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Research Article

Crumb pasting and staling properties of white and traditional Vakfıkebir breads

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Abstract: The crumb pasting properties of Vakfıkebir bread (VB) produced by the sourdough method traditionally and standard white bread (WB) produced by the straight dough method were investigated. For both bread types, 2 different weights of loaf were produced (500 and 1500 g). One hour after removal from the oven the loaves were wrapped in 2-layer polyethylene bags and stored at room temperature (about 20 °C) for 5 days. During storage, crumb and crust aw, pH, softness, and pasting properties of bread crumb were determined for both bread types. The aims of this study were to compare the crumb pasting properties of VB and WB and to determine the causes of changes during storage. No previous study has examined the pasting properties of any sourdough bread crumb. The pH value of bread crumb exhibited a significant positive correlation with softness (r = 0.87) and bump area (r = 0.89), and a negative correlation with pasting temperature (r = -0.62) and peak viscosity (r = -0.48). In addition, the pasting properties of VB were completely different from those of WB.

Key words: Vakfıkebir bread, sourdough, water activity, pH, softness, crumb pasting properties

Beyaz ve geleneksel Vakfıkebir ekmeklerinin ekmek içi çirişlenme ve bayatlama özellikleri

Özet: Bu çalışmada geleneksel ekşi hamur metoduyla üretilen Vakfıkebir ekmeği (VE) ve direkt hamur metoduyla üretilen standart Beyaz ekmeğin (BE) ekmek içi çirişlenme özellikleri araştırılmıştır. Her iki ekmek tipi için iki farklı ağırlıkta (500 ve 1500 g) somunlar üretilmiştir. Somunlar fırından çıkarıldıktan 1 saat sonra çift katlı polietilen poşetlere konulmuş ve oda sıcaklığında (yaklaşık 20 °C) 5 gün süreyle depolanmıştır. Depolama süresince; her iki ekmek tipi için ekmek içi ve kabuğunun su aktivitesi, pH, yumuşaklık ve çirişlenme özellikleri tespit edilmiştir. Bu çalışmanın amacı VE ve BE ekmek içi çirişlenme özelliklerini karşılaştırmak ve depolama esnasında bu ekmeklerin çirişlenme özelliklerinin nasıl değiştiğini saptamaktır. Ekşi hamur ekmeği içinin çirişlenme özellikleri üzerine yapılmış bir çalışma yoktur. Ekmek içi pH değeri; çirişlenme sıcaklığı (r = -0,62) ve pik viskozitesi (r = -0,48) ile negatif ilişki gösterirken ikinci pik alanı (r = 0,89) ve yumuşaklık (r = 0,87) ile pozitif ilişki sergilemiştir. Buna ilaveten, Vakfıkebir ekmeğinin ekmek içi çirişlenme özelliklerinin beyaz ekmeğinkinden çok farklı olduğu görülmüştür.

Anahtar sözcükler: Vakfıkebir ekmeği, ekşi hamur, su aktivitesi, pH, yumuşaklık, ekmek içi çirişlenme özellikleri

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Introduction

Bakery products are the most important type of processed food worldwide and of these the product consumed most is bread (Azizi and Rao, 2004). Bread has a shorter shelf life than most other processed foods. Bread's sensorial freshness properties such as flavor and texture decline discernibly during storage. Therefore, bread is rejected by the consumer, even though it has no potential harmful effects on human health. Therefore, the limited shelf life of bread results in financial losses of billions of dollars worldwide per year (Baik and Chinachoti, 2000; Ribotta et al., 2004; Karaoğlu, 2006a). For that reason, bread staling has been widely investigated for a long time in order to solve this problem. However, the mechanism of bread staling is an extremely complex phenomenon and is not yet fully understood. Broadly speaking, staling is connected with all changes that occur in bread after baking, except microbiological spoilage.

One of the most discernible changes in bread occurs in the starch fraction of the crumb during staling. Schoch and French (1947) suggested that bread staling was closely associated with starch retrogradation. It is generally accepted that starch retrogradation is one of the major factors in bread staling, but it cannot be the only factor (Chen et al., 1997; Baik and Chinachoti, 2000; Gray and Bemiller, 2003; Ribotta et al., 2004).

