สภาวะพื้นผิวตอบสนองที่เหมาะสมของสนามไฟฟ้าและสนามแม่เหล็ก ต่อคุณสมบัติทางเคมีของขนมปัง

Response Surface Optimization of Electric Field and Magnetic Field on the Chemical Properties of Bread

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บทคัดย่อ

วัตถุประสงค์ของงานวิจัยนี้คือทดสอบผลของสนามไฟฟ้าและสนามแม่เหล็กต่อปริมาณความชื้นและปริมาณน้ำอิสระของขนมปัง โดยศึกษาที่สนามไฟฟ้าความเข้ม 0 - 8 KV, สนามแม่เหล็ก 0 - 1400 mT และเวลาในการทดลอง 0 – 2 ชั่วโมง และศึกษาผลกระทบที่เกิดขึ้นจากสนามไฟฟ้า สนามแม่เหล็กและเวลาด้วยวิธีพื้นผิวตอบสนองของสามตัวแปรแต่ละตัวแปรมีสามระดับ แบบจำลองพหุนามอันดับสองมีความสอดคล้องผลการทดลองที่ได้ของความชื้นและปริมาณน้ำอิสระโดยมีค่าสหสัมพัทธ์ 0.9854 และ 0.9737 ตามลำดับ โดยทั้งสามตัวแปรคือ สนามไฟฟ้า 8 KV สนามแม่เหล็ก 1400 mT และเวลา 2 ชั่วโมง ส่งผลอย่างมีนัยสำคัญต่อปริมาณความชื้นและปริมาณน้ำอิสระ โดยปัจจัยหลักที่ส่งผลปริมาณความชื้น คือ สนามไฟฟ้า จากค่าสัมประสิทธิ์ของสนามไฟฟ้า เท่ากับ 0.2951 และค่าสัมประสิทธิ์ของสนามแม่เหล็ก เท่ากับ 0.001579 สอดคล้องกับปริมาณน้ำอิสระที่มีผลจากสนามไฟฟ้ามากกว่าเช่นกันจากค่าสัมประสิทธิ์ของสนามไฟฟ้า เท่ากับ 0.01159 และค่าสัมประสิทธิ์ของสนามแม่เหล็ก เท่ากับ 0.000024 ความสัมพันธ์ระหว่างสนามแม่เหล็กและสนามไฟฟ้าไม่ส่งผลต่อปริมาณความชื้นและปริมาณน้ำอิสระของขนมปัง

คำสำคัญ: การออกแบบบล็อคเบนเคน สนามไฟฟ้า สนามแม่เหล็ก ความชื้น น้ำอิสระ

Abstract

The objectives of this research are to examine the effect of the electric field and magnetic field on the moisture content and water activity of bread. We studied how the electric field (0-8 KV), magnetic field (0-1400 mT) and treatment time (0-2 hrs.) affect the moisture content and water activity of bread. The effects of moisture content and water activity on bread were determined. Response surface methodology (RSM) based on three factor three level central composite design was applied to determine the effect of electric field level, magnetic field level and treatment time. A second-order polynomial model fitted well to the experimental data (R^2=0.9854 and 0.9737) for moisture content and water activity, respectively. Significant moisture content and water activity were observed at the maximum treatment conditions of 8 KV of electric field, 1400 mT of magnetic field and treatment time 2 hrs., indicating stability of moisture content and water activity in bread. The main factor was electric field. The coefficients of moisture content were 0.2951 for electric field and 0.001579 for magnetic field. It was related with coefficients of water activity, which were 0.01159 and 0.000024 for electric field and magnetic field, respectively. The interaction of electric field and magnetic field was no significant for moisture content and water activity in bread.

Keywords: Box-Behnken design, electric field, magnetic field, moisture content, water activity

