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Effects of Wheat Flour and Baking Temperature on the Quality of Iranian Flat Bread-Part II: Thermophysical Properties

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In this sequel, trends of temperature variations at the top, middle and bottom of bread made of three commercial wheat flour cultivars (Pishtaz, Marvdasht and Chamran) are presented and discussed. Main factors of wheat flour cultivars at three different backing temperatures (232, 249 and 260 °C) and 10 backing times are considered in this research. Results show that the effects of wheat variety, baking temperature and backing time are significant at 1 %. The interactions of baking temperature on backing time are significant at 1 % for the measured dependent factors at the top and inside of bread while it is significant at 5 % for the bread bottom temperature. However, the interaction effects of variety on baking temperature, variety on backing time and also triple interaction of variety, baking temperature and baking time factors aren't significant. Results of regression analysis showed that the trend of temperature variations follow a third degrees equation.

Key Words: Bread, Dough, Wheat cultivars, Baking temperature.

INTRODUCTION

Bread is a staple foodstuff made and eaten in most of the countries around the world. Bread products have evolved to take many forms, each based on quite different and distinctive characteristics. The character of bread and other fermented products depends heavily on the formation of gluten network in the dough[1]. Bread quality is determined by the complex interactions of the raw materials, their qualities and quantities used in the recipe and the dough processing method[2]. Many different bread types have been evolved with the passage of time and all require their own individual bubble structures, processing techniques, equipment and control mechanisms. Baking is the last but most important step in bread making procedure. Various physical, chemical and biological changes such as evaporation of water, formation of porous structure, volume expansion, increase in yeast activities, carbon dioxide contesting, gluten coalescence, starch gelatinization, external crust formation, *etc*. take place during bread baking. Each of these changes happens at different temperatures and has a great effect on bread properties. Heat transfer in the oven is influenced by size, geometry, heating mode and wall properties of the oven, as well as size, geometry and the thermo-physical properties of the baked products. Experimental and theoretical studies, design of baking process and optimization of baking oven conditions, material properties to obtain a better product quality and more efficient process have been investigated (to various degrees of detail, depending on their sophistication) by many researchers[3-8] for some decades. Critical reviews of these technological applications is provided by Sablani *et al.*[9] and Mondal and Datta[10]. These models designed either to obtain a detailed description of heat and mass transfer phenomena between oven components and the processed cereal product or to describe simultaneous heat and moisture transport phenomena in cereal products during hot-air baking. The distinction between these theories is as follows: In the former models heat transfer by convection (between the product and the atmosphere of baking chamber), by thermal radiation (between the product and the oven walls) and finally by contact (between the product and the oven band) are described[3-5]. These theories, however, ignore temperature gradient in heat transfer and only consider the effects of mean temperature. In the latter models, the focus is on identifying transfer mechanisms that underlie product heating and drying processes, while the descriptions of heat and mass follows between the product and the environment during cooking are greatly simplified[6-8]. These theories take temperature and moisture content gradients within the bread into account.

Thermo-physical properties of dough have an important role in quality control of bread. Temperature of environment in which dough is prepared and the temperature of baking process are basic parameters during different stages of preparing dough and baking process. Few studies have been conducted on determining the effects of baking temperature in the quality of Iranian breads so far. Akram *et al.*[11] investigated the effects of moisture and temperature variations on physical properties of Barbari bread made of two wheat cultivars (Tajan and Mahdavi).

In this study, the focus will lie on the trends of temperature variations of bread, made from three wheat cultivars (Marvdasht, Chamran and Pishtaz) and baked in an electric oven maintained at temperatures of 232, 249 and 260 °C. The effects of physical and chemical properties of these cultivars and the properties of resulting flour and dough on physical characteristics of bread were presented by Akram *et al.*[12]. By consequence, physio-chemical insight was gained in the main causes of low/high quality of flat bread. However, as mentioned above, thermo-physical properties of dough have an important role in quality of bread. In this sequel, our focus lies on the temperature variations within the dough. Particularly, we will be interested to find an empirical expression to model the temperature variations at the top, inside and bottom of bread.

EXPERIMENTAL

Dough preparation: The dough was prepared by no-time dough method according to the standard recipe for Iranian flat bread, provided by Iranian S.B.S.I. Institute[13]. The following amounts and ingredients were used for one loaf of bread[12]:

Wheat flour: 400 g (for each cultivar); Dry yeast: 4 g; Salt: 6 g; Sugar: 4 g; Water varied (for each cultivar).