The use of sourdough in the preparation of bread has a positive effect on bread volume, crumb structure, flavor, and mold-free shelf life (Corsetti et al., 1998; Corsetti et al., 2000; Clarke et al., 2004; Katina et al., 2006). Sourdough bread is the oldest and the most original form of leavened bread. It is reported that sourdough has been used in bread making since 3000 BC. In today's bread making technology, the aim of sourdough usage is to improve texture and aroma characteristics and to lengthen the shelf life of breads (Hansen and Schieberle, 2005; Kotancılar et al., 2008). Katina (2005) reported that the rate of starch retrogradation is lower for sourdough breads.

It is well known that bread firmness increases or bread softness decreases during storage. It was reported that the acidification by sourdough lactic acid bacteria and these bacteria's activities, including proteolysis of gluten and hydrolysis of starch, had a positive effect in delaying both bread firmness and staling (Corsetti et al., 1998). Acidification was related to the improved softness, as the pH of sourdough correlated positively with firmness values (Katina et al., 2006). Singh et al. (2002) stated that acetic and lactic acids are used in bread formulation to improve the shelf life of bread.

Vakfıkebir bread (VB), a kind of sourdough bread, is unique to Trabzon province in the Black Sea region of Turkey. Besides being made by the sourdough method, the features of this bread are as follows: a thick and hard outer crust, big pores, a long processing time and high tolerance, rich aroma, high quality, high volume and weight, late staling, and long baking time (Kotancılar et al., 1998).

Several studies have suggested that the amylograph could be used for investigating the staling of bread (Banecki, 1972; Kim and D'Appolonia, 1977; Morad and D'Appolonia, 1980; Karaoğlu, 2006a). However, no studies have been reported on the pasting properties of sourdough bread crumb. The first aim of this study was to analyze changes in the pasting properties of VB sourdough bread during storage.

Materials and methods

Materials

Wheat flour (15.1% water, 12.1% protein, 0.54% ash, 28.5% gluten, and 60.2% water absorption), fresh baker's yeast, and salt were obtained from the local market.

Production of VB

VB was baked using traditional procedures. In order to produce VB, a piece of dough remaining from the first batch was incubated at 25 °C for 15 h and used as the first sourdough. The first sourdough was supplemented with 2.5 times flour and 45% tap water based on flour and kneaded for 20 min to create the second sourdough. During the main dough preparation, 10 kg of the second sourdough was mixed with 2.2 kg of salt, 100 kg of flour, 60 kg of water (28 °C) and 1 kg of compressed baker's yeast, and kneaded for 20 min. The main dough was fermented at 75% RH for 130 min. The main dough prepared was divided into 550- and 1650-g pieces to obtain 500- and 1500-g loaves and the dough was rounded by hand. The rounded dough was fermented at 25 °C for 100 min in plastic bowls whose inner surface was covered with cloth. After the final fermentation, 550- and 1650-g dough pieces were traditionally decorated and baked at 175 ± 5 °C for 30 and 90 min, respectively.

Production of white bread (WB)

WB was produced by the straight dough method, in which 100 kg of flour, 63 kg of tap water, 1.3 kg of salt, and 5 kg of baker's yeast were mixed and kneaded for 40 min. The dough was rested for bulk fermentation at 75% RH and 25 °C for 10 min. The dough prepared was divided into 550- and 1650-g pieces for 500- and 1500-g loaves and rounded by hand. The rounded bread dough was fermented at 75% RH and 25 °C for 100 min as the final fermentation. Then 550- and 1650-g dough pieces were baked at 175 ± 5 °C for 20 and 40 min, respectively.

Water activity (a_w) and pH measurements: Water activity values of the crumb and crust were measured using a NOVASINA AW sprint TH-500 (Pfäffikon, Switzerland). pH measurements of the crumb were performed according to Elgün et al. (2002) with some modifications. Bread crumb (10 g) was suspended in 100 mL of distilled water and the suspension was homogenized using an Ultra-Turrax TP 18/10 (Janke & Kunkel, IKA Werk Staufen, Germany) at 2000 rpm for 1 min and then pH values were measured using a pH meter (INOLAB pH 720, WTW, Weilheim, Germany).