Introduction

The world population is expected to increase to 8.1 thousand million in next 20 years (Varachai, 2011). With this increasing population, food is an important global factor to consider; this has been named by the Food and Agriculture Organization of the United Nations (FAO) as the 'World Food Crisis'. Food preservation or extending the shelf life of foods is one necessity of mitigating such problems. Since the origin of agriculture, bread has been the main food of all human beings. Providing 50% of the calories to over half the world's population, bread is the main source of proteins, carbohydrates and vitamins globally. In bread, the carbohydrate content varies from 45-58%, while the protein content is usually around 6%. The fat content is usually between 0.5 and 2% but is greatly increased when shortening is used in the recipe. Bread is also 1.5-3% mineral content. Additionally, bread contains the major vitamins Thiamin (0.46 mg/100 g), Choline (202 mg/100 g), Niacin (4.39 mg/100 g) and Riboflavin (0.29 mg/100 g) (Pomeranz, 1987). There are 29 kcal in a 11.4g (a single slice) of bread, or 254 kcal in 100 g of bread (Kent, 1975). The biological effects of low-frequency electromagnetic fields on living systems have been studied by many researchers (Fojt et al., 2004; Novak et al., 2007) but the effects of static magnetic fields on the living systems are rarely researched and the results are quite controversial (WHO, 2006). In order to research the biological effects of static magnetic fields on the living systems, it is helpful to classify static magnetic fields as weak (<1mT), moderate (1mT to 1T), strong (1-5T). and ultrastrong (>5T) (Luciana & Luigi, 2005). Electric current has been used for a long time to inactivate bacteria. It was related with very high electric field strengths which caused water dissociation in liquid water (Cassone et al., 2014). When water content of food is reduced below 0.7, microbial spoilage is prevented Labuza et al. (1972). Although the food would not spoil from microorganisms, the food may still deteriorate in other ways. Furthermore, magnetic field had effect to the friction coefficient of water in thin films, indicating a possible reduction in hydrogen bond strength (Cai et al., 2009). Response Surface Methodology is defined as the statistical tool that uses quantitative data from appropriate experimental design to determine and simultaneously solve multivariate equations which specify the optimum product for specified set of factors through mathematical models, while considering interactions among test factors (Giovanni, 1983). Response Surface Methodology has been used extensively for optimizing processes in the tropical fruit juice production (Lee et al., 2006). RSM does this by solving multivariate equations that determine the interaction between factors that affect the optimum product using quantitative data from other experiments that have been appropriately designed (Liu et al., 2009). The Box–Behnken fractional factorial design is often preferred for product optimization while evaluating sensory attributes, since interaction parameter estimates are not completely confounded and the design is considerably smaller than other fractional factorial designs (Dean & Voss, 1999). Also, fractional factorial designs are rotatable or nearly rotatable (Montgomery, 1991).

Objectives

This study was to investigate the effect of electric field and magnetic field on changes in moisture content and water activity of bread as a function of treatment time, electric field and magnetic field level by using response surface methodology.

Materials and Methods

Sample Preparation

Bread were purchased from the local market. Then, bread were cut into smaller sample pieces with the size 50 mm × 50 mm × 10 mm. Sample of bread were analyzed according to the American Association of Cereal Chemist (AOAC, 2000) to determine fat content, thiobarbituric acid (TBA), were 16.32 g/100 g and 0.024. Triplicate samples were analyzed, and the mean was recorded.

High Voltage Electric and Static Magnetic fields

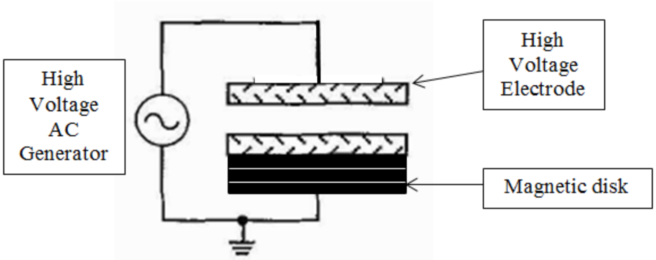

Figure 1 Schematic view of the electric field and magnetic field.

The discharge was generated between two aluminum electrodes (Al_2O_3). The electrode plates were 250mm × 250mm and the gap between them was 30 mm. A high alternating current (AC) voltage generated a plasma between the plates. The static magnetic fields were generated by ferrite permanent magnets (Pro-tech Ferrite Co., Ltd. Thailand). Each magnet was 220 mm in diameter and 10 mm in thickness and had a magnetic field intensity of around 480 mT. The static magnetic field (SMF) from 3 magnets was 1400 mT. The high AC voltage and magnetic disks were assembled as shown in Figure 1. Bread were placed in high voltage alternating current (4.0 KV 50Hz and 8.0 KV 50Hz) with static magnetic fields (1400 mT) for 0, 1 and 2 hrs.

Moisture Content

The Moisture content was determined based on American Association of Cereal Chemist method (AOAC, 2000). Moisture content (MC) (%, g water/100 g sample) of crumb (from loaf center, 10 mm thick) was determined by weight loss by drying in a forced-air oven (Memmert, Germany) at 105 ^{o}C to constant weight. At least triplicate samples of bread were analyzed for each bread loaf.

