Journal of Cereal Science 74 (2017) 103–111

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs

An investigation on the effect of heat-moisture treatment on baking quality of wheat by using response surface methodology

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ARTICLE INFO

Article history:
Received 11 September 2016
Received in revised form
24 November 2016
Accepted 2 January 2017
Available online 5 January 2017

Keywords:
Heat-moisture treatment
Response surface methodology
Bread wheat
Quality

ABSTRACT

Effect of heat-moisture treatment on quality properties of two bread wheats (cvs. Tosunbey and Bayraktar) were investigated by using response surface methodology (RSM). Temperature and moisture conditions in the experimental design were in the range of 55–95 °C and 13–19%. Heat-moisture treated grains were milled into flour and quality properties were determined. The optimum moisture-temperature combination for the highest dry gluten, Zeleny sedimentation, Alveograph W and bread volume values were estimated as 14%-63 °C for Tosunbey and 19%-55 °C for Bayraktar samples. Alveograph W seems to be a good indicator of baking quality for wheats treated at higher temperatures. In order to describe the relationship between the dependent and independent variables (moisture, temperature), the response values were fitted by second order polynomial models. Significance analysis showed that the effect of both moisture and temperature on dry gluten content, sedimentation and falling number values for Tosunbey; falling number and damaged starch values for Bayraktar were significant ($p < 0.05$). The effect of temperature on Farinograph water absorption, W and P/G, bread volume and firmness values were significant for both cultivars ($p < 0.05$). It can be concluded that improvement in baking quality can be achieved and flours with different properties can be produced by heat-moisture treatments on wheat.

1. Introduction

Wheat is the principal cereal grain used for bread making because of its unique baking properties. Crumb and crust properties of bread as well as loaf volume are influenced by physical and chemical properties of flour and the rheological properties of dough. Heat treatment is applied to wheat and flour to achieve modifications in physical, rheological or shelf-life properties of wheat flour (Bucsella et al., 2016; Gomez and Martínez, 2016). Gluten proteins are susceptible to heat treatment. Heating wet gluten progressively decreases its breadmaking performance and at 75 °C most of its functionality is reported to be lost (Lagrain et al., 2005). Properties of starch, including its crystallinity, gelatinisation, pasting and birefringence properties are also significantly affected by wheat drying temperatures (Koksel et al., 1993; Chung et al., 2009; Sun et al., 2014). Flour products with specific properties can be produced with selection of proper heat process parameters (Bucsella et al., 2016). Therefore, heat treatment of wheat and the resulting changes in rheological properties are of considerable importance for the characteristics of the final baked products (Lagrain et al., 2005).

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimising processes in which a response of interest is influenced by several variables and the objective is to optimize this response. RSM has important applications in the design, development and formulation of new products, as well as in the improvement of existing product design. RSM generates a mathematical model that accurately describes the overall process with limited number of experiments (Senanayake and Shahidi, 2002; Bas and Boyacı, 2007; Kahraman et al., 2015).

Although, considerable research has been undertaken to investigate the effects of heat and moisture treatment on various quality characteristics of wheat (Ghaly and Taylor, 1982;

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http://dx.doi.org/10.1016/j.jcs.2017.01.002
0733-5210/© 2017 Published by Elsevier Ltd.

Grochowicz and Zawioelak, 2002; Lagrain et al., 2005; Stathopoulosa et al., 2008; Noranizan et al., 2010; Neill et al., 2012; Mann et al., 2013; Sudha et al., 2016; Bucsella et al., 2016), further studies are still needed on this matter. First of all, most of the previous heat-moisture treatment studies in the literature are concentrated on the effects of drying on wheat quality, due to the fact that, in certain areas, large amounts of grain must be dried for safe storage. In the drying studies, a big portion of the moisture in the grain should be removed at the earlier stages of drying so that heat is not applied at constant moisture content, but at a range of moisture contents which is mainly a function of time and temperature and other drying conditions such as air velocity. Hence, it is difficult to interpret the data reported in the drying studies regarding the effects of heat and moisture on quality characteristics. On the other hand, in the present study, heat treatment was applied to wheat in sealed bags to eliminate possible moisture losses during the heat treatment which allowed us to investigate the effect of different temperatures at certain constant moisture contents. Secondly, in a considerable part of the previous studies in the literature, heat and moisture are applied on flour rather than on wheat. Therefore, there are some major differences between the present study and the other heat treatment studies reported in the literature. Furthermore, we have not encountered systematic studies investigating the effect of heat-moisture treatment combinations on wheat kernel by using response surface methodology. Therefore, further studies are still needed to investigate combined effect of heat and moisture on wheat quality, especially by using RSM. The aim of this study was to investigate the effects of heat and moisture treatments on the chemical, physicochemical and rheological properties of bread wheats. In this study, the impact of heat and moisture treatments on the properties of wheat was determined by analyzing its Zeleny sedimentation, dry gluten and damaged starch contents, Farinograph water absorption, Alveograph W and P/G values. The impact of heat and moisture treatments on the bread quality was determined by bread volume and bread firmness measurements.

2. Materials and methods

2.1. Materials

Two different bread wheat varieties (cv. Tosunbey and cv. Bayraktar 2000) obtained from Central Research Institute for Field Crops, Ankara, Turkey were used in this study. The name of cultivar Bayraktar 2000 was shortened as Bayraktar in the text for convenience. The chemicals used in the study were of analytical grade unless stated otherwise.