The amount of water required for each cultivar was calculated by Farinograph. This test is commonly used in the determination of flour water absorption. It is based on mixing a flour and water under prescribed conditions. Evaluation of the mixing curve can supply data on protein quality using the parameters on dough development time, dough stability and degree of softening[14]. The properties of dough will vary according to the level of added water. Water is mixed with flour, salt, sugar and the leavening agent (yeast) and stirred for 1 min using a 1400 rpm mixer machine based on rapid mix test (RMT) in the laboratory temperature ranges 26-27 °C. To get a better mixture, the dry ingredients were mixed at first and then water was added. Mixing plays a major role on forming and developing the gluten structure in the dough and incorporating the necessary gas bubbles for cell structure formation in the baked product. The dough was then kept in a steel container inside an incubator (Cenco Model No 95086) with temperature ranges of 30-32 °C and relative humidity of 80 % for 0.5 h. The second stage of dough preparing is rising. In order to provide conditions for further activities of yeast, the mixed dough is then allowed to rest for 1 min resting period. The main function of yeast is to produce carbon dioxide gas to expand the dough at its various processing stages, particularly during proof and the early stages of baking. The overall effect of resting time after mixing is to change dough rheological characters with time. In particular its character becomes less elastic and more extensible and the effects of subsequent sheeting are less severe. The degree of change in dough rheology is influenced by temperature and varies for different flours[14]. Due to second fermentation, the dough was allowed to rise on baking sheet and then kept in the incubator for another 45 min, before being put into the oven. In the next stage, loaves are formed and the bread is baked in an electrical oven with dimensions 68 cm × 86.5 cm × 87.5 cm. The bread was baked by traditional method at three different backing temperatures of 232, 249 and 260 °C.

Experimental set-up for measuring temperature variations: The control of final dough temperature to a constant value is essential to ensure consistency of product quality. To measure and control temperature variations at top, middle and bottom of bread during backing, an automatic computer-based monitoring system (Fig. 1) was developed. The hardware components include a DC power supply, thermometer, data logger, K-type thermocouple sensors and a PC. Electrical signals from sensors, due to temperature variation, are sent to thermometer. The sensors have good accuracy in ranges between 0-500 °C, easily calibrated and their outputs are completely linear in temperature range of 0-200 °C. Thermocouples were calibrated with Iskra device. Thermometer is equipped with an analog to digital converter (A/D) using an operational amplifier. The system is capable of storing signals in data logger memory or sending them to the PC *via* RS232 port for on-line monitoring and further processing. Heating of the cavity (oven set point) is controlled by the thermometer, which keeps the heating elements on/off according to the pre-determined set point. The main controlling board of this system was designed using ATMEGA32L chip (ATMEL Corporation, 2005), a 2 × 12 segment liquid crystal display (LCD) module, a power supply, 32 I/O port pins, ADC 8-channel, 8Kb In system programmable (ISP) flash memory, an IC MAX 232 interface card for sending/receiving data to microcontroller from RS 232 serial port to/from PC and many other peripherals. Eight channels were specialized for receiving signals of thermometer. The other ports were utilized for LCD display. The micro issues necessary commands for receiving information from A/D channels, converting and sending them to PC using RS-232 port.

After dough preparing, the temperature variations of dough during baking process was measured using the developed apparatus. The thermocouples were placed at three different sites in the sample (Fig. 1) in the centre, at the bottom and near the surface. Due to sample thickness, they were installed in appropriate distances from bottom of dough using clay columns. By adjusting the data logger, the temperature data was recorded every 10 s throughout the baking period. The experiments were replicated three times for each baking temperature and each variety of wheat flour. In order to automate the experiments, a custom program was developed in Visual Basic 6.0 environment which could automatically save data in MS Access file for further analysis. On the average, 840 data was collected from each sensor during backing.

