SİDAS MEDYA
Akademik Gıda® / Academic Food Journal
ISSN Print: 1304-7582, Online: 2146-9377
http://www.academicfoodjournal.com

Akademik Gıda 10(2) (2012) 14-18

Research Paper / Araştırma Makalesi

Effects of Damaged Starch on Physicochemical Properties of Wheat Flour and its Bread Making Potential

Sule Keskin[1], Hazim Ozkaya[2], Secil Turksoy[2]

[1]Abant İzzet Baysal University, Faculty of Engineering and Architecture, Department of Food Engineering, Bolu, Turkey
[2]Ankara University, Faculty of Engineering, Department of Food Engineering, Ankara, Turkey

Received (Geliş Tarihi): 16.03.2012, Accepted (Kabul Tarihi): 20.06.2012
Corresponding author (Yazışmalardan Sorumlu Yazar): sulekeskin12@gmail.com (S. Keskin)
+90 374 254 10 00 +90 374 253 45 58

ABSTRACT

The study was aimed to determine the effects of damaged starch on physicochemical properties of wheat flour and bread making potential. Hard (HRW) and soft wheat (SWW) varieties were either milled after tempering or milled without tempering. Wheat samples were remilled three (RM3) and five (RM5) times with decreasing roll gaps in order to increase the level of damaged starch and physical, chemical and physicochemical properties of flour and quality attributes of bread samples were investigated. The damaged starch content of HRW and non-tempered flour was higher in comparison with other samples. The falling number decreased as the content of damaged starch increased. Farinogram characteristics were negatively affected by increasing damaged starch content. Increasing levels of damaged starch increased bread volume and specific volume but decreased crumb grain and Dallmann value. It was shown that bread made from tempered flour had better than that from non-tempered wheat. The penetrometer value was significantly affected by milling treatments in the tempered samples of SWW and non-tempered samples of HRW.

Key Words: Bread properties, Damaged starch, Penetrometer value, Rheological properties

Zedelenmiş Nişastanın Buğday Ununun Fizikokimyasal Özelliklerine ve Ekmek Yapma Potansiyeline Etkisi

ÖZET

Bu çalışmanın amacı zedelenmiş nişasta miktarının buğday ununun fizikokimyasal özelliklerine ve ekmek yapma potansiyeline etkisini araştırmaktır. Bu amaçla sert (HRW) ve yumuşak (SWW) buğday çeşitleri tavlandıktan sonra ve tavlanmadan öğütülmüştür. Zedelenmiş nişasta miktarını artırmak için değirmenin vals aralıkları daraltılmış, örnekler bu valslerden 3 kez (RM3) ve 5 kez (RM5) geçirilmiştir. Elde edilen unların zedelenmiş nişasta miktarları, bazı kimyasal ve fizikokimyasal özellikleri ile ekmek özellikleri araştırılmıştır. HRW çeşidinin ve tavlanmadan öğütülen unların zedelenmiş nişasta miktarları diğer örneklere göre daha yüksek çıkmıştır. Düşme sayısı zedelenmiş nişasta miktarı arttıkça düşmüştür. Farinogram özellikleri artan zedelenmiş nişasta miktarından olumsuz yönde etkilenmiştir. Zedelenmiş nişasta miktarının artışıyla ekmek hacmi ve spesifik hacim değerleri artarken, ekmek içi yapısı ve Dallmann değerleri düşmüştür. Tavlanmış öneklerden yapılan ekmeklerin tavlanmamış örneklerden yapılanlara göre daha iyi olduğu görülmüştür. Penetrometre değeri üzerine öğütme uygulamasının etkisi SWW çeşidinin tavlanmış örneklerinde, HRW çeşidinin ise tavlanmamış örneklerinde önemli düzeyde bulunmuştur.