2.2. Methods

2.2.1. Experimental design for the heat-moisture treatments

Response surface methodology (RSM) was applied to investigate the effect of heat-moisture treatments on quality properties of wheat by using Design Expert software (Stat-Ease Inc., Minneapolis, MN, USA) to generate the experimental design. Temperature (T) and moisture (M) were chosen as two independent variables in the heat-moisture treatment. Quality properties of the samples; dry gluten and damaged starch contents, Zeleny sedimentation, falling number, Alveograph W, Alveograph P/G, Farinograph water absorption, bread volume and bread firmness values were selected as the dependent variables. For the experimental design, five levels, for each factor, were selected. The temperatures were 55, 65, 75, 85, 95 °C and moisture contents were 13, 14.5, 16, 17.5, 19%. Fourteen temperature-moisture combinations were created with two points in the centre (Tables 1 and 2).

2.2.2. Heat and moisture treatments

Wheat samples (1100 g each) were tempered according to the moisture levels stated in the experimental design (Tables 1 and 2) and left overnight in closed containers. Prior to the heat and moisture treatments, wheat samples were placed in cooking bags (Koroplast, Turkey) and the bags were sealed by using sealing machine (PackTech, Kiev, Ukraine) in order to eliminate the possible moisture losses. Heat treatments were carried out for 1 h, after reaching the target temperatures (Tables 1 and 2) in a drying

Table 1
Quality characteristics of heat-moisture treated Tosunbey samples [a, b, c].

Sample	Heat moisture treatment conditions		Quality characteristics							
	Temperature (°C)	Moisture (%)	Dry gluten (%)	Zeleny sed. (ml)	Falling number (sec)	Damaged starch (UCD_c)	Alveograph W (10^{-4} J)	Alveograph P/G	Bread volume (ml)	Bread firmness (g)
T-0	Control sample		10.0 b	63 cd	521 cde	27.8 abcd	281 abc	7.3 f	413 c	1068 cd
T-1	55 (−1)	13 (−1)	10.3 ab	59 f	447 f	27.1 defg	253 cd	7.1 f	425 bc	1100 cd
T-2	55 (−1)	16 (0)	10.5 a	64 bcd	479 ef	27.4 bcdefg	257 bcd	5.5 f	428 abc	1024 cd
T-3	55 (−1)	19 (+1)	10.3 ab	65 abc	516 cde	27.8 abcd	250 d	7.4 f	443 ab	825 cd
T-4	65 (−0.5)	14.5 (−0.5)	10.3 ab	64 bcd	469 f	27.3 cdefg	243 d	6.8 f	443 ab	1010 cd
T-5	65 (−0.5)	17.5 (+0.5)	10.2 ab	66 ab	490 def	27.5 abcde	284 ab	5.8 f	453 a	777 cd
T-6	75 (0)	13 (−1)	9.7 c	62 de	492 def	26.2 h	302 a	6.9 f	408 c	1381 c
T-7	75 (0)	16 (0)	9.4 cd	66 ab	489 def	26.5 gh	289 a	9.3 e	413 c	978 cd
T-8	75 (0)	16 (0)	9.3 d	67 a	526 cd	26.5 gh	241 d	10.5 e	415 c	659 d
T-9	75 (0)	19 (+1)	8.3 e	60 ef	532 bcd	26.8 fgh	172 e	13.2 d	355 d	1275 cd
T-10	85 (+0.5)	14.5 (−0.5)	–	67 a	550 abc	27.4 bcdef	85 f	18.0 a	303 e	2361 b
T-11	85 (+0.5)	17.5 (+0.5)	–	48 g	533 bcd	28.1 a	38 g	16.7 ab	250 f	5179 a
T-12	95 (+1)	13 (−1)	–	50 g	584 a	26.9 efg	30 g	15.7 bc	248 f	5718 a
T-13	95 (+1)	16 (0)	–	37 h	572 ab	28.0 ab	18 g	14.1 cd	215 g	–
T-14	95 (+1)	19 (+1)	–	29 I	574 ab	27.9 abc	19 g	14.1 cd	213 g	–

[a] Means with different letters within each column are significantly different ($p < 0.05$).
[b] T-0 indicates the untreated (control) Tosunbey sample.
[c] Coded values are shown in parentheses.

Table 2
Quality Characteristics of heat-moisture treated Bayraktar samples [a, b, c].

Sample	Heat moisture treatment conditions		Quality characteristics							
	Temperature (°C)	Moisture (%)	Dry gluten (%)	Zeleny sed. (ml)	Falling number (sec)	Damaged starch (UCD$_c$)	Alveograph W (10^{-4} J)	Alveograph P/G	Bread volume (ml)	Bread firmness (g)
B-0	Control sample		8.0 b	32 d	331 cd	22.2 ef	107 b	2.1 de	335 f	2852 b
B-1	55 (−1)	13 (−1)	8.0 b	36 bc	275 ef	23.5 cde	116 b	2.9 de	415 b	2059 c
B-2	55 (−1)	16 (0)	8.0 b	35 bc	322 cd	22.5 def	108 b	2.2 de	360 d	2506 bc
B-3	55 (−1)	19 (+1)	8.3 a	41 a	257 f	24.1 bc	159 a	1.9 de	430 a	1319 d
B-4	65 (−0.5)	14.5 (−0.5)	8.0 b	32 d	314 cd	22.3 ef	100 b	1.7 e	345 e	3579 a
B-5	65 (−0.5)	17.5 (+0.5)	8.4 a	35 bc	339 cd	22.4 def	104 b	2.0 de	388 c	2639 b
B-6	75 (0)	13 (−1)	7.9 b	34 cd	305 e	22.9 cde	94 b	2.4 de	393 c	2422 bc
B-7	75 (0)	16 (0)	7.0 c	34 cd	318 cd	21.5 f	114 b	3.3 d	385 c	2386 bc
B-8	75 (0)	16 (0)	6.9 c	37 b	341 cd	22.2 ef	107 b	3.3 d	343 e	2818 b
B-9	75 (0)	19 (+1)	4.3 d	35 bc	349 bc	23.9 bc	43 c	8.7 c	298 g	3897 a
B-10	85 (+0.5)	14.5 (−0.5)	–	40 a	349 bc	22.9 cde	38 cd	8.8 c	295 g	3661 a
B-11	85 (+0.5)	17.5 (+0.5)	–	37 b	339 cd	23.7 bcd	29 cd	9.5 bc	245 h	–
B-12	95 (+1)	13 (−1)	–	40 a	334 cd	23.4 cde	19 cd	9.4 bc	230 i	–
B-13	95 (+1)	16 (0)	–	32 d	379 b	24.8 b	20 cd	10.4 b	213 j	–
B-14	95 (+1)	19 (+1)	–	27 e	435 a	26.8 a	12 d	12.6 a	188 k	–

[a] Means with different letters within each column are significantly different ($p < 0.05$).
[b] B-0 indicates the untreated (control) Bayraktar sample.
[c] Coded values are shown in parentheses.

oven (Protech, Ankara, Turkey).

