Effect of flour particle size and damaged starch on the quality of cookies

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Abstract Two wheat varieties ‘C 306’ and ‘WH 542’ were milled to obtain flour fractions of different particle sizes. Various physicochemical parameters such as wet and dry gluten, falling number, solvent retention capacity (SRC), alkaline water retention capacity (AWRC) and damaged starch content of the flour fractions were analyzed. The damaged starch values ranged from 5.14% to 14.79% for different flour fractions and increased significantly with decrease in particle size. AWRC and SRC of the flour fractions also increased with decrease in particle size. AWRC($r=0.659$) showed positive correlation and cookie spread ratio ($r=-0.826$) was strongly negatively correlated with the damaged starch levels. Hardness of the cookies in term of compression force showed increasing trend as damaged starch of the flour fractions increased. Spread ratio of the cookies ranged from 6.72 to 10.12. Wheat flour of particle size greater than 150 μm produced cookies with best quality.

Keywords Milling · Particle size · Damaged starch · Solvent retention capacity (SRC) · Cookies

Introduction

Cereals such as wheat, rice, oats and barley are utilized as staple foods globally (Das et al. 2011). Among these cereals, wheat is the most important crop in terms of production and consumption. Wheat is milled into flour which is processed

into various baked products such as cookies, bread, chapatti, pita bread and cakes (Singh and Khatkar 2005; Khatkar and Schofield 1997). Wheat flour milling is a grinding process which gives different fractions of wheat flour which affect the quality of bakery products (Shekara et al. 2011). During wheat milling a portion of the starch granules sustains mechanical damage, the level of which depends on wheat hardness and milling technique. Millers are of the opinion that granulation is very important in the production of quality flour. It has been suggested that flour particle size, damaged starch and protein quality and quantity have effects on the baked products (Guttieri et al. 2001). Hard wheat is more difficult to reduce to flour-sized particles. Therefore, hard wheat flour has a larger mean particle size than that of soft wheat flour. Alsberg and Griffing (1925) first reported that the flour particle size changes flour characteristics like water absorption, conversion of starch by enzymes, damage starch content and baking quality. Okkada et al. (1986) found that grinding the same flour for an increased number of times increases the level of starch damage. Hard wheat produced larger flour particle with higher damaged starch levels when compared with soft wheat (Farrand 1972). Hard and soft wheat fracture differently during the milling process which cause differences in damaged starch levels and particle size (Simmonds 1974). Soft wheat flours are used for cookies. Flours that produce larger diameter and lower height cookies are considered to have better quality. Another aspect of cookie quality is the cracking that occurs on the top surface of the cookie referred to as cookie top grain. Good top grain (many surface cracks) results from recrystallization of sucrose at the cookie surface during baking (Doescher and Hosene 1985). Damaged starch absorbs much more water than intact starch. In soft wheat products, especially in cookies, high levels of damaged starch are detrimental to quality. Gaines et al. (1988) demonstrated that increasing damaged starch led to sugar snap cookie of

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dough stiffness and decrease in cookie diameter. Reduction of flour particle size reduces cookie spread because starch is damaged during particle size reduction (Yamazaki 1959). Substituting damaged starch for flour in a sugar snap cookie formulation or for native prime starch in an all starch cookie model system increased alkaline water retention capacity (AWRC) and decreased cookie diameter (Donelson and Gaines 1998).

The objective of the study was to investigate the effect of particle size and damaged starch content on physicochemical characteristics of the wheat flour and cookie quality.

Materials and methods

Raw material and preparation of sample

Pure wheat cultivars of ‘C 306’ and ‘WH 542’ were selected for the study. The cleaned grains were tempered for 24 h prior to milling. The grains of individual cultivars were milled on a Chopin (Model, CD 1) laboratory mill into flour after tempering. Physico-chemical characterization of the flour of the tempered wheat varieties was carried out which is presented in Table 1. Flour particles of different sizes (>150 µm, 100–150 µm and <100 µm) were separated with the help of mechanical sifter using sieves of pore sizes 150 µm and 100 µm. Thus, three fractions of each of the wheat varieties were obtained.