Anahtar Kelimeler: Ekmek özellikleri, Zedelenmiş nişasta, Penetrometre değeri, Reolojik özellikler

INTRODUCTION

During milling of wheat, a proportion of starch granules are damaged mechanically. The level of starch damage varies with hardness of wheat kernel, severity of milling and tempering process. Hard wheat grains require more grinding energy than soft wheat grains to reduce endosperm into flour and during this milling process larger number of starch granules becomes physically damaged [1-4]. These granules hydrate more easily during dough preparation. Therefore, the level of starch damage affects the water absorption and dough mixing properties and is of technological significance [5]. Farrand [6] reported that while undamaged starch granules absorbs 30% water at 30°C, damaged starch granules can absorb water as much as its own weight at the same temperature. Intact granules have strong interchain bonds in the crystalline zone. Therefore, water enters only in the amorphous zone. Upon distribution of the crystalline regions, water gains access to the whole granule [7].

Starch damage has been recognized as one of the important factors affecting bread texture. Excessive starch damage negatively affects bread quality causing formation of slacking dough and sticky crumb texture while the reverse causes low volume and heavy texture [1, 6-9]. Certain level of starch damage is desirable because it optimizes hydration and promotes fermentation activity during bread making. Barrera et al. [4] also explained that in formulas containing little or no added sugar, damaged starch levels should be high enough for good yeast gas production to occur, but not so high that dough handling problems are encountered. Damaged starch granules are susceptible to diastatic enzymes and increase gassing power of dough during fermentation. The gassing power of dough affects directly the quality of bread or oven products since the production of CO_2 is necessary for swelling of bread and crumb texture [2, 10-13]. Therefore, the aim of the present study was to investigate physicochemical, chemical and rheological properties of wheat flour containing different amount of damaged starch by decreasing roll gaps during milling. The influence of damaged starch on the quality of bread was also investigated.

MATERIALS and METHODS

Preparation of Materials

Two wheat cultivars, soft white winter (SWW) and hard red winter (HRW) with the physical and chemical properties given in Table 1 were used in this study. The wheat samples were obtained from the Research and Application Farm of Ankara University, Faculty of Agriculture (Ankara, Turkey). The soft and hard wheat samples (5 kg) were milled without tempering (NT) or with tempering (T) to 15.5% and 17.0% moisture respectively in a Buhler laboratory mill (Buhler Bros. Inc., Uzwil, Switzerland). The flour sample obtained from the first milling was used as a control (RM0). Then, in order to increase the content of damaged starch, the tempered and non-tempered samples from both wheat cultivars were remilled three (RM3) or five times (RM5) by decreasing roll gaps.

Table 1. Some physical and chemical properties of wheat samples*

Sample	Test weight (kg/hL)	1000 kernel weight (g, db)	Vitreousness (%)		Kernel size (%)	Flour yield (%)		Protein (%, Nx5.7, db)	Ash (%, db)
			Vitreous	Mealy	>2.8mm	T	NT		
SWW	78.2	35.8	14	86	86.3	65.1	68.1	11.1	1.56
HRW	80.5	33.6	87	13	74.9	65.6	67.7	14.3	1.57

*:T: Tempered wheat; NT: Non-tempered wheat, db: dry basis.

Tests on Wheat and Flour Samples

The test weight was determined by using an Ohaus test weight apparatus and reported on 'as is' moisture basis. The 1000 kernel weight was determined by counting the number of seeds in 20 g of grain and reported on dry basis. Kernel vitreousness was determined by using Grobecker apparatus. Flour yield of the wheat samples were done according to Standard Methoden für Getreide Mehl und Brot [14]. Moisture and ash contents, sedimentation values, falling number and farinogram properties of the samples were determined using ICC Standard Methods [15]. Dry gluten contents were determined according to Greenaway and Watson [16]. AACC Approved Methods were used for the determination of protein and damaged starch contents of the flours [17].