2.2.3. *Milling*

Heat-moisture treated samples were milled according to AACCI Method 26-50 (AACC International, 2000) by using a Buhler MLU 202 pneumatic Laboratory Mill (Uzwil, Sweden).

2.2.4. *Quality analyses*

2.2.4.1. Physical analyses. Thousand kernel weights were determined according to the ISO Method (No: 520:2010) by using Tripette& Renaud Numigral II (Villeneuve, France). Hardness of the untreated kernels was determined according to the AACCI Method 55–30.01 (AACC International, 2000) in terms of the particle size index (PSI).

2.2.4.2. Chemical analyses. Moisture contents were determined using the AACCI Method 44-15A (AACC International, 2000). Protein (Nx5.7) contents (Velp-NDA 701 Dumas Nitrogen Analyzer, Usmate, Italy) and falling number values (Perten Falling Number 1500, Huddinge, Sweden) of the flours were determined by using the AACCI Method 46-30 and 56–81B, respectively (AACC International, 2000).

2.2.4.3. Physicochemical analyses. The Zeleny sedimentation values of the flour samples were obtained according to ICC (International Association for Cereal Science and Technology) Method 116/1 (ICC, 2008). Dry gluten (Perten Glutomatic and Glutork 2020,Huddinge, Sweden) and damaged starch contents (Chopin SDMatic, Villeneuve, France) of the flour samples were determined according to AACCI Method 38-12A and 76–30.02, respectively (AACC International, 2000).

2.2.4.4. Rheological analyses. Farinograph properties of the flour samples were determined according to AACCI Method 54-21 (AACC International, 2000) using a Farinograph (BrabenderFarinograph-AT, Duisburg, Germany) equipped with a 50-g bowl. From the Farinograph curves, the water absorption (% of water required to yield a dough consistency of 500 BU) were obtained. Alveograph (Chopin, Villeneuve, France) characteristics (W and P/G) were determined according to AACCI Method 54-30A (AACC International, 2000). Alveograph W (deformation energy) indicates the necessary work input needed to inflate the dough and the P/G ratio indicates tenacity/index of swelling.

2.2.5. *Breadmaking and quality evaluation*

Bread samples were prepared according to the AACCI Method 10-10B (AACC International, 2000) as modified by Ozturk et al. (2009). The formula included 100 g of flour (14% mb), 25 ml salt solution (non-iodized, 6.0%), 25 ml yeast solution (8.0%) and water (according to the Farinograph water absorption value). Doughs were mixed by using a pin mixer (National Mfg, Lincoln, NE, USA). The dough samples were punched after 30 min of fermentation and left for fermentation for another 30 min. After the second fermentation, the dough was molded and panned. Final proof was 55 min (Ozturk et al., 2009). The loaves were baked in a laboratory rotary oven (Despatch, Minneapolis, MN, USA) at 230 °C for 25 min. The baking tests were performed in duplicate and mean values were reported. The volumes of bread samples were determined by the rapeseed displacement method using a loaf volumeter (National Mfg, Lincoln, NE, USA) after cooling the loaves at room temperature for 2 h. They were placed in plastic bags and stored for 24 h at room temperature for the determination of firmness according to AACCI Method 74-09 (AACC International, 2000). A texture analyzer (Stable Microsysytems, TA-XT plus, Godalming, Surrey, England) equipped with 5 kg load cell and a 36 mm cylinder probe was used for texture analysis. The force (firmness, N) required to compress 40% of two slices (1.25 cm each) was determined at 1.7 mm/sec test speed.

2.2.6. *Statistical analysis*

All experiments were performed in duplicates and mean values were recorded. Quality characteristics of the samples were analyzed, using one-way analysis of variance (ANOVA). When significant ($p < 0.05$) differences were found, Duncan's test was used to determine the differences among means.

In order to describe the relationship between the independent variables (Moisture and Temperature) and dependent variables (quality properties), the response values were fitted by second order polynomial (quadratic) regression models using a multiple regression analysis (Standard Least Square Fitting) using Design Expert (Stat-Ease, Minneapolis, MN, USA) (Eq. (1));

$$Y = b_0 + b_1X_{1i} + b_2X_{2i} + b_3X_{1i}X_{2i} + b_4X_{1i}^2 + b_5X_{2i}^2 \tag{1}$$

where Y is the response (one of the quality properties), X_{1i} and X_{2i} are the independent variables (Moisture and Temperature, respectively) in coded values (see designations in Tables 1 and 2). The b_0 is a constant value; b_1 and b_2 show the linear effect of X_{1i} and X_{2i}, respectively; b_3 shows the interaction effect between X_{1i} and X_{2i}; b_4 and b_5 show the quadratic effects of X_{1i} and X_{2i}, respectively.

To describe both individual and interactive effects of the independent variables, three-dimensional (3D) response surface plots were also developed by Design Expert (Stat-Ease, Minneapolis, MN, USA).