Analysis of wheat flour fractions

All fractions of flour were analyzed for the moisture content, wet gluten, dry gluten, damaged starch and falling number values. Moisture was determined according to AACC 2000 approved methods. Chopin SDmatic was used for determination of the damaged starch in the different flour fractions.

A solution of 120 ml of distilled water, 3 g boric acid, 3 g potassium iodide and one drop of sodium thiosulfate ($\text{Na}_2\text{O}_3\text{S}_2$) at 0.1 mol/l was taken in the reaction bowl. Flour (1 g) was weighed accurately and was placed in the spoon in the SDmatic and the arm of the SDmatic was folded down. After 6 min of the SDmatic cycle, the damaged starch content of the flour sample was noted. For wet and dry gluten determination 10.0 g±0.01 g of flour was weighed and put into the Glutomatic 2200 (Perten) wash chamber with an 88 µm polyester sieve. Salt solution of 4.8 ml was added to the flour sample. Flour and the salt solution were mixed to form dough for 20 s. After termination of the mixing phase, the washing started automatically and continued for 5 min. Exactly 30 s after washing was completed the wet gluten obtained was weighed and dried at 150 °C for 4 min in the Glutork 2020 to obtain dry gluten. Falling number apparatus (Perten Model 1100) was used for determination of falling number value. For this, 7 g of the flour was taken in a falling number tube and shook vigorously for 40 s to obtain homogenous suspension and kept in the falling number apparatus to obtain the falling number value. All results were obtained in triplicates.

Solvent retention capacity (SRC) and alkaline water retention capacity (AWRC) determination of wheat flour fractions

Solvent retention capacity profile (SRC) was obtained according to the AACC 56–11 method. Wheat flour samples (5 g) were suspended in each of 25 g of water, 500 g/l sucrose, 50 g/l sodium carbonate and 50 g/l lactic acid. The samples were hydrated for 20 min and centrifuged at $1000 \times g$ for 15 min. Each precipitate obtained was weighed and the SRC for each solvent was calculated using the following equation (Haynes et al. 2009):

$$\% \text{SRC} = \left\{ \left[\left(\frac{\text{tube, stopper, gel wt.} - \text{tube, stopper}}{\text{flour weight}} \right) - 1 \right] \left(\frac{86}{100 - \text{flour moisture}} \right) \times 100 \right\}$$

Alkaline water retention capacity (AWRC) was determined according to the AACC 56–10 method. Flour (1 g) was

suspended in 5 ml of 8.4 g/l NaHCO_3 , hydrated for 20 min and centrifuged at $1000 \times g$ for 15 min at room temperature. The sediment obtained was weighed and the AWRC was calculated. All determinations were made in triplicate.

Table 1 Physico-chemical characteristics of wheat varieties

Parameters	‘WH 542’	‘C 306’
Moisture%	11.2±0.05	11.1±0.08
Ash%	0.46±0.02	0.53±0.03
Protein%	11.5±0.04	10.8±0.06
SDS sedimentation vol. (ml)	36.0±0.0	31.0±0.0

^a The values are mean ± S.D. of determinations made in triplicates

Preparation of cookies

Cookies were prepared according to AACC Approved method 10–50D (2000). The ingredients used were flour (225 g), sugar (130 g), shortening (64 g), dextrose solution (33 ml), sodium bicarbonate (2.5 g), sodium chloride (2.1 g) and distilled water (16 ml). The dough was sheeted to

10 mm thickness on a dough sheeter and cut into round shape with cutter of 60 mm diameter. Baking was performed in baking oven at 204 °C for 10 min. Cookie preparation was done in triplicate.

Textural analysis of cookies

The hardness of cookies was determined by Texture Analyzer (Model TA-XT 2i) with software Texture expert exceed (version 2.61), Stable Micro Systems, U.K. The probe used was Warner –Bratzler blade using 50 kg load cell. The test mode used was force in compression with pre test speed, test speed and post test speed of 1.5, 2.0 and 10.0 mm/s, respectively.