Preparation of Bread

Bread making and evaluation of bread samples were carried out using the methods as described in Standard Methoden für Getreide Mehl und Brot [14]. Ingredients (on flour basis) used in bread formula were as follows: 5.0% pressed yeast, 1.5% salt, 1.0% sugar, 1.0% fat and water, adjusted according to the farinograph water absorption. All ingredients were mixed for 1 min (1400 rpm/min). The dough was fermented at 32°C for 20 min. The dough was degassed and fermented for further 10 min. Then it was scaled into four 400 g portions, rounded manually and kept at 32°C and 80 ± 5% RH for 30 min. The dough pieces were baked at 225 ± 5°C for 25 min. Penetrometer values of each slice of bread were determined at five different points using a Sur penetrometer PNR-6 with 218 g of total test weight 24 h after removing from oven.

Statistical analysis

All analyses were done in duplicates. Data obtained were subjected to three-way analyses of variance (ANOVA) using SPSS statistical software (SPSS for

Windows, release 11.0.0, SPSS, Chicago, IL, USA). Duncan's multiple range tests was used to determine the differences among means ($p<0.05$).

RESULTS and DISCUSSION

The effect of wheat cultivar, tempering process and milling treatment on the chemical and physicochemical properties of flour samples are presented in Table 2. The damaged starch content of hard wheat flour and non-tempered wheat flour samples were higher than that of soft wheat flour and tempered wheat flour samples ($p<0.05$). The non-tempered samples of HRW had the highest damaged starch content (10.66%). Flour obtained from hard wheat had a higher content of damaged starch because hard wheat grain offered higher resistance to milling. Grain hardness was influenced by the degree of sticking between starch granules and protein. Soft wheat has lover sticking degree, thus tend to release starch granules more freely during milling and therefore starch granules less damages [18]. D'Appolonia et al. [10] also explained that flours from hard wheat have more damaged starch when hard and soft wheat are ground to same fineness. In addition, the tempering process is one of the main factors affecting the level of damaged starch [19]. Tempering is the process of adding water to wheat before milling to toughen the bran and mellow the endosperm of the kernel [20]. Starch granules exposed to more damage in the non-tempered samples because the endosperm is not mellow. Milling treatment increased gradually the damaged starch content of the flour samples ($p<0.05$). However, this increase was more prominent in the tempered wheat flour samples for both wheat varieties. In the non-tempered samples, most of the starch was damaged already at the beginning of milling process for both wheat varieties (RM0). This situation might result from higher endosperm brittleness in the non-tempered wheat.

Table 2. The effects of wheat cultivar, tempering process and milling treatment on some chemical and physicochemical properties

Sample	Milling treatment	Damaged starch* (%, db)		Ash (%, db)		Protein (%, Nx5.7, db)		Dry Gluten (%)		Sedimentation Value (mL, 14% mb)		Falling Number (sn, 15% mb)	
		T	NT	T	NT	T	NT	T	NT	T	NT	T	NT
	RM0	5.82^{cBy}	6.56^{cAy}	0.42^{Bx}	0.50^{Ax}	9.6^{y}	9.6^{y}	8.53^{y}	8.50^{y}	21.17^{Ay}	16.70^{bBy}	430^{aBy}	446^{aAy}
SWW	RM3	6.61^{bBy}	7.38^{bAy}	0.43^{Bx}	0.50^{Ax}	9.5^{y}	9.5^{y}	8.47^{y}	8.55^{y}	21.38^{Ay}	18.14^{abBy}	426^{abAy}	436^{bAy}
	RM5	7.41^{aBy}	7.87^{aAy}	0.42^{Bx}	0.50^{Ax}	9.6^{y}	9.5^{y}	8.47^{y}	8.50^{y}	21.37^{Ay}	18.83^{aBy}	417^{bAy}	430^{bAy}
	RM0	7.91^{cBx}	9.92^{cAx}	0.40^{Bx}	0.49^{Ax}	13.2^{x}	13.2^{x}	12.14^{x}	12.45^{x}	40.37^{Ax}	35.29^{Bx}	798^{aAx}	749^{aBx}
HRW	RM3	8.69^{bBx}	10.33^{bAx}	0.40^{By}	0.50^{Ax}	13.2^{x}	13.1^{x}	12.29^{x}	12.45^{x}	40.98^{Ax}	34.72^{Bx}	798^{aAx}	730^{bBx}
	RM5	9.51^{aAx}	10.66^{aAx}	0.42^{Bx}	0.49^{Ax}	13.2^{x}	13.2^{x}	12.55^{x}	12.58^{x}	41.44^{Ax}	35.02^{Bx}	746^{bAx}	728^{bAx}