3. Results and discussion

3.1. Properties of the untreated control samples

Protein content and Zeleny sedimentation value of Bayraktar flour sample were 10.8% and 32 ml, respectively. Tosunbey had higher protein content and Zeleny sedimentation value (13.8% and 63 ml, respectively) which indicate its better quality. Tosunbey is a hard white winter wheat with strong gluten properties while Bayraktar is a white medium hard wheat with medium strong gluten properties. Particle Size Index of Tosunbey and Bayraktar samples were 38.5 and 48.4 and their thousand kernel weights were 31.4 and 36.1 g, respectively. The lower PSI value of Tosunbey indicated that it was harder as compared to Bayraktar.

3.2. Effects of the heat-moisture treatments on the quality parameters

The quality parameters of the heat-moisture treated Tosunbey and Bayraktar samples are shown in Tables 1 and 2, respectively. Dry gluten contents of Tosunbey and Bayraktar samples treated at 55 and 65 °C, regardless of the treatment moisture, were comparable to the ones of the respective untreated samples. The Tosunbey and Bayraktar samples treated at 75 °C had lower dry gluten content and the differences between these samples and the untreated sample were generally significant ($p < 0.05$). It was not possible to analyse the samples treated at 85 and 95 °C in terms of dry gluten content for both Tosunbey and Bayraktar samples, probably due to protein denaturation with increasing temperature. Similar to the findings of the present study, Ragasits (1993) reported that wet gluten content drastically decreased by drying of wheat at 80 °C and gluten could not be washed out at higher temperatures.

Zeleny sedimentation values of untreated Tosunbey and Bayraktar samples were 63 and 32 ml, respectively. Zeleny sedimentation values of the heat-moisture treated Tosunbey and Bayraktar samples were in the range of 29–67 ml and 27–41 ml, respectively. Tosunbey samples treated at 95 °C had significantly lower Zeleny sedimentation values compared to the untreated one ($p < 0.05$). Most of the Bayraktar samples, except the one treated at 95 °C and 19% moisture content had similar or higher Zeleny sedimentation values as compared to that of the untreated one. Ragasits (1993) also reported that Zeleny sedimentation values were 61, 60, 42 and 11 ml for the wheat samples dried at 20, 60, 80 and 100 °C, respectively, indicating a drastic decrease at the temperatures of 80 °C and above.

In Tosunbey and Bayraktar cultivars, there was a similar trend in Zeleny sedimentation values and bread volumes for the wheat samples treated up to 75 °C. However, Zeleny sedimentation values did not decrease parallel to the bread volumes in the samples heat treated at 85 and 95 °C. Therefore, it can be concluded that Zeleny sedimentation value was not a good indicator of bread making quality for wheat samples treated at higher temperatures. This is also in agreement with the results of Ghaly et al. (1973) who reported that the sedimentation test failed to be an index of quality in a wheat drying study.

Untreated Tosunbey sample had a falling number value of 521 (sec) and the falling number values of the heat-moisture treated Tosunbey samples were in the range of 447–584 s. Falling number values of the Tosunbey samples treated at 95 °C were significantly higher than the Tosunbey samples heat-moisture treated at 55, 65 and 75 °C, except the one treated at 75 °C and 19% moisture content. Falling number value of the untreated Bayraktar sample was 331 s and the falling number values of the heat-moisture treated Bayraktar samples were in the range of 257–435 s. Falling number values of the Bayraktar samples at the same moisture content generally increased with increasing heat treatment temperature and the increases were significant ($p < 0.05$) only for the samples treated at 95 °C for all moisture contents. Ragasits (1993) also reported that falling number values of the wheat samples dried at 100 °C were higher than that of the ones dried at lower temperatures which are in agreement with the results of the present study. Also Sudha et al. (2016) stated that falling number values of flour samples dry heat treated at 100 °C and moist heat treated at 60 °C were higher than that of untreated sample. Falling number values of untreated and heat-moisture treated Tosunbey samples were generally higher than those of Bayraktar samples, indicating the lower α-amylase activity of Tosunbey samples.

Damaged starch content (UCD_c) of untreated Tosunbey and Bayraktar samples were 27.8 and 22.2, respectively. Damaged starch content of the heat-moisture treated Tosunbey and Bayraktar samples were in the range of 26.2–28.1 and 21.5–26.8, respectively. Damaged starch content of Tosunbey samples treated at 75 °C was significantly lower as compared to that of the untreated sample. The effect of heat-moisture treatment on damaged starch content of cv. Bayraktar was significant at the highest moisture content (19%) as compared to the untreated sample.

The Alveograph W determines the gluten strength of a dough by measuring the force required to blow the bubble of dough until it ruptures. The Alveograph W value was 281 10^{-4} J for untreated Tosunbey sample. The samples treated at 55, 65 and 75 °C generally had similar or better Alveograph W values as compared to that of the untreated sample. Generally, Alveograph W values significantly decreased at the treatment temperatures of 85 and 95 °C ($p < 0.05$). The effects of heat-moisture treatments on Alveograph W values of Tosunbey samples drastically decreased from 172 to 38 and 18 10^{-4} J as the heat treatment temperatures increased from 75 to 85 and 95 °C, respectively. The Alveograph W value was 107 10^{-4} J for the untreated Bayraktar sample. The Bayraktar samples treated at 55, 65 and 75 °C had generally similar Alveograph W values compared to the untreated sample. Alveograph W values of Bayraktar samples drastically decreased from 100 to 29 and 12 10^{-4} J as the heat treatment temperatures increased from 65 to 85 and 95 °C, respectively.