Measurement of bread crumb softness: Bread crumb softness was measured using a penetrometer (PNR-10 Penetrometer, Petrotest Instruments Gmbh & Co. KG, Dahlewitz, Germany) (Karaoğlu, 2006a). Two slices of 27 mm were taken from both sides of centre slice of the loaf and each sample was compressed at 6 points by 54.6-g conical probe for 5 s. The measurement data for the 6 points from each slice were averaged and the compressibility value is expressed as penetrometer unit (PU) [1 PU = 0.1 mm].

Pasting properties of bread crumb: The pasting properties of VB and standard WB crumb were determined on a Brabender amylograph (model 8101; Brabender, Duisburg, Germany) (Karaoğlu, 2006a). The bread crumb was removed from the loaf and freeze-dried on a freeze-dryer (Hetosicc, CD 2.5; Heto Co., Allerod, Denmark). It was then ground in a Wiley mill (Brabender) and crumb powder was passed through a 60-mesh sieve. The sample (55 g) was suspended in 350 mL of distilled water. The suspension was agitated using a Waring blender (Bright BR-A750, China) at low speed for 1 min to obtain homogeneity. The suspension was poured into the amylograph bowl and the blender was rinsed into the bowl with 100 mL of additional distilled water. The crumb suspension was heated from 30 to 95 °C and held at 95 °C for 15 min and then cooled to 50 °C. Pasting temperature, bump area, and viscosity (peak, holding end, and cooling end) were calculated from the amylograph curve according to Karaoğlu (2006a). Bump area was calculated using a planimeter.

Statistical analysis

All the experiments were carried out in triplicate and in 2 different trials. All statistical analyses were performed with SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA, 2004). The effect of storage time (0, 1, 2, 3, 4, and 5 days), type of bread (VB and WB) and loaf weight (500 and 1500 g) were tested for significance using analysis of variance (ANOVA). Differences among the mean values were tested using Duncan's multiple range test ($P < 0.05$). All the data are presented as the mean ± standard error (mean ± SE).

Results

The effects of loaf weight and storage time on water activity, pH, and softness values of VB are presented in Table 1. Crumb a_w slightly decreased while crust a_w greatly increased ($P < 0.01$) during storage for both loaf weights of VB. During storage the increase in crust a_w in the 1500-g VB was greater than that in the 500-g VB. Czuchajowska and Pomeranz (1989) reported that water activity slightly decreased in the center of the crumb while water activity of the crust increased rapidly during the first 24 h and slowly thereafter. pH values of the 500-g VB increased while those of the 1500-g VB slightly decreased as storage time increased. Softness values for both VB loaves gradually decreased with increasing storage time, but the decreases were not statistically significant.

Table 1. Effects of loaf weight and storage time on some crumb and crust properties of Vakfıkebir bread (mean ± standard error).

Loaf Weight (g)	Storage Time (day)	n	Crumb a_w	Crust a_w	Crumb pH	Crumb Softness (PU)
500	0	2	0.967 ± 0.000 ab	0.925 ± 0.003cd	4.46 ± 0.01 cd	14.00 ± 0.00 a
	1	2	0.966 ± 0.001 cd	0.926 ± 0.002b	4.48 ± 0.02 bc	12.20 ± 0.80 a
	2	2	0.965 ± 0.001 def	0.931 ± 0.003bc	4.54 ± 0.01 ab	11.30 ± 0.60 a
	3	2	0.964 ± 0.001 fg	0.937 ± 0.003ab	4.42 ± 0.01 de	10.45 ± 1.75 a
	4	2	0.962 ± 0.001 i	0.936 ± 0.002ab	4.48 ± 0.03 bc	10.20 ± 2.70 a
	5	2	0.962 ± 0.000 hi	0.940 ± 0.001a	4.55 ± 0.02 a	9.45 ± 2.55 a
1500	0	2	0.968 ± 0.000 a	0.879 ± 0.003f	4.43 ± 0.02 cde	16.00 ± 1.00 a
	1	2	0.967 ± 0.000 bc	0.890 ± 0.002e	4.38 ± 0.01ef	13.55 ± 1.55 a
	2	2	0.965 ± 0.000 de	0.897 ± 0.003e	4.38 ± 0.01 ef	11.50 ± 0.50 a
	3	2	0.964 ± 0.000 efg	0.914 ± 0.005d	4.33 ± 0.03 f	11.30 ± 0.00 a
	4	2	0.965 ± 0.001 def	0.922 ± 0.001cd	4.39 ± 0.01 e	11.00 ± 0.90 a
	5	2	0.963 ± 0.000 gh	0.922 ± 0.004cd	4.40 ± 0.04 e	9.80 ± 0.00 a
		P	**	**	**	NS