*Values followed by different lower case letters (a-c) in the same column indicate significant differences among the starch damage process ($p<0.05$). Values followed by different uppercase letters (A-B) in the same row indicate significant differences between the tempering process ($p<0.05$). Values followed by different lower case letters (x-y) in the same column indicate significant differences between the wheat cultivars ($p<0.05$). SWW: Soft white wheat; HRW: Hard red wheat; T: Tempered; NT: Non-tempered; RM0: Control; RM3: Remilled three times; RM5: Remilled five times, db: dry basis, mb: moisture basis.

Ash content in the non-tempered samples was higher than in the tempered samples for both wheat varieties ($p<0.05$). In the non-tempered samples, wheat bran was not resistive. Therefore, bran was broken into small pieces and mixed with endosperm during the milling, resulting in increased ash content. Tempering process and milling treatment did not affect the content of protein. Dry gluten content was not influenced by tempering and milling treatment. In a previous work [4], it was found that protein and wet gluten content did not show significant differences among different starch damaged content. Sedimentation value was affected significantly by wheat cultivar and tempered process ($p<0.05$), as a result hard wheat flour and the tempered flour samples had higher sedimentation values. Generally, the effect of milling treatment on sedimentation value was insignificant. Falling number value of HRW was higher than SWW. Tempering process also influenced falling number ($p<0.05$). Differences between the tempered and non-tempered controls for SWW and tempered and non-tempered controls, tempered RM3 and non-tempered RM3 for HRW were statistically significant ($p<0.05$). Milling treatment decreased falling number ($p<0.05$). Leon et al. [3] also found that the falling number value deceased as the damaged starch content increased because of high amount of granules available to amylase action.

Farinogram properties of the flour samples are shown in Table 3. Milling treatment slightly affected the water absorption content of both wheat cultivars ($p<0.05$). There was insignificant effect of milling treatment on water absorption of non-tempered samples but it was slightly higher than that of tempered ones ($p<0.05$). However, water absorption of HRW was significantly ($p<0.05$) higher than that of SWW. Milling treatment decreased dough development time of RM5 samples. Dough development time and stability were higher in the HRW flour samples than SWW. The effect of tempering process was shown on the HRW samples and development time was found higher tempered samples of HRW than non-tempered samples ($p<0.05$). RM5 sample of SWW was also influenced from tempering process ($p<0.05$). The effect of milling treatment on stability was shown only tempering samples of HRW. Similar results found by Rao et al. [21]. The stability values of the tempered samples was higher than in the non-tempered samples in both wheat varieties ($p<0.05$). The main effects of wheat cultivar, tempering and milling treatment were found statistically significant on the mixing tolerance index ($p<0.05$). The means of SWW and HRW was determined as of 142.5 and 130.0, respectively. The means of mixing tolerance index for tempering samples was 128.3 and non-tempering samples was 144.2. Milling treatment created significant differences between RM0 and RM3. Wheat cultivar and tempering process influenced softening degree. HRW samples and non-tempered samples had higher value than SWW and tempered samples, respectively. Tempering process influenced significantly the valorimeter value of HRW but not that of SWW (p<0.05). Milling treatment also affected valorimeter value of HRW. In addition, valorimeter value of HRW was significantly (p<0.05) higher than that of SWW.