The Alveograph P/G ratio indicates tenacity/index of swelling. Alveograph P/G values of the untreated Tosunbey and Bayraktar samples were 7.3 and 2.1 and the Alveograph P/G values of the heat-moisture treated Tosunbey and Bayraktar samples were in the range of 5.5–18.0 and 1.7–12.6, respectively. Alveograph P/G values of Tosunbey samples treated at 55 and 65 °C were not significantly different. There was a similar trend in the respective samples of Bayraktar. Heat treatment at 85 and 95 °C caused significant increases in Alveograph P/G values ($p < 0.05$) of both cultivars, indicating that heat treatment decreases dough extensibility. There are some studies investigating the effects of heat-moisture treatments on viscoelastic properties by using Extensograph. The studies indicated that heat treatment of flour decreased gluten extensibility (Ghaly et al., 1973; Magee and Neill, 2011; Neill et al., 2012). Neill et al. (2012) suggested that decreased dough extensibility might be due to a reduction in gliadin level and protein denaturation caused by the heat treatment.

Bread volumes of the untreated Tosunbey and Bayraktar samples were 413 and 335 ml, respectively. Heat-moisture treatments resulted in significantly higher bread volumes in some of the samples. The highest bread volume in Tosunbey samples was obtained at 65 °C and 17.5% moisture content (453 ml) and the bread volumes of the samples treated at 55 and 65 °C were not significantly different (in the range of 428–453 ml) except the one treated at 55 °C and 13% moisture content. The highest bread volume in the Bayraktar samples was obtained at 55 °C and 19% moisture content (430 ml). On the other hand, the bread volumes of the samples heat treated at 55, 65 and 75 °C were similar or better (in the range of 343–430 ml) as compared to the untreated Bayraktar sample, except the one treated at 75 °C and 19% moisture content. In a heat-moisture treatment study on two wheat cultivars (Vázquez et al., 2001) it was reported that bread volumes were similar or better than the untreated sample at the treatments of 40 and 60 °C. They observed improving effect at relatively lower temperatures which is in agreement with the results of the present study. The improving or deteriorating effects on bread volumes were observed at slightly different heat-moisture combinations for different cultivars. In both Tosunbey and Bayraktar cultivars, heat-moisture treatments at higher temperatures resulted in smaller loaf volumes and the shape of the loaves became more irregular which was more evident at 95 °C. The deterioration was more obvious in cv. Bayraktar. Lupano and Anon (1987) also reported that they observed smaller loaf volumes at high treatment temperatures. They concluded that the loss of baking quality during wheat drying correlates with the alterations observed in the proteins.

Bread firmness of the untreated Tosunbey and Bayraktar samples were 1068 and 2852 g, respectively. The bread firmness values of Tosunbey samples treated at 95 °C (at moisture contents of 16 and 19%) could not be measured as they were beyond the capacity of the texture analyser load cell. There was a similar situation in cv. Bayraktar. The bread firmness values of Bayraktar samples treated at 85 °C (at a moisture content of 17.5%) and 95 °C (at all moisture contents) could not be measured. The bread firmness values of the Tosunbey samples heat treated at 55, 65 and 75 °C and that of untreated sample were not significantly different ($p < 0.05$). However, treatment at 85 and 95 °C caused significant increases in the firmness values ($p < 0.05$). Bayraktar samples treated at 55 °C (at all moisture contents) had softer crumbs than that of the untreated sample (2852 g). The differences between the firmness values of the samples treated at 55 °C and that of the untreated sample were significant except the one treated at 55 °C and 16% moisture content.

3.3. *Investigation of heat-moisture treatments by response surface methodology (RSM)*

In order to describe the relationship between the independent variables (moisture and temperature) and dependent variables (quality properties), the response values were fitted by second order polynomial (quadratic) regression models. ANOVA analyses for the models of Tosunbey and Bayraktar samples are presented in Tables 3 and 4, respectively.

Table 3
Analysis of variance (ANOVA) for the models of Tosunbey samples.

Source of variance	df	Dry gluten (%)		Zeleny sedimentation (ml)		Falling number (sec)		Farinograph water absorption (%)		Alveograph W (10^{-4} J)		Alveograph P/G		Bread volume (ml)		Bread firmness (g)	
		F	*p*	*F*	*p*	*F*	*P*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Linear																	
M (Moist.)	1	78.44	0.0009*	5.76	0.0431*	10.573	0.0117*	0.026	0.8761	1.02	0.3428	0.24	0.6365	1.30	0.2868	2.32	0.1786
T (Temp.)	1	342.04	<0.0001*	53.88	<0.0001*	124.93	<0.0001*	94.64	<0.0001*	37.43	0.0003*	19.27	0.0023*	97.91	<0.0001*	41.39	0.0007*
Interaction																	
MT	1	40.28	0.0032*	13.71	0.0060*	13.212	0.0066*	2.13	0.1821	0.07	0.7991	0.11	0.7492	1.20	0.3061	3.15	0.1262
Quadratic																	
M^2	1	11.31	0.0282*	0.77	0.4061	0.515	0.4933	0.0037	0.9571	0.03	0.859	0.016	0.9024	0.011	0.9200	0.01	0.9252
T^2	1	77.36	0.0009*	24.69	0.0011*	6.793	0.0313*	2.86	0.1291	7.15	0.0282*	0.0002	0.9895	10.70	0.0113*	16.98	0.0062*
Residual	8																
Model	5	113.06	0.0002*	20.69	0.0002*	31.542	<0.0001*	19.97	0.0002*	9.2	0.0036*	3.93	0.0427*	22.44	0.0002*	10.19	0.0068*
R^2		0.9930		0.9282		0.9517		0.9258		0.8518		0.7105		0.9334		0.8946	

* indicates the significant factors ($p < 0.05$).
df: Degrees of freedom.

Table 4
Analysis of variance (ANOVA) for the models of Bayraktar samples.