[a] Means with different letters in the same column are significantly different at P < 0.05,
P: Probability, * P < 0.05, ** P < 0.01. PU, Penetration Units.

The changes in the crumb pasting properties of VB and the effects of bread weight and storage time on them are given in Table 2. The pasting temperature of the 500-g VB decreased, while that of the 1500-g VB did not significantly change as the storage time increased. Bump area increased for the both weights of VB during storage. All of the viscosity values (peak, holding end, and cooling end) significantly increased ($P < 0.01$) with increased storage time.

The loaf weight significantly ($P < 0.01$) affected the crumb a_w, crust a_w, pH, and softness values of WB (Table 3). Crumb a_w of the 500-g WB decreased gradually while the changes in that of the 1500-g WB were not equable during storage. It was observed that the crust a_w increased for both weights with increasing storage time. pH values for both weights also increased as storage time increased. The pH of the 1500-g WB was higher than that of the 500-g loaf. The softness value of WB significantly ($P < 0.01$) decreased with increasing storage time. The 1500-g WB had a higher softness value on day 0 while the lowest value was observed for the 500-g WB on day 5. The decrease in softness for the 500-g WB was greater than that of the 1500-g loaf; it decreased from 125.5 to 45.9 PU.

The pasting properties of WB are presented in Table 4. The changes in pasting temperature values of WB were not stable and were always in the same direction. There was a significant decrease in peak viscosity ($P < 0.01$), holding end viscosity ($P < 0.01$), and cooling end ($P < 0.05$) viscosity of WB with increasing storage time, except for the cooling end viscosity of the 500-g WB.

The effect of bread type, loaf weight, and storage time on crumb water activity (a_w), pH, and softness value of the both VB and WB loaves are shown in Table 5. Bread type had a significant effect ($P < 0.01$) on the water activity of the crumb and crust, and pH and softness values of the crumb. The changes in crumb and crust a_w values of VB and WB loaves were different. Crust a_w of VB was higher than that of WB, while crumb a_w of VB was lower than that of WB. pH values of VB were lower than those of WB, as expected. The softness value of WB was much higher than that of VB. WB had crumb almost 10 times softer than that of VB. Crumb a_w, crust a_w, and softness values of the 1500-g bread were significantly higher ($P < 0.01$) than that of the 500-g bread. pH value of the light bread was lower than that of the heavy bread. During storage, crumb a_w and softness

Table 2. Effects of loaf weight and storage time on the pasting properties of Vakfıkebir bread's crumb on amylograph (mean ± standard error).