Statistical analysis

The experimental data collected in triplicate was analyzed for significant differences with the help of analysis of variance (ANOVA) conducted using SPSS 16.0 software. The Pearson's correlation coefficients for the different quality parameters of the flour fractions of wheat varieties were calculated using SPSS 16.0 software.

Principal component analysis

Principal component analysis (PCA), which is a multivariate approach designed for multicorrelated data, was done using Statgraphics Plus 3.0 (Statpoint Technologies). It makes it possible to get an overview of the data and to find which properties are related, and which properties are most important in distinguishing between samples.

Results and discussion

Physico-chemical analysis of the flour fractions

Particle size of flour did not have any substantial effect on the moisture content, wet and dry gluten content (Table 1). The damaged starch levels for the wheat varieties varied from 5.14% (flour fraction >150 µm of wheat variety 'C 306') to 14.79% (< 100 µm flour fraction of wheat variety 'WH 542'). The variety 'WH 542' had significantly higher damaged starch content than the variety 'C 306'. This may be due to the higher grain hardness of variety 'WH 542' as compared to 'C 306' (Gupta et al. 2006). Thus, 'WH 542' produced flour with higher damaged starch than 'C 306' which further increased as the particle size of the flour decreased. The Falling Number profile of the flour fractions did not show any specific pattern inferring that particle size does not have profound effect on the amylase activity of the flour.

Flour quality analysis

The data on the solvent retention capacity (SRC) and alkaline water retention capacity (AWRC) are presented in Table 2. SRC is useful for studying the contribution of the flour components to end-use quality and selection of wheat for production of flour with required functionality. Generally, lactic acid SRC is associated with gluten protein characteristics. Sodium carbonate SRC is related to levels of damaged starch and sucrose SRC with pentosan components. Water SRC is influenced by all water absorbing components in flour. The combined pattern of these flour SRC results establishes a practical flour quality and functionality profile that is useful in predicting baking performance. The SRC test showed significant differences between the two wheat varieties. Sodium carbonate SRC varied from 85.03% to 110.15%, lactic acid SRC 83.74% to 102.22%, sucrose SRC 97.82% to 124.25% and distilled water SRC 70.61% to 86.28%. The values increased significantly with the decrease in particle size of the flour. Varietal differences were observed for all the SRC test values with 'WH 542' showing higher values than 'C 306'. Sodium carbonate SRC was affected the most with the particle size of the flour. It increased from 96.32% to 110.15% for 'WH 542' variety and from 85.03% to 95.45% for 'C 306' variety as the particle size of flour decreased. This was because sodium carbonate reacts with the damaged starch component of the flour the levels of which increased with the decrease in particle size of the flour. 'WH 542' showed higher values than 'C 306' for the sodium carbonate SRC because harder wheat variety 'WH 542' had more damaged starch due to the milling process. Further, lactic acid SRC values were also recorded higher in variety 'WH 542' than 'C 306' inferring stronger gluten protein characteristics of the flour fractions of the 'WH 542' variety. AWRC is conducted to select flours of good cookie quality. Good cookie flours have low AWRC values and produce cookies with large diameters. The AWRC values showed significant increase from 84.66% to 107.28% with decrease in flour particle size for both the varieties. 'WH 542' variety recorded higher values of AWRC ranging from 91.15% (>150 µm fraction) to 107.28% (< 100 µm fraction). This could be attributed to the combined effect of greater damaged starch and varietal differences.