Table 3. The effects of wheat cultivar, tempering process and milling treatment on the farinograph properties of the flour samples

Sample	Milling treatment	Water absorption* (%)		Devolopment time (min)		Stability (min)		Mixing tolerance index (BU)		Softening degree (BU)		Valorimeter value	
		T	NT	T	NT	T	NT	T	NT	T	NT	T	NT
	RM0	53.6^{bBy}	56.4^{Ay}	2.0^{Ay}	2.0^{aAy}	3.0^{Ay}	2.4^{By}	130^{bBy}	145^{bAy}	170^{Ay}	180^{Ay}	30^{Ay}	28^{Ay}
SWW	RM3	55.4^{aBy}	56.6^{Ay}	2.0^{Ay}	2.0^{aAy}	3.0^{Ay}	2.5^{By}	140^{aBy}	150^{aAy}	170^{By}	190^{Ay}	28^{Ay}	28^{Ay}
	RM5	55.8^{aBy}	56.6^{Ay}	$2.1^{A\ y}$	1.5^{bBy}	3.0^{Ay}	2.5^{By}	140^{aBy}	150^{aAy}	170^{By}	190^{Ay}	28^{Ay}	27^{Ay}
	RM0	58.6^{cBx}	61.1^{Ax}	5.0^{aAx}	3.5^{aBx}	6.0^{bAx}	3.5^{Bx}	110^{cBx}	130^{cAx}	280^{Bx}	320^{Ax}	48^{aAx}	44^{aBx}
HRW	RM3	59.6^{bBx}	61.1^{Ax}	5.0^{aAx}	3.5^{aBx}	6.5^{aAx}	3.5^{Bx}	120^{bBx}	140^{bAx}	280^{Bx}	330^{Ax}	45^{bAx}	32^{bBx}
	RM5	60.2^{aBx}	61.0^{Ax}	4.5^{bAx}	3.0^{bBx}	5.0^{cAx}	3.5^{Bx}	130^{aBx}	150^{aAx}	280^{Bx}	330^{Ax}	44^{bAx}	32^{bBx}

*Values followed by different lower case letters (a-c) in the same column indicate significant differences among the starch damage process (p<0.05). Values followed by different uppercase letters (A-B) in the same row indicate significant differences between the tempering process (p<0.05). Values followed by different lower case letters (x-y) in the same column indicate significant differences between the wheat cultivars (p<0.05). SWW: Soft white wheat; HRW: Hard red wheat; T: Tempered; NT: Non-tempered; RM0: Control; RM3: Remilled three times; RM5: Remilled five times, BU: Brabender Unit.

Properties of the bread samples are given in Table 4. Bread volume and specific volume, which are among the most important bread properties, were higher in the tempered samples of HRW than SWW, in reverse to those in the non-tempered samples. Volume was lower in the non-tempered samples than in the tempered samples. In addition, starch damage resulted in a slight increase in bread volume and spesific volume ($p<0.05$). The lowest bread volume and specific volume were seen in the non-tempered samples of HRW. Crumb grain was negatively influenced by increased damaged starch content ($p<0.05$). In addition, tempering process affected crumb grain and the tempered samples had higher scores than the non-tempered samples (p<0.05). The increasing in the bread volume originated from coarsen crump grain that result of increasing damaged starch level. Dallmann values, which is calculated in accordance with bread volume and crumb properties [14], were found higher in the tempered samples of HRW and non-tempered samples of SWW (p<0.05). While Dallmann values were negatively affected by milling treatment, they were positively affected by the tempering process (p<0.05). As shown in Table 4, the effect of tempering process was obvious especially for the bread samples of HRW. Although bread volume slightly increased, Dallmann value decreased because of broken crumb grain and texture characteristics. Barrera et al. [4] also explain that high level of damaged starch reduce baking characteristics. They informed that the negative effect of damaged starch on the bread quality might be explained by the competition for the water between damaged starch and protein that prevents optimum gluten formation during mixing. Penetrometer values that show staling of bread were higher in the samples of HRW compared to SWW and in the tempered samples compared to the non-tempered ones (p<0.05). Furthermore, milling treatment only influenced tempered samples of SWW and non-tempered samples of HRW (p<0.05) (Table 4). Leon et al. [3] also reported bread crumb firmness increased with increasing damaged starch levels.