Loaf Weight (g)	Storage Time (day)	n	Pasting temperature (°C)	Bump area (cm^2)	Viscosity (BU)		
					Peak	Holding end	Cooling end
500	0	2	90.6 ± 0.30 bc	16.9 ± 0.7 fg	229 ± 1.5 c	225 ± 5.0 d	413 ± 2.5 d
	1	2	90.2 ± 0.25 cd	28.2 ± 2.1 ef	198 ± 7.5 d	210 ± 5.0 e	398 ± 2.5 de
	2	2	89.4 ± 0.05 e	35.4 ± 1.9 cde	282 ± 3.0 a	310 ± 0.0 a	560 ± 0.0 a
	3	2	89.6 ± 0.10 de	30.8 ± 1.0 def	248 ± 2.5 b	283 ± 2.5 b	505 ± 9.5 b
	4	2	89.4 ± 0.10 e	27.6 ± 0.9 ef	243 ± 2.5 bc	271 ± 1.0 c	525 ± 15.0 b
	5	2	89.3 ± 0.05 e	38.5 ± 3.1 bcd	288 ± 7.5 a	311 ± 4.5 a	570 ± 10.0 a
1500	0	2	91.2 ± 0.15 ab	24.2 ± 0.4 fg	140 ± 10.0 g	123 ± 7.5 i	285 ± 15.0 f
	1	2	91.2 ± 0.15 ab	42.3 ± 0.2 bc	150 ± 5.0 fg	143 ± 2.5 h	375 ± 10.0 e
	2	2	91.1 ± 0.25 ab	46.3 ± 0.4 b	173 ± 2.5 e	160 ± 0.0 g	415 ± 0.0 d
	3	2	91.5 ± 0.15 a	43.3 ± 1.2 bc	151 ± 1.0 fg	140 ± 0.0 h	378 ± 2.5 e
	4	2	91.3 ± 0.25 a	36.9 ± 0.7 bcde	159 ± 1.5 ef	155 ± 5.0 g	395 ± 15.0 de
	5	2	91.1 ± 0.25 ab	56.3 ± 8.7 a	189 ± 1.5 d	175 ± 0.0 f	445 ± 5.0 c
		P	**	**	**	**	**

[a] Means with different letters in the same column are significantly different at P < 0.05,
P: Probability, * P < 0.05, ** P < 0.01, NS = not significant. BU, Brabender Units.

Table 3. Effects of loaf weight and storage time on some crumb and crust properties of white bread (mean ± standard error).

Loaf Weight (g)	Storage Time (day)	n	Crumb a_w	Crust a_w	Crumb pH	Crumb Softness (PU)
	0	2	0.973 ± 0.001 a	0.682 ± 0.001 k	6.00 ± 0.01 f	125.50 ± 22.50 abcd
	1	2	0.970 ± 0.001 bc	0.758 ± 0.001 i	5.95 ± 0.01 h	116.50 ± 2.50 abcde
500	2	2	0.969 ± 0.001cd	0.870 ± 0.001 h	6.01 ± 0.01 f	101.65 ± 7.35 bcdef
	3	2	0.968 ± 0.001 d	0.889 ± 0.001 c	6.05 ± 0.01 e	92.35 ± 1.95 cdef
	4	2	0.960 ± 0.001 f	0.879 ± 0.001 f	6.06 ± 0.01 de	67.05 ± 2.35 fg
	5	2	0.948 ± 0.001 g	0.872 ± 0.001 g	6.06 ± 0.01 de	45.95 ± 0.35 g
	0	2	0.969 ± 0.001cd	0.743 ± 0.001 j	5.92 ± 0.01 i	152.00 ± 0.00 a
	1	2	0.969 ± 0.001 cd	0.883 ± 0.001 de	5.98 ± 0.01 g	136.00 ± 26.00 ab
1500	2	2	0.964 ± 0.001e	0.882 ± 0.001 e	6.07 ± 0.01 d	134.00 ± 9.00 abc
	3	2	0.971 ± 0.001 b	0.884 ± 0.001d	6.15 ± 0.01 c	121.00 ± 21.00 abcde
	4	2	0.971 ± 0.001 b	0.921 ± 0.001a	6.22 ± 0.01 b	88.75 ± 6.25 def
	5	2	0.961 ± 0.001 f	0.897 ± 0.001b	6.29 ± 0.01 a	80.20 ± 0.70 efg
		P	**	**	**	**

[a] Means with different letters in the same column are significantly different at P < 0.05,
P: Probability, ** P < 0.01. PU, Penetration Units.

Table 4. Effects of loaf weight and storage time on the pasting properties of white bread's crumb on amylograph (mean ± standard error).