Quality parameters of cookies

Higher cookie diameter and higher spread ratio are considered as the desirable quality attributes (Yamamoto et al. 1996). The diameter of cookies (Table 3) prepared from

Table 2 Physico-chemical analysis of flour fractions of wheat varieties

Flour Fractions	Moisture (%)	Wet Gluten (%)	Dry Gluten (%)	Damaged Starch (%)	FallingNo.(s)
Wheat Variety ‘WH 542’					
Control	11.3±0.05d	24.7±0.22a	7.9±0.05a	11.1±0.08e	572.1±4.01b
>150 µm	11.2±0.10b,c	24.7±0.42a	7.9±0.05a	5.4±0.04a	590.3±3.51c
100–150 µm	11.4±0.06e	24.9±0.19a,b	7.9±0.07a	10.5±0.11d	606.3±4.04d
<100 µm	11.6±0.05f	25.1±0.08b	8.0±0.05a	14.8±0.11g	525.6±3.07a
Wheat Variety ‘C 306’					
Control	11.1±0.03a,b	28.5±0.07d,e	9.1±0.04b,c	9.3±0.06c	654.1±4.38f
>150 µm	11.7±0.02g	28.1±0.08c	9.1±0.08b	5.1±0.09a	648.4±2.64e
100–150 µm	11.1±0.03a,b	28.3±0.09c,d	9.2±0.07b,c	9.1±0.03b	658.7±3.54f
<100 µm	11.1±0.04a	28.7±0.08e	9.2±0.05c	12.6±0.03f	600.3±3.03d

^a The values are mean ± S.D. of determinations made in triplicates. Values followed by different letters are significantly different at 5% level of significance ($P<0.05$)

various particle size ranges of flour showed increasing trend (77.28 mm to 86.79 mm) with increase in particle size. The spread ratio decreased from 8.63 to 6.72 for ‘WH 542’ and from 10.12 to 7.38 for ‘C 306’ flour fractions with decrease in particle size. This was due to higher AWRC values and damaged starch content of finer particle size flour. Spread ratio in cookies was negatively affected by damaged starch content in both the varieties. At lower levels of damaged starch, the effect on the spread ratio of the two varieties was more prominent. Moreover, the decrease in the spread ratio with increase in damaged starch content was variety specific with wheat variety ‘C306’ showing more effect than variety ‘WH 542’ (Fig. 1).

Good cookie flours hold less water (Faridi et al. 1994). The main hydrophilic components of a cookie formula are

the flour and sugar. Lower water absorption by flour raises the water absorption by sugar that increments syrup and decreases dough viscosity during baking. This allows the dough to spread more producing cookies of larger diameter (Slade and Levine 1994). Damaged starch absorbs more water than the intact starch that leads to cookie dough stiffness, decreased cookie diameter and lower spread. Moreover, higher percent of damaged starch makes the starch more susceptible to enzyme attack that results in smaller cookies. The flour fraction of particle size >150 µm of ‘C 306’ variety recorded lowest values for AWRC (84.66%), damaged starch (5.14%) and SRC tests and thus produced cookies with higher spread. Spread ratio of cookies showed direct relationship with particle size of flour fractions. More prominent relationship was observed

Table 3 Solvent Retention Capacity (SRC) of flour fractions of wheat varieties

Flour Fractions	H2OSRC (%)	SCSRC (%)	LASRC (%)	SSRC (%)	AWRC (%)
Wheat Variety ‘WH 542’					
Control	81.5±0.54e	101.2±0.21f	98.6±0.18e	121.5±0.18f	96.3±0.28f
>150 µm	76.4±0.91d	96.3±0.27e	97.2±0.24d	118.2±0.29d	91.1±0.34e
100–150 µm	83.7±0.33f	103.3±0.41g	98.1±0.15e	120.8±0.22e	99.4±0.17g
<100 µm	86.3±0.25g	110.1±0.44h	108.4±0.56f	124.2±0.34g	107.3±0.35h
Wheat Variety ‘C 306’					
Control	71.2±0.24a	89.3±0.17b	86.0±0.28b	100.8±0.32b	85.8±0.28b
>150 µm	70.6±0.31a	85.0±0.22a	83.7±0.36a	97.8±0.24a	84.6±0.38a
100–150 µm	72.5±0.56b	90.7±0.29c	85.6±0.61b	100.6±0.59b	86.4±0.45c
<100 µm	75.1±0.22c	95.4±0.35d	91.5±0.59c	104.3±0.31c	88.3±0.40d