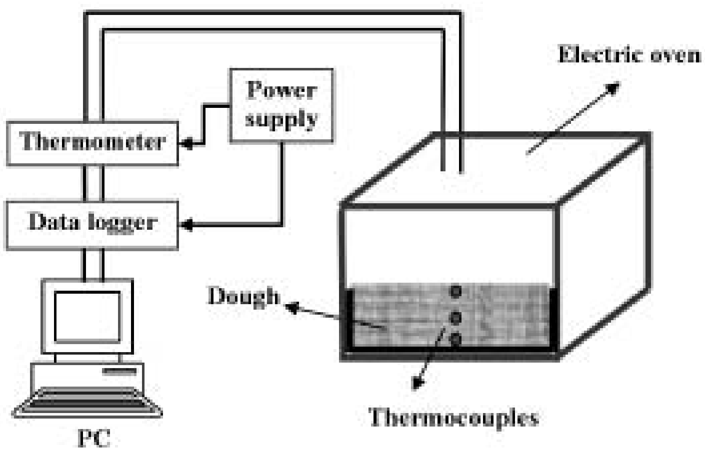

Fig. 1. Schematic diagram of data acquisition system for measuring bread temperature variations

Statistical analysis: The effects of three levels of baking temperatures (232, 249 and 260 °C) and 10 different baking time increments (from 1 to 10 min) are investigated for three selected main factors of wheat variety (Pishtaz, Marvdasht and Chamran). In order to compare temperature variations ratio (and 3 replications), completely randomized design and factorial statistical design (3 × 3 × 10) are used. Statistical analyses of data are all carried by using MINITAB 14.1 software (www.minitab.com).

RESULTS AND DISCUSSION

Since the effects of physical and chemical properties of different wheat cultivars and also the properties of resulting flour and dough on physical characteristics of bread are important have been investigated. The measurements included grain colour, grain moisture, grain hardness, protein content, water absorption and bread volume during baking. A summary of basic physicochemical properties of different varieties of wheat flour are given in Table-1. Results show that the highest and lowest values of bread increasing volume was belonging to Marvdasht and Chamran varieties, respectively while Chamran and Pishtaz had the minimum and maximum decrease in bread weight during backing, respectively. From viewpoint of protein and water absorption per cent, results shows Pishtaz has the maximum values followed by Chamran and Marvdasht varieties, respectively. The amount of the proteins contained in the flour serve as an indicator of the quality of the bread dough and the finished bread. Then it can be concluded that Pishtaz wheat flour has a better quality for bread making than the two other varieties.

TABLE-1
SOME PHYSICOCHEMICAL PROPERTIES OF THREE DIFFERENT VARIETIES OF WHEAT

Property	Wheat cultivar		
	Pishtaz	Chamran	Marvdasht
Grain colour	Red	Yellow	Yellow
Moisture (%)	11.47 ± 0.05	12.30 ± 0.01	11.30 ± 0.10
Grain hardness	59.67 ± 0.23	59.12 ± 0.15	52.67 ± 0.28
Protein content (%)	11.47 ± 0.06	10.90 ± 0.10	9.13 ± 0.06
Water absorption (%)	65.87 ± 0.06	63.17 ± 0.06	57.50 ± 0.40
Bread volume (cc)	420.34 ± 0.57	513.12 ± 0.23	293.67 ± 0.28

In order to determine the effects of wheat variety, baking temperature and backing time, the average temperature was consider as a data for each property in each replication. Results of variance analysis are summarized in Table-2. Results of variance analysis for the averages of top, middle and bottom of bread temperature show that the effects of cultivar, various baking temperature and backing time separately on top, middle and bottom temperature of bread are statistically significant at 1 %. The interaction effects of cultivar on different baking temperatures and also cultivar on baking time on measured top, middle and bottom temperature is not significant, whereas interaction effect between baking temperature and baking time is significant at 5 % for bottom crust and at 1 % for top and middle of bread temperature. The interaction effect among cultivar, baking temperatures and different baking time is not significant. According to variance analysis of main and interaction affects of cultivar, baking temperature and 1 min time interval factors, the temperature ratio varies during baking period depended to baking temperature and wheat flour variety

TABLE-2
VARIANCE ANALYSIS OF VARIETY, BAKING TEMPERATURE AND TIME FACTORS

Source	DOF	MS		
		Bottom curst	Middle crust	Top curst
Varieties	2	85.69**	158.41**	196.1**
Baking temperature	2	5157.77**	1639.94**	5403.2**
Time intervals	9	79344.09**	6439.33**	18265.4**
Variety × Baking temperature	4	86.22 ns	9.06 ns	16.7 ns
Variety × Time intervals	18	38.57ns	6.00 ns	17.7 ns
Baking temperature × Time intervals	18	329.16*	24.99**	49.1**
Variety × Baking temperature × Time intervals	36	55.92ns	2.21 ns	5.7 ns
Error	90	895.23	5.12	19.7