Loaf Weight (g)	Storage Time (day)	n	Pasting temperature (°C)	Bump area (cm^2)	Viscosity (BU)		
					Peak	Holding end	Cooling end
500	0	2	88.8 ± 0.25 c	127.7 ± 3.0 a	195 ± 5.0 ab	183 ± 7.5 a	538 ± 22.5 a
	1	2	88.9 ± 0.45 c	126.6 ± 4.4 a	178 ± 22.5 abc	150 ± 17.0 ab	500 ± 35.0 a
	2	2	89.1 ± 0.10 bc	119.4 ± 1.1 a	200 ± 10.0 ab	163 ± 7.5 ab	520 ± 20.0 a
	3	2	89.3 ± 0.25 abc	114.5 ± 0.1 a	201 ± 11.0 a	175 ± 15.0 a	540 ± 25.0 a
	4	2	88.9 ± 0.10 c	107.2 ± 12.1 a	162 ± 41.5 abc	133 ± 47.5 ab	455 ± 95.0 a
	5	2	88.7 ± 0.25 c	101.7 ± 4.9 a	170 ± 15.5 abc	138 ± 17.5 ab	460 ± 45.0 a
1500	0	2	89.4 ± 0.05 abc	98.1 ± 4.4 a	150 ± 5.0 abcd	123 ± 2.5 abc	438 ± 7.5 ab
	1	2	90.2 ± 0.30 a	88.7 ± 9.4 a	125 ± 5.0 cde	108 ± 2.5 bcd	400 ± 10.0 ab
	2	2	90.2 ± 0.20 a	96.2 ± 11.0 a	140 ± 0.0 abcde	118 ± 7.5 abc	429 ± 21.5 ab
	3	2	90.1 ± 0.10 ab	100.4 ± 1.8 a	136 ± 1.0 bcde	103 ± 2.5 bcd	395 ± 10.0 ab
	4	2	89.6 ± 0.60 abc	103.2 ± 18.8 a	93 ± 27.5 de	63 ± 17.5 cd	288 ± 57.5 cd
	5	2	89.4 ± 0.35 abc	79.3 ± 32.7 a	85 ± 25.0 e	49 ± 29.0 d	233 ± 97.5 c
		P	*	NS	**	**	*

[a] Means with different letters in the same column are significantly different at P < 0.05,
P: Probability, ** P < 0.01. BU, Brabender Units.

Table 5. The general effects of bread type, loaf weight, and storage time on some crumb and crust properties of the breads (mean ± standard error).

Factor	n	Crumb a_w	Crust a_w	Crumb pH	Crumb Softness (PU)
Bread Type (T)					
Vakfıkebir	24	0.965 ± 0.000 b	0.918 ± 0.003 a	4.43 ± 0.01 b	11.73 ± 0.48 b
White Bread	24	0.966 ± 0.000 a	0.846 ± 0.022 b	6.05 ± 0.02 a	105.08 ± 6.76 a
P		**	**	**	**
Loaf Weight (gram, W)					
500	24	0.964 ± 0.001 b	0.878 ± 0.016 b	5.25 ± 0.16 a	51.38 ± 9.42 b
1500	24	0.966 ± 0.001 a	0.886 ± 0.009 a	5.24 ± 0.18 b	65.43 ± 11.93 a
P		**	**	*	**
Storage Time (day)					
0	8	0.969 ± 0.001 a	0.807 ± 0.037 e	5.19 ± 0.29 d	76.87 ± 24.03 a
1	8	0.968 ± 0.001 b	0.864 ± 0.024 d	5.19 ± 0.29 d	69.56 ± 22.14 ab
2	8	0.964 ± 0.001 d	0.895 ± 0.009 c	5.25 ± 0.29 c	64.61 ± 20.69 ab
3	8	0.966 ± 0.001 c	0.906 ± 0.008 b	5.23 ± 0.33 c	58.77 ± 18.93 b
4	8	0.964 ± 0.002 e	0.914 ± 0.008 a	5.28 ± 0.32 b	44.25 ± 13.12 c
5	8	0.958 ± 0.002 f	0.907 ± 0.010 b	5.32 ± 0.32 a	36.35 ± 11.10 c
P		**	**	**	**

[a] Means with different letters in the same column are significantly different at P < 0.05,
P: Probability, ** P < 0.01. PU, Penetration Units.

values consistently decreased, while crust a_w and pH values significantly increased (P < 0.01).