^a The values are mean S.D. of determinations made in triplicates. Values followed by different letters are significantly different at 5% level of significance ($P<0.05$). H2O SRC –distilled water SRC; SCSRC –sodium carbonate SRC; SSRC- sucrose SRC; LASRC- lactic acid SRC; AWRC- alkaline water retention capacity

Fig 1 Effect of damaged starch and flour particle size on the spread ratio of cookies ($n=3$)

in case of 'C 306' than 'WH 542' variety of wheat as indicated by R^2 values. More pronounced difference in the spread ratio of cookies prepared from two varieties was observed at higher flour particle sizes as compared to their spread ratio at lower end of the flour particle range i.e. $<100 \mu\text{m}$ (Fig. 1). The results obtained in the study were in agreement with the findings of other authors (Abboud et al. 1985; Gaines et al. 1988; Donelson and Gaines 1998; Leon et al. 1996) who demonstrated that

increased damaged starch and AWRC decreases cookie diameter.

The hardness of the cookies as indicated by the compression force followed an increasing trend with decrease in particle size for both the varieties. This was caused due to increase in water absorption capacity of the flour with finer particle size which resulted in stiffness of dough that resulted in harder cookies with lower spread ratio. The lowest compression force of 2657.6 g was observed for the flour fraction $>150 \mu\text{m}$ of 'C 306' variety. Moreover, a strong relationship was observed between diameter and texture of cookies. As the diameter of cookies increased the compression force applied to the cookies decreased substantially from 4437.6 to 2657.6 g.

Correlation analysis among the quality parameters of flour fractions

A correlation matrix was developed using distilled water SRC, sodium carbonate SRC, sucrose SRC, lactic acid SRC, AWRC, damaged starch and spread ratio (Table 4). Significant positive correlations were observed among different SRC. Correlation analysis indicated positive correlation between sodium carbonate SRC and distilled water SRC ($r=0.978$), AWRC ($r=0.970$) and lactic acid SRC ($r=0.968$). Damaged starch also showed strong positive correlation with sodium carbonate SRC ($r=0.723$) and AWRC ($r=0.659$). Thus, increase in damaged starch content increased the sodium carbonate SRC and AWRC values. Cookies spread ratio reported negative correlations with sodium carbonate SRC ($r=-0.921$), distilled water SRC ($r=-0.880$), lactic acid SRC ($r=-0.850$), AWRC and damaged starch ($r=-0.826$) and comparatively less significant correlation with sucrose SRC ($r=-0.777$). The results were in concordance with several authors who reported negative

Table 4 Effect of flour fractions on quality parameters of cookies

Flour Fractions	Thickness (mm) (T)	Diameter (mm) (D)	Spread Ratio (D/T)	Compression Force (g)
Wheat Variety 'WH542'				
Control	10.8 $\pm$ 0.05e	80.5 $\pm$ 0.02c	7.4 $\pm$ 0.04c	3656.4 $\pm$ 2.12e
$>150 \mu\text{m}$	9.9 $\pm$ 0.04d	85.9 $\pm$ 0.05g	8.6 $\pm$ 0.03d	3183.3 $\pm$ 1.15c
100–150 μm	10.9 $\pm$ 0.06f	80.4 $\pm$ 0.04b	7.3 $\pm$ 0.04b	3851.6 $\pm$ 1.51f
$<100 \mu\text{m}$	11.5 $\pm$ 0.01g	77.3 $\pm$ 0.04a	6.7 $\pm$ 0.02a	4437.6 $\pm$ 1.56h
Wheat Variety 'C 306'				
Control	8.9 $\pm$ 0.04b	85.8 $\pm$ 0.02f	9.5 $\pm$ 0.05f	3028.4 $\pm$ 3.23b
$>150 \mu\text{m}$	8.5 $\pm$ 0.03a	86.8 $\pm$ 0.03h	10.1 $\pm$ 0.03g	2657.6 $\pm$ 2.55a
100–150 μm	9.7 $\pm$ 0.05c	85.4 $\pm$ 0.02e	8.8 $\pm$ 0.06e	3464.6 $\pm$ 3.05d
$<100 \mu\text{m}$	10.9 $\pm$ 0.03f	80.6 $\pm$ 0.05d	7.4 $\pm$ 0.04b,c	4286.2 $\pm$ 1.58g