Source of variance	df	Dry gluten (%)		Falling number (sec)		Damaged starch (UCD$_c$)		Farinograph water absorption (%)		Alveograph W (10^{-4} J)		Alveograph P/G		Bread volume (ml)		Bread firmness (g)	
		F	*p*	*F*	*p*	*F*	*P*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*P*	*F*	*p*
Linear																	
M (Moist.)	1	0.41	0.5404	5.38	0.049*	24.03	0.0012*	0.36	0.5628	0.078	0.7867	3.96	0.0870	2.11	0.1843	2.52	0.1637
T (Temp.)	1	43.04	0.0002*	29.31	0.0006*	27.17	0.0008*	34.20	0.0004*	37.77	0.0003*	52.35	0.0002*	59.69	<0.0001*	26.78	0.0021*
Interaction																	
MT	1	0.0046	0.9476	6.00	0.0399*	11.38	0.0097*	0.36	0.5645	1.06	0.3328	1.50	0.2597	1.42	0.2678	3.44	0.1129
Quadratic																	
M^2	1	0.037	0.8531	1.36	0.2778	15.57	0.0043*	0.39	0.5517	0.10	0.7545	0.43	0.5309	0.52	0.4894	0.073	0.7959
T^2	1	2.54	0.1496	0.33	0.5819	25.69	0.0010*	0.12	0.7389	0.38	0.5556	1.88	0.2131	4.54	0.0658	5.54	0.0568
Residual	8																
Model	5	9.21	0.0036*	8.42	0.0048*	23.79	0.0001*	7.07	0.0082*	7.91	0.0058*	12.11	0.0024*	13.56	0.0010*	5.83	0.0266*
R^2		0.8520		0.8404		0.9370		0.8155		0.8318		0.8964		0.8944		0.8293	

* indicates the significant factors ($p < 0.05$).
df: Degrees of freedom.

In the case of the dry gluten contents of Tosunbey and Bayraktar flour samples, the *p* values of the models (0.0002 and 0.0036, respectively) indicated that the models were reliable. The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that only 0.7% and 14.8% of the total variation could not be explained by the models. The linear effect of moisture (coded as M) and temperature (coded as T), interaction effect of moisture and temperature (coded as MT) and the quadratic effect of moisture and temperature (coded as M^2 and T^2) had significant effect on the dry gluten content of the Tosunbey flour samples, and temperature had the highest influence on dry gluten content of the samples ($p < 0.0001$). However, only linear effect of temperature (coded as T) had significant effect on the dry gluten content of the Bayraktar flour samples.

The *p* value (0.0002) of the model for the Zeleny sedimentation value of the Tosunbey flour samples indicated that the model was reliable. The linear effect of moisture (M) and temperature (T), the interaction effect of moisture and temperature (MT) and the quadratic effect of temperature (T^2) had significant effects on the Zeleny sedimentation values of the Tosunbey flour samples, and temperature had the highest influence ($p < 0.0001$). On the other hand, the *p* value ($p > 0.05$) of the model for the Zeleny sedimentation value of the Bayraktar flour samples indicated that the model was not reliable.

In the case of the falling number values of the Tosunbey and Bayraktar samples, the *p* value of the models ($p < 0.0001$ and $p = 0.0048$, respectively) indicated that the models were reliable. The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that 95.2% and 84.0% of the total variation could be explained by the model. The linear effects of moisture (M) and temperature (T), interaction effect of moisture and temperature (MT) and the quadratic effect of temperature (T^2) had significant effects on the falling number values of the Tosunbey samples. Temperature had the highest influence on the falling number values of the samples ($p < 0.0001$). On the other hand, the linear effects of moisture (M) and temperature (T) and interaction effect of moisture and temperature (MT) had significant effects on the falling number values of the Bayraktar samples. Temperature had the highest influence on the falling number values of the Bayraktar samples ($p = 0.0006$).

The p values ($p < 0.05$) of the models for the Farinograph water absorption values of Tosunbey and Bayraktar flour samples indicated that the models were reliable ($p = 0.0002$ and 0.0082, respectively). The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that only 7.4% and 18.5% of the total variation could not be explained by the models. Linear effect of temperature (T) had significant influence on the Farinograph water absorption value of both cultivars ($p < 0.0001$ and $p = 0.0004$, respectively).

The *p* value of the model for the damaged starch value (UCD$_c$) of the Tosunbey flour samples indicated that the model was not reliable. However, for the Bayraktar samples, the *p* value (<0.0001) indicated that the model was reliable. The regression coefficient (R^2) of the model for Bayraktar flour samples, provided by the ANOVA, indicated that only 6.3% of the total variation could not be explained by the model. The influence of the linear effects of moisture (M) and temperature (T), interaction effect (MT) and the quadratic effects of both moisture (M^2) and temperature (T^2) were significant ($p = 0.0012$, 0.0008, 0.0097, 0.0043, 0.0010, respectively). Significance analysis of coefficients of each factor showed that the temperature had the highest influence on UCD$_c$ value of the samples ($p = 0.0008$).

In the case of the Alveograph W value, the *p* values of Tosunbey and Bayraktar flour samples indicated that the models were reliable ($p = 0.0036$ and 0.0058, respectively). The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that only 14.8% and 16.8% of the total variation could not be explained by the model. The linear effects of temperature (T) and the quadratic effect of temperature (T^2) had significant effect on the Alveograph W value of Tosunbey flour samples ($p = 0.0003$ and 0.0282, respectively). However, the linear effect of temperature (T) was the only factor that had influence on Alveograph W value of Bayraktar flour samples ($p = 0.0003$).

The *p* values ($p < 0.05$) of the model for the Alveograph P/G value of Tosunbey and Bayraktar flour samples indicated that the models were reliable ($p = 0.0427$ and 0.0024, respectively). The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that only 29.0% and 10.4% of the total variation could not be explained by the models. Linear effect of temperature (T) had significant influence on the Alveograph P/G values of both cultivars ($p = 0.0023$ and 0.0002, respectively).