The general effects of bread type, bread weight, and storage time on the pasting properties of bread are presented in Table 6. Pasting temperature, peak viscosity, and holding end viscosity values of VB crumb were higher than those of WB. However, the bump area of WB was significantly (P < 0.01) higher than VB. The pasting temperature of the heavy bread was higher than that of the light bread, while viscosity values (peak, holding end, and cooling end) of the 500-g bread were significantly higher. Pasting temperature, and peak and holding end viscosity of the crumb changed slightly as storage time increased.

Table 7 shows the correlation coefficients of amylogram readings, water activity values, pH, and softness of the crumb. The water activity of the crumb showed a significant positive correlation (r = 0.38) with softness. Karaoğlu (2006a) reported that the water activity of the crumb was correlated with softness (r = 0.454). The pH value of the crumb significantly correlated with softness and bump area, while pH of the crumb showed a negative correlation with pasting temperature and peak viscosity. Softness value of the crumb negatively correlated with pasting temperature, peak viscosity, and holding end viscosity of crumb slurry while it positively correlated with the bump area (P < 0.01).

Discussion

As seen in Table 5, crust a_w of VB was higher than that of WB. The reason for this situation may be the thick and hard outer covering of VB. Kotancılar et al. (1998) reported that VB had a thick and hard crust. It is possible that the thicker crust may hold more water than a thinner crust. Because of utilizing sourdough, pH values of VB were lower than those of WB (Table 5). Due to the lactic acid bacteria activities existing

Table 6. The general effects of bread type, loaf weight. and storage time on the pasting properties of bread crumb on amylograph (mean ± standard error).

Factor	n	Pasting temperature (°C)	Bump area (cm^2)	Viscosity (BU) Peak	Viscosity (BU) Holding end	Viscosity (BU) Cooling end
Bread Type (T)						
Vakfıkebir	24	90.5 ± 0.17 a	35.5 ± 2.2 b	204 ±10.5 a	209 ±13.9 a	439 ±17.1 a
White Bread	24	89.4 ± 0.13 b	105.3 ± 3.9 a	153 ±8.7 b	125 ±9.1 b	433 ±21.4 a
P		**	**	**	**	NS
Loaf Weight (gram, W)						
500	24	89.3 ± 0.12 b	72.9 ± 9.2 a	216 ± 8.9 a	212 ± 13.7 a	499 ± 13.2 a
1500	24	90.5 ± 0.16 a	67.9 ± 6.3 a	141 ± 6.4 b	121 ± 7.8 b	373 ± 15.3 b
P		**	NS	**	**	**
Storage Time (day, S)						
0	8	89.9 ± 0.37 ab	66.7 ± 17.9 a	178 ± 13.6 ab	163 ± 16.5 bc	418 ± 34.4 a
1	8	90.1 ± 0.32 a	71.4 ± 14.8 a	163 ± 11.4 b	153 ± 14.3 c	418 ± 19.6 a
2	8	89.9 ± 0.29 ab	74.3 ± 13.3 a	199 ± 19.9 a	188 ± 27.6 a	481 ± 23.7 a
3	8	90.1 ± 0.32 a	72.2 ± 13.5 a	184 ± 16.7 ab	175 ± 25.5 ab	454 ± 26.8 a
4	8	89.8 ± 0.36 ab	68.7 ± 14.5 a	164 ± 22.2 b	155 ± 29.9 bc	416 ± 39.3 a
5	8	89.6 ± 0.35 b	68.9 ± 11.1 a	183 ± 27.8 ab	168 ± 36.2 abc	427 ± 50.5 a
P		*	NS	**	**	NS

[a] Means with different letters in the same column are significantly different at P < 0.05,
P: Probability, * P < 0.05, ** P < 0.01, NS = not significant. BU, Brabender Units.

Table 7. Correlation coefficients among water activity, pH, softness, and some amylogram values of bread crumb.