^a The values are mean $\pm$ S.D. of determinations made in triplicates. Values followed by different letters are significantly different at 5% level of significance ($P<0.05$)

Fig 2 Principal component analysis of various physicochemical parameters of wheat varieties. *DWSRC* distilled water SRC; *SCSRC* sodium carbonate SRC; *SSRC* sucrose SRC; *LASRC* lactic acid SRC; *AWRC* alkaline water retention capacity; *DS* damaged starch; *SR* spread ratio; *WG* wet gluten; *FN* falling number

correlations between AWRC and spread ratio (Leon et al. 1996; Kissel and Lorenz 1976; Abboud et al. 1985). Guttieri et al. (2001) found that cookie diameter and top grain score is negatively correlated with sodium carbonate, sucrose, and lactic SRC.

Principal component analysis

Principal component analysis of the solvent retention capacities, protein content, falling number, damaged starch and spread ratio was carried out. According to the computed eigen values, only two out of nine principal components were found important as their value was larger than 1, which is usually considered as the criterion of significance. The PCA identified two main factors explaining 95.717% of the

total variability. PC 1 alone explained 83.763% of the total variability while PC 2 explained remaining 11.954% of the total variation (Fig. 2). The plot of PC 1 vs PC 2 loadings showed, along the P1 axis, a strong relationship among the different solvent retention capacities and damaged starch. The spread ratio was the main variable influencing PC 2. Falling number was inversely correlated with the different solvent retention capacities. Spread ratio was inversely correlated with the solvent retention capacities and damaged starch as evident from the loading plot and data given in Table 5. The wet gluten correlated negatively with the solvent retention capacities. It can be concluded that the varieties having higher values for solvent retention capacities and damaged starch are not recommended for cookie making as they result in lower spread ratio.

Conclusion

The study showed the influence of damaged starch content on the quality of flour and cookie and also the relation of the particle size with damaged starch. It was found that damaged starch level increased from 5.14% to 14.79% as the flour particle size decreased. The values of SRC and AWRC of wheat flours increased significantly with increase in damaged starch content. Cookie quality was adversely affected with increase in damaged starch content. It was observed that the effect of the damaged starch content on the cookie quality was variety specific. Thus, damaged starch content could be included in the quality control analysis as an important criterion for determining the cookie making potential of wheat varieties with greater damaged starch inferring poorer cookies. From the study it was concluded that wheat flour of particle size greater than 150 μm produced cookies with best quality.

Table 5 Correlation coefficients among various quality parameters of flour fractions of wheat varieties

	H ₂ O SRC	SCSRC	SSRC	LASRC	AWRC	DS	SR
H ₂ O SRC	1						
SCSRC	0.978**	1					
SSRC	0.932**	0.918**	1				
LASRC	0.943**	0.968**	0.946**	1			
AWRC	0.976**	0.970**	0.899**	0.904**	1		
DS	0.650**	0.723**	0.427*	0.521**	0.659**	1	
SR	-0.880**	-0.921**	-0.777**	-0.850**	-0.826**	-0.826**	1

^a H₂O SRC-distilled water SRC; *SCSRC* sodium carbonate SRC; *SSRC* sucrose SRC; *LASRC* lactic acid SRC; *AWRC* alkaline water retention capacity; *DS* damaged starch; *SR* spread ratio

^b ** Correlation is significant at 0.01 level, * correlation is significant at 0.05 level

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