Table 4. The effects of wheat cultivar, tempering process and milling treatment on the bread properties and the penetrometer value of the bread samples

Sample	Milling treatment	Loaf volume (mL/100g flour)		Specific volume		Crump grain		Dallmann value		Penetrometer	
		T	NT	T	NT	T	NT	T	NT	T	NT
	RM0	507.5^{cAy}	493.3^{cBx}	3.63^{bAy}	3.43^{bBx}	80.0^{aAy}	70.0^{aBx}	152.1^{aAy}	134.0^{aBx}	50^{aAx}	39^{By}
SWW	RM3	521.7^{bAy}	512.3^{bAx}	3.70^{abAx}	3.51^{bBx}	75.0^{bAy}	70.0^{aBx}	140.6^{bAy}	119.3^{bBx}	40^{bAy}	37^{Ax}
	RM5	535.6^{aAy}	532.8^{aAx}	3.77^{aAx}	3.65^{aAx}	65.0^{cAy}	65.0^{bAx}	119.1^{cAy}	113.2^{cBx}	39^{bAy}	37^{Ay}
	RM0	529.7^{cAx}	467.3^{bBy}	3.70^{bAx}	3.12^{bBy}	85.0^{aAx}	60.0^{aBy}	174.8^{aAx}	95.2^{aBy}	54^{Ax}	53^{aAx}
HRW	RM3	538.8^{bAx}	501.2^{aBy}	3.74^{abAx}	3.39^{aBy}	80.0^{bAx}	55.0^{bBy}	155.5^{bAx}	87.8^{bBy}	53^{Ax}	47^{bBx}
	RM5	554.8^{aAx}	502.3^{aBy}	3.80^{aAx}	3.39^{aBy}	70.0^{cAx}	45.0^{cBy}	139.2^{cAx}	66.2^{cBy}	50^{Ax}	46^{bBx}

*Values followed by different lower case letters (a-c) in the same column indicate significant differences among the starch damage process (p<0.05). Values followed by different uppercase letters (A-B) in the same row indicate significant differences between the tempering process (p<0.05). Values followed by different lower case letters (x-y) in the same column indicate significant differences between the wheat cultivars (p<0.05). SWW: Soft white wheat; HRW: Hard red wheat; T: Tempered; NT: Non-tempered; RM0: Control; RM3: Remilled three times; RM5: Remilled five times.

CONCLUSIONS

From the result of this study it can be concluded that starch damage is higher in hard wheat than soft wheat when milled under the same condition. This should be taken into consideration when choosing appropriate milling conditions and tempering regimes. In the case of non-tempered wheat, the levels of damaged starch increased. This effect was more pronounced in hard wheat. This result confirmed the importance of tempering process in milling. Farinogram characteristics were negatively affected by starch damage. Although higher content of damaged starch slightly increased the volume of bread loaves, it declined crumb grain and texture characteristics. As a result, increasing levels of damaged starch had negative effect on the overall bread quality.

REFERENCES

[1] Evers, A.D., Stevens, D.J., 1985. Starch damaged. In: Advances in Cereal Science and Technology, Edited by. Y Pomeranz, AACC, St. Paul, MN, USA, pp 321-347.

[2] Leman, P., Bijttebier, A., Goesaert, H., Vandeputte, G.E., Delcour, J.A., 2006. Influence of amylases on the rheological and molecular properties of partially damaged wheat starch. *J. of the Sci of Food and Agric.* 86: 1662-1669.