**Significant at 1 %; *Significant at 5 %; ns = non-significant.

which is in disagreement with the theory of constant temperature ratio variations in cooking bakery products presented in works like as drying process of agricultural products[4]. Results of this research show that the assumption of constant temperature ratio is not valid and its value varies during baking process, a disagreement with Kaiser's theory[3]. Zanoni *et al.*[6] considered three different detached region including bread crust which its temperature increases rapidly, deploy evaporation with 100 °C and bread middle with a temperature of *ca.* 100 °C which corresponds with results of this study. The ratio of temperature variation of different varieties has a significant difference and was a function of baking temperature which increasing baking temperature caused to increase temperature variation ratio. The ratio of temperature variation of bread middling was slow at first and then gradually increased *ca.* to 100 °C at the end of backing process. Temperature variation in upper crust of bread was quick at first but its variation decreases gradually to the end like temperature variation in bottom crust while bottom crust temperature was lower than upper crust.

The average temperature at the top, middle and bottom crust of bread for the three varieties of wheat are shown in Figs. 2-4, respectively. Temperature near the surface increases more rapidly than the center temperature during baking and tends to the oven temperature. This concurs well with bread-baking studies[7,8,15]. Diagram of upper temperature crust for different varieties (Fig. 2) shows that the ratio of temperature variation was approximately similar initially for different varieties, but due to the differences in evaporation level of wheat varieties they deviate gradually at longer baking time. Based on average temperature diagram at the middle of bread (Fig. 3), the ratio of temperature variations for Pishtaz variety is greater than Chamran and Marvdasht varieties due to its minimum increasing in volume. Temperature is the dominating factor in baking. Marvdasht variety has the lowest ratio of temperature and its middle has dough state. According to Fig. 3, the middle temperature

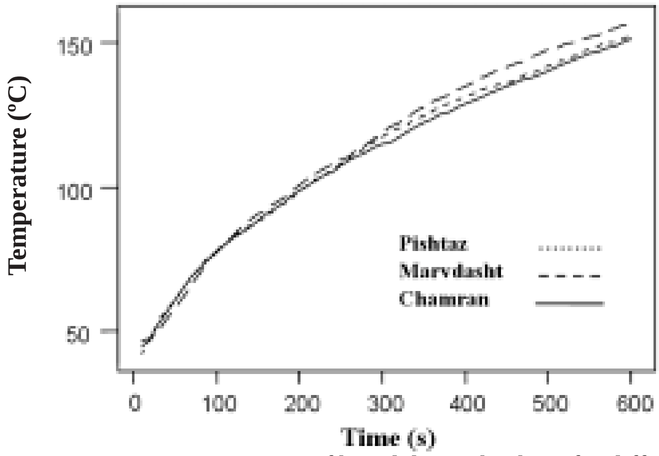

Fig. 2. Average temperature at top curst of bread during backing for different varieties of wheat flour

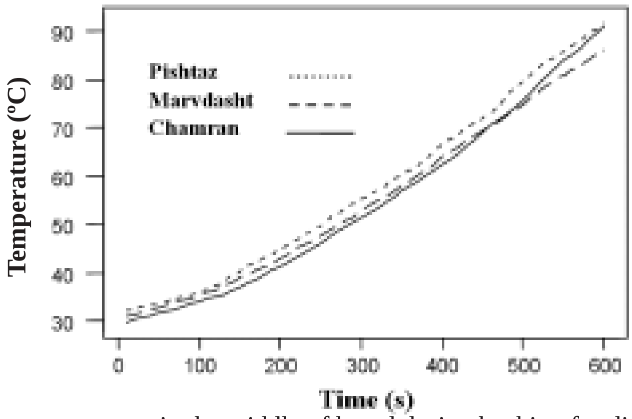

Fig. 3. Average temperature in the middle of bread during backing for different varieties of wheat flour