In the case of the bread volume, the *p* values of the models for Tosunbey and Bayraktar flour samples indicated that the models were reliable ($p = 0.0002$ and 0.0010, respectively). The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that only 6.7% and 10.6% of the total variation could not be explained by the models. Linear and quadratic effects of temperature (T and T^2) had significant influence on the bread volume of the

Table 5
Response model equations for the Tosunbey and Bayraktar samples [a].

Sample	Dependent variable (Y)	Equation	R^2
Tosunbey	Dry Gluten Content (%)	$Y_1 = 9.28-0.68M-2.81T-0.71MT-0.28M^2-1.54T^2$	0.9930
	Zeleny Sedimentation (ml)	$Y_1 = 64.68-3.71M-11.36T-7.35MT-2.25M^2-12.75T^2$	0.9282
	Falling Number (sec)	$Y_1 = 505.43 + 14.54M + 49.96T-20.85MT + 5.32M^2+19.32T^2$	0.9517
	Farinograph Water Abs. (%)	$Y_1 = 58.57-0.05M-3.02T-0.58MT + 0.029M^2-0.87T^2$	0.9258
	Alveograph W (10^{-4} J)	$Y_1 = 222.18-21.07M-127.86T-7.06MT + 6.36M^2-92.64T^2$	0.8518
	Alveograph (P/G)	$Y_1 = 10.67 + 0.56M + 5.00T-0.48MT + 0.24M^2-0.026T^2$	0.7105
	Bread Volume (ml)	$Y_1 = 389.64-13.04M-113.04T-16.03MT-1.96M^2-61.96T^2$	0.9334
	Bread Firmness (g)	$Y_1 = 1282.54 + 589.39M + 3123.78T + 1000.36MT + 53.91M^2+2881.92T^2$	0.8946
Bayraktar	Dry Gluten Content (%)	$Y_1 = 5.61-0.45M-4.65T-0.062MT + 0.23 M^2-1.88 T^2$	0.8520
	Zeleny Sedimentation (ml)	$Y_1 = 34.93-1.11M-1.11T-4.44MT + 0.48 M^2-0.27 T^2$	0.5702
	Falling Number (sec)	$Y_1 = 336.32 + 19.11M + 44.61T + 25.91MT-15.91M^2+7.84T^2$	0.8404
	Damaged Starch (UCD_c)	$Y_1 = 22.12 + 0.79M + 0.84T + 0.70MT + 1.05M^2+1.35T^2$	0.9370
	Farinograph Water Abs. (%)	$Y_1 = 50.22-0.21M-2.01T-0.26MT + 0.35M^2-0.20T^2$	0.8155
	Alveograph W (10^{-4} J)	$Y_1 = 82.93-2.61M-57.25T-12.32MT-5.00M^2-9.50T^2$	0.8318
	Alveograph (P/G)	$Y_1 = 4.61 + 1.28M + 4.67T + 1.02MT + 0.73M^2+1.51T^2$	0.8964
	Bread Volume (ml)	$Y_1 = 337.68-18.04M-95.89T-18.97MT + 14.91M^2-43.84T^2$	0.8944
	Bread Firmness (g)	$Y_1 = 3227.9 + 651.74M + 2649.13T + 1109.97MT-222.58M^2+1812.27T^2$	0.8229

[a] Y_1 is the dependent variable stated in the second column, and M and T are the coded values of independent factors (moisture and temperature, respectively).

Tosunbey flour samples ($p < 0.0001$ and $p = 0.0113$, respectively). However, temperature (T) was the only factor that had influence on bread volume of Bayraktar flour samples ($p < 0.0001$).

In the case of the bread firmness value, the p values of Tosunbey and Bayraktar flour samples indicated that the models were reliable ($p = 0.0068$ and 0.0266, respectively). The regression coefficients (R^2) of the models, provided by the ANOVA, indicated that only 10.5% and 17.1% of the total variation could not be explained by the model. The linear effect of temperature (T) and the quadratic effect of temperature (T^2) had significant effect on the bread firmness of Tosunbey flour samples ($p = 0.0007$ and 0.0062, respectively). However, the linear effect of temperature (T) was the only factor that had influence on bread firmness value of the Bayraktar flour samples ($p = 0.0021$).

In order to minimize error, all factors (coded as M, T, MT, M^2 and T^2) with significant and nonsignificant coefficients given in Tables 3 and 4 were considered in the models. The final estimative response model equations for the dependent variables of Tosunbey and Bayraktar samples, in terms of the coded factors, were generated by Design Expert Software and given in Table 5. The Zeleny sedimentation data obtained for the Bayraktar samples and damaged starch data obtained for the Tosunbey samples were not fitted by a regression model, in other words the model was not reliable for those data. Therefore, the final estimative response model equations were not presented in Table 5.

Some of the equations given in Table 5 are plotted as 3D response surface plots and shown in Fig. 1a-f. Fig. 1a and b represent the effect of treatment temperature and moisture on falling number values of Tosunbey and Bayraktar flour samples, respectively. It can be observed from the figures that at the same moisture content, the increase in the treatment temperature caused an increase in falling number values of both cultivars. The increase in the moisture content (at the same treatment temperature) caused an increase in falling number values of Tosunbey samples (except the temperatures closer to 95 °C). For Bayraktar samples, when the temperature was higher than 75 °C, the increase in the moisture content (at the same treatment temperature) caused an increase in falling number values.

Fig. 1c and d represent the effect of temperature and moisture on Alveograph W values of Tosunbey and Bayraktar flour samples, respectively. At the same treatment moisture, increase in the temperature decreased the Alveograph W values of both cultivars. Whereas at the same treatment temperature, the change in the moisture did not seem to affect the Alveograph W values.

Fig. 1e and f represent the effect of temperature and moisture on bread volumes of Tosunbey and Bayraktar flour samples, respectively. Similar to the effect of moisture and temperature on Alveograph W values of the samples, at the same treatment temperature, the change in the moisture did not cause a remarkable change in the bread volume values of the samples. However, the increase in the temperature (at constant moisture) caused decrease in the bread volume values of the samples.