[3] Leon, A.E., Barrera, G.N., Perez, G.T., Ribotta, P.D., Rosell, C.M, 2006. Effect of damaged starch levels on flour-thermal behaviour of bread stailing. *Eur. Food Res. Technol.* 224: 187-192.

[4] Barrera, G.N., Perez, G.T., Ribotta, P.D., Leon, A.E., 2007. Influence of damaged starch on cookie and bread-making quality. *Eur. Food Res. Technol.* 225: 1-7.

[5] Ghodke, S.K., Ananthanarayan, L., Rodrigues, L., 2009. Use of response surface methodology to investigate the effects of milling conditions on damaged starch, dough stickiness and chapatti quality. *Food Chem.* 112: 1010–1015.

[6] Farrand, E.A., 1972. The influence of particle size and starch damage on the characteristics of bread flours. *The Baker's Dig.* 46: 22-26.

[7] Mao, Y., Flores, R., 2001. Mechanical starch damage effects on wheat flour tortilla texture. *Cereal Chem.* 78: 286-293.

[8] Özkaya, B., Özkaya, H., 1994. Öğütme sırasındaki nişasta zedelenmesi ve ekmekçilikteki önemi. *1. Türkiye Değirmencilik Sanayi ve Teknolojisi Sempozyumu*, 10-11 Mayıs, 1994, Konya 118-121s.

[9] Rogers, D.E., Gelroth, J.A., Langemeier, J.M., Ranhotra, G.S., 1994. Evaluation of starch damage value determined enzymatically or amperometrically. *Cereal Chem.* 71: 578-581.

[10] D'Appolonia, B.L., Gilles, K.A., Osman, E.M., Pomeranz, Y., 1971. Carbohydrates. In: Wheat Chemistry and Technology, Edited by Y. Pomeranz, AACC,St. Paul, MN, USA, pp 301-392.

[11] Pomeranz, Y., Shellenberger, J.A., 1971. Bread Science and Technology. The Avi Publishing Co. Inc. Wesport Connecticut.

[12] Pyler, E.J., 1973. Bakery Science and Technology. Vol. I. Published by Siebel Publishing Co. Chicago IL. USA.

[13] Ranhotra, G.S., Gelroth, J.A., and Eisenbraun, G.J., 1993. Correlation between Chopin and AACC methods of determining damaged starch. *Cereal Chem.* 70: 236-237.

[14] Anonymous, 1971. Standard Methoden Fur Getreide Mehl Und Brot, Im. Verlag Moritz, Scheafer, Detmold.

[15] ICC, 2002. Standard Methods of International Association of Cereal Science and Technology, (Method No: 104; 106; 107; 110; 115; 116), Vienna

[16] Greenaway, W.T., Watson, C.A., 1975. The glutomatic for semiautomatic determination of wet and dry gluten content of wheat flour. *Cereal Chem.* 52: 367-373.

[17] AACC, 2000. Approved methods of the American Association of Cereal Chemist, (Method No: 46-10; 76-30A), 10th ed. The Association: St Paul, MN.

[18] Maghirang, E.B., Dowell, F.E., 2003. Hardness measurement of bulk wheat by single-kernel visible and near-infrared reflectance spectroscopy. *Cereal Chem.* 80: 316-322.

[19] Williams, P.C., 1969. Nature of mechanically damaged starch. Its production in flour. *Northwestern Miller* 276: 8-12.

[20] Kweon, M., Martin, R., Souza, E., 2009. Effect of tempering conditions on milling performance and flour functionality. *Cereal Chem.* 86: 12-17.

[21] Rao, P.H., Leelavahi, K., Shurpalekar, R., 1989. Effect of damaged starch on the chapatti-making qualityof whole wheat flour. *Cereal Chem.* 66:329-333.