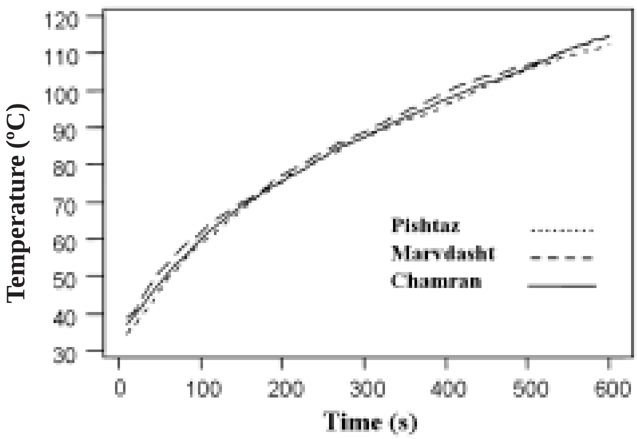

Fig. 4. Average temperature at the bottom of bread during backing for different varieties of wheat flour

of bread get to *ca.* 95 °C in period less than 10 min and will not get higher than 100 °C in baking period, which corresponds with those obtained in[5,6,16]. The significant amount of water in the middle of bread would not allow the internal temperature to rise above 95 °C, even at the end of baking. Study of the average temperature in the bottom crust of bread (Fig. 4) shows that the ratio of temperature variation is approximately similar in the three cultivars of wheat. This is expected because of using same aluminum pans at the bed. Although a small difference is seen in temperatures due to distinction in water absorption of different varieties at first, distinction in evaporation values will cause to regulate this difference.

The backing curves obtained from the experimental data for different varieties of wheat were fitted to 3 linear and nonlinear models. Results of related regression analysis are summarized in Tables 3-5. Results show that the effects of linear, quadratic and cubic models are all significant at 1 %. From these results it can be stated that the temperature variations at the top, inside and bottom of bread could be best modeled by a cubic equation as following:

$$T_i^{ave} = A + B \times 10^{-2} t_i + C \times 10^{-4} t_i^{\ 2} + D \times 10^{-8} t_i^{\ 3} \quad (1)$$

where T_i^{ave} and t_i (i = 1, 2, 3; 1 = Pishtaz 2 = Marvdasht, 3 = Chamran) are the average temperature during backing and backing time, respectively. A, B, C and D are the coefficients of the third degree equation of bread temperature model which are calculated and summarized in Table-6.

TABLE-3
REGRESSION ANALYSIS OF BREAD TOP TEMPERATURE EQUATIONS

Model	DOF	MS		
		Chamran	Marvdasht	Pishtaz
Total regression	3	17036.8**	20547.7**	17988.7**
Linear	1	49311.2**	59348.9**	51896.8**
Quadratic	1	1620.1**	2189.2**	1939.1**
Cubic	1	179.0**	104.9**	130.1**
Error	56	0.9	1.6	1.4

**Significant at 1 %.

TABLE-4
REGRESSION ANALYSIS OF BREAD MIDDLE TEMPERATURE EQUATIONS

Model	DOF	MS		
		Chamran	Marvdasht	Pishtaz
Total regression	3	17036.8**	20547.7**	17988.7**
Linear	1	49311.2**	59348.9**	51896.8**
Quadratic	1	1620.1**	2189.2**	1939.1**
Cubic	1	179.0**	104.9**	130.1**
Error	56	0.9	1.6	1.4

**Significant at 1 %.

TABLE-5
RESULTS OF REGRESSION ANALYSIS OF BREAD BOTTOM TEMPERATURE EQUATIONS

Model	DOF	MS		
		Chamran	Marvdasht	Pishtaz
Total regression	3	9052.72**	8621.92**	9140.92**
Linear	1	26248.8**	24946.2**	26234.2**
Quadratic	1	791.9**	851.9**	1045.2**
Cubic	1	117.4**	67.7**	143.3**
Error	56	0.28	0.55	0.51

**Significant at 1 %.

TABLE-6
CONSTANT COEFFICIENTS OF BREAD TEMPERATURE EQUATION MODEL

Wheat cultivar	Position	A	B	C	D	R^2
Chamran	Top	42.9913	0.424	-5.82	37.9190	0.99
	Center	29.4871	-4.920	1.47	3.2200	1.00
	Bottom	35.0268	34.300	4.50	28.0722	0.99
Marvdasht	Top	40.8249	0.325	-5.22	39.2096	0.99
	Center	30.8265	-0.144	1.95	2.7500	1.00
	Bottom	40.8249	0.261	-3.79	26.2144	0.99
Pishtaz	Top	42.3917	0.361	-5.43	38.0515	0.99
	Center	31.2227	-9.720	1.64	3.8600	0.99
	Bottom	42.3917	0.361	-5.43	38.0515	0.99

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