	Crust a_w	Crumb pH	Crumb Softness (PU)	Pasting temperature (°C)	Peak viscosity (BU)	Holding-end viscosity (BU)	Cooling-end viscosity (BU)	Bump area (cm^2)
Crumb a_w	-0.36*	0.08	0.38**	0.16	-0.11	-0.11	-0.04	0.16
Crust a_w	-	-0.51**	-0.67**	0.38**	0.20	0.28	-0.15	-0.64**
Crumb pH	-	-	0.87**	-0.62**	-0.48**	-0.59	-0.06	0.89**
Crumb Softness (PU)	-	-	-	-0.43**	-0.44**	-0.52**	0.00	0.83**
Pasting temperature (°C)	-	-	-	-	-0.21	-0.12	-0.42**	-0.54**
Peak viscosity (BU)	-	-	-	-	-	0.97**	0.83**	-0.33**
Holding-end viscosity (BU)	-	-	-	-	-	-	0.74**	-0.46**
Cooling-end viscosity (BU)	-	-	-	-	-	-	-	0.19

BU, Brabender units; PU, penetration units.
* Correlation is significant at the 0.05 level,
** Correlation is significant at the 0.01 level.

naturally in sourdough microflora, the acidification effect of sourdough increased (Mentes et al., 2007). In a previous study, Kotancılar et al. (1998) stated that the crumb of VB was resistant to compression, and more elastic and softer. Katina (2005) suggested that the acidity level of sourdough is an important factor for crumb softness, as strong acidity (pH 3.6-3.8) leads to a harder crumb structure and moderate acidity (pH 4.7-5.8) increases softness. The higher crust a_w and softness value of heavy loaves can be explained by the hygroscopic behavior of crust mass and the distance between the loaf's center and crust in heavy breads. Because of the water migration from crumb to crust during the storage period, crumb a_w decreased while crust a_w increased. Crumb a_w and softness value decreased while crust a_w and pH value increased as storage time increased.

Pasting temperature, bump area, peak viscosity, and holding end viscosity values between VB and WB were significantly different ($P < 0.01$) (Table 6). This difference in pasting temperature may be explained by the fact that sugar arising from degradation of starch happened during longer fermentation and the baking condition over a long time at low temperature for VB. Plessas et al. (2005) observed that the residual sugar level increased as fermentation time increased. In addition, Karaoğlu (2006b) reported that pasting temperature increased with increasing sugar levels. The bump area of WB was higher than that of VB ($P < 0.01$). As can be seen in Table 5, the softness value of WB was almost 10 times higher than VB. It was reported that the high bump area was associated with a high concentration of amylose-lipid complex, and it was connected to the softening effect of the bread crumb (Karaoğlu, 2006b). In Table 7, it is seen that softness value of bread crumb positively correlated with bump area (correlation coefficient $r = 0.83$, $P < 0.01$). The pasting temperature of the 1500-g bread was higher, while viscosity values (peak, holding-end, and cooling-end) of the 500-g bread were higher. This could be associated with baking time. Starch might be more damaged due to excessive gelatinization in the bread baked for a longer time and more damaged starch may cause lower viscosity values. There are no linear changes in the values of the crumb pasting properties with increasing storage time. Morad and D'Appolonia (1980) reported that the pasting temperature of bread crumb did not change highly with increasing storage time. Under the circumstances, it could be concluded that the pasting properties of bread crumb were significantly affected by the use of sourdough. As a result, it can be said that the cause of the longer freshness time of VB crumb is not its crumb's pasting properties, but possibly its residual sugar content.

Because of the sourdough usage in VB baking process, VB had normally lower pH values, from 4.33

to 4.55 (Table 1). The other cause of the rough texture of its crumb may be high acidity (Kotancılar et al., 1998; Katina, 2005).

In conclusion, the use of sourdough in the production of bread had a significant effect on water activity, pH, softness, and pasting properties of bread crumb. The pH value of bread crumb exhibited a significant positive correlation with softness (r = 0.87) and bump area (r = 0.89), while it showed a negative correlation with pasting temperature (r = -0.62) and peak viscosity (r = -0.48). In particular, it was observed that the pasting properties of VB crumb were very different from those of WB. It was observed that the increase in loaf weight had a significant effect on bread properties, especially softness value, for both bread types.

These findings indicate that the cause of the long lasting freshness of VB is not the pasting properties of the crumb. The main reason is the high residual sugar and moisture content of the crumb due to the low baking temperature and long baking time during its manufacture.

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