The optimum moisture and temperature combination to reach the highest dry gluten content, Zeleny sedimentation, Alveograph W and bread volume values were determined by solving the regression equations given in Table 5, using Design Expert Software. The moisture and temperature values were estimated as 14% and 63 °C for Tosunbey samples and 19% and 55 °C for Bayraktar samples.

4. Conclusion

In this work, the impact of heat and moisture treatments on the properties of wheat was determined by using Response Surface Methodology. Second order polynomial regression models were fitted to describe the relationship between the independent variables (Moisture and Temperature) and dependent variables (quality characteristics). The results revealed that RSM can be used to predict the relationship between responses and the independent variables. The RSM results indicated that temperature of the heat-moisture treatment had a greater influence than had moisture on the quality of both wheat cultivars.

The effects of heat-moisture treatments on sedimentation values and bread volumes were similar up to 75 °C. However, sedimentation values did not decrease parallel to the bread volumes in the samples heat treated above 75 °C. Therefore, it can be concluded that sedimentation value was not a good indicator of bread making quality for the wheats treated at higher temperatures. Heat-moisture treatments at higher temperatures resulted in smaller loaf volumes with unacceptable shapes especially at 95 °C. The loss of baking quality during heat treatment might have been caused by the alterations in the protein structure (Lupano and Anon, 1987). Generally, Alveograph W values significantly decreased at the treatment temperatures of 85 and 95 °C ($p < 0.05$). Hence, Alveograph W values seem to be a better indicator of bread making quality for the wheats treated at higher temperatures. The optimum moisture-temperature combination to attain the highest dry gluten content, Zeleny sedimentation, Alveograph W and bread

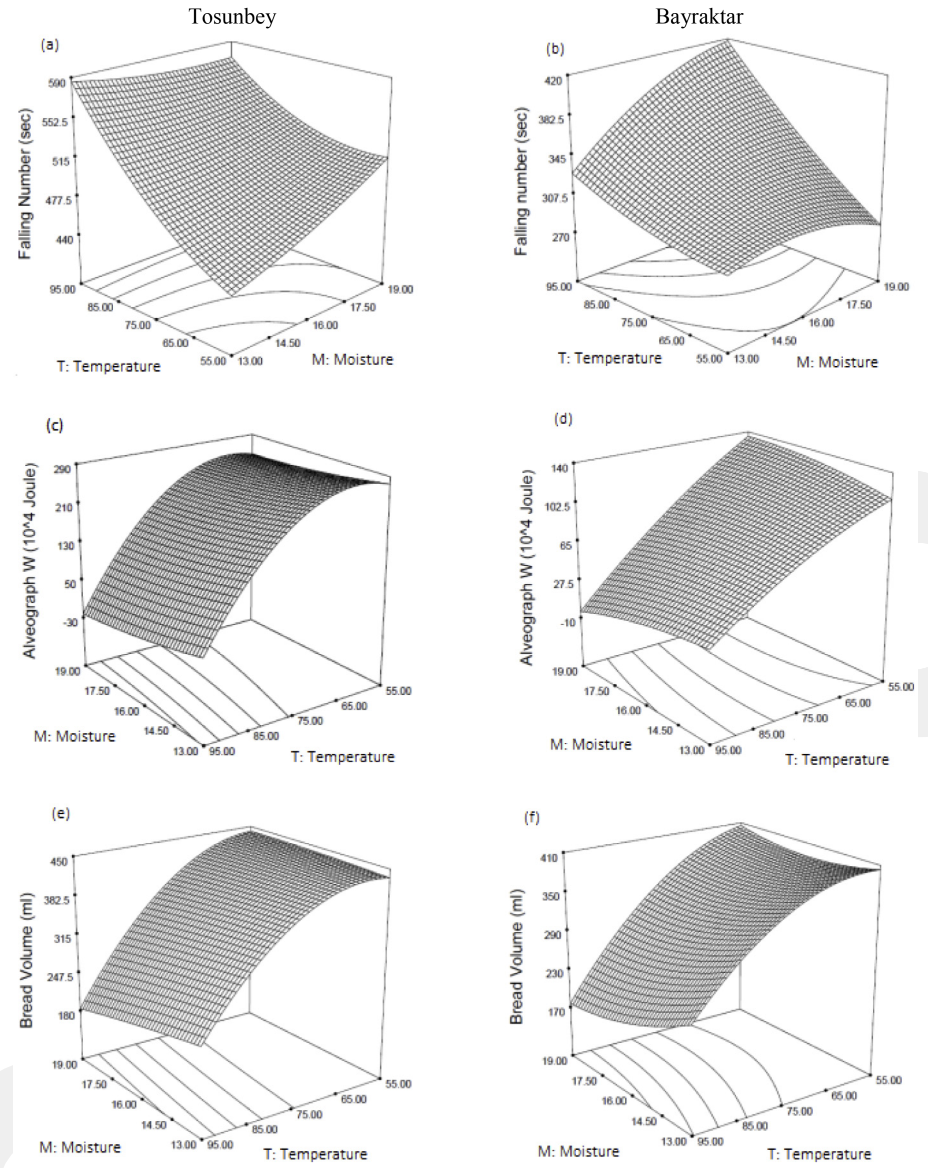

Fig. 1. 3D response surface plots of Falling Number (a, b), Alveograph W (c, d) and Bread Volume (e, f) values of Tosunbey and Bayraktar samples as a function of Moisture (M, %) and Temperature (T, °C).

volume values were determined. The optimum moisture and temperature values were estimated as 14% and 63 °C for Tosunbey samples and 19% and 55 °C for Bayraktar samples. It can be concluded that improvement in baking quality can be achieved at different moisture-temperature combinations for different cultivars. Furthermore, flours with diverse properties can be produced by various heat-moisture treatments on wheat.

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