wheat flour. Overall considering the milling, packaging and storage effects, variety HD3086 was found more stable as compared to PBW725, due to better retention of desirable quality characteristics.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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