Water Activity

The water activity value was set by NaCl (Sigma Aldrich, Buchs, Switzerland) according to Rödel, Krispien & Leistner (1979) and controlled by aw-meter (Aw-sprint TH500, Novasina, Lachen, Switzerland). Triplicate samples were analyzed, and the mean were recorded.

Color measurement

The color analysis was based on the method described in Perkins-Veazie et al. (2001) using Minolta Colorimeter CR-300, Japan. This colorimeter is based on the CIE (Commission International ede L'Eclairage) *L a b* color space. Triplicate samples were analyzed, and the mean was recorded.

Experimental design and statistical analysis

The data in this research was analyzed by the response surface method (RSM) and Box–Behnken designs. A 3-factor experiment with 15 runs was the central composite design and this was repeated three times. The results of the central composite design were statistically analyzed for appropriateness of the mathematical models. The experimental results of mathematical modeling are represented by the following equation.

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i \neq j=1}^{n} \beta_{ii} X_i X_j \quad (1)$$

Where Y is the predicted response, β_0 is the constant coefficient, β_i is the linear coefficient, β_{ii} is the quadratic coefficient, β_{ij} is the cross-product coefficients. X_i and X_j are independent variables. Three dimensional curves of the response surface were developed using Minitab Ver.17 (Minitab Solution Center Ltd.) software while holding the variables constant in the second-order polynomial model. The validity of the model was determined by comparing the experimental and predicted values.

Table 1 Independent variables used in the optimization study.

Independent variable	Code	Coded variable		
		-1	0	+1
Electric field (KV)	X_1	0	4	8
Magnetic field (mT)	X_2	0	700	1400
Time (hr.)	X_3	0	1	2

The experiments were based on a central composite rotational design (Cochran & Cox, 1957) with a quadratic model employed to study the combined effect of three independent variables i.e. electric field, magnetic field and time treatment. These three variables can be used to determine the moisture content and water activity in bread. Coded as X1, X2, and X3, each independent variable had three levels, -1, 0, and 1. According to Baumann (1981), these three chosen variables are responsible for the moisture content and water activity (AW) in bread. A Box Behnken configuration for the three chosen variables was used in a total of 15 combinations with three replicates of the center point were carried out in a random order. Table 1 shows the level of an independent variable and the coded variable. The dependent variables (y) measured were the moisture content and water activity (AW) of the bread. These dependent variables were expressed individually as a function of the independent variables known as response function. The variance for each factor assessed was partitioned into linear, quadratic and interactive components and were represented using the second order polynomial. The regression coefficients were then used to generate contour maps from the regression models. The three-dimensional (3D) plots were generated by keeping one variable constant at the center point and varying the other variables within the experimental range.

The experiment was conducted to determine the optimal of electric field and magnetic field and time treatment conditions for bread using the RSM method The Box-Behnken experiment was designed to investigate the electric field, magnetic field and treatment time taken to measure Table 1 with appropriate moisture content and water activity (AW).

Results and Discussion

Chemical analysis of bread presents an initial and after process fat content of 16.23±0.57, Thiobarbituric acid (TBA) number of 0.024±0.007 and color value of L 55±1.27, a 7.3±0.4 and b 22.6±1.5 which the change of results was insignificant ($p \geq 0.05$). But the experimental value and analysis of variance for response variables moisture content and water activity under different magnetic field and electric field conditions were presented in Table 2. Table 2 showed that the electric field and magnetic field conditions can decreased both moisture content and water activity (AW). Electric field, magnetic field and treatment time were important factors that affect the water activity (AW) and moisture content. However, it was necessary to have a combined use of the electric field intensity and time treatment to make it more efficient.

Table 2 Experimental data for the response surface analysis.

Run order	Electric field (KV)	Magnetic field (mT)	Time (hr.)	%Moisture content	Water activity
1	0 (-1)	1400 (+1)	1 (0)	33.19	0.917
2	0 (-1)	700 (0)	0 (-1)	34.15	0.932
3	4 (0)	700 (0)	1 (0)	31.48	0.865
4	0 (-1)	700 (0)	2 (+1)	31.93	0.911
5	0 (-1)	0 (-1)	1 (0)	33.82	0.927
6	4 (0)	1400 (+1)	0 (-1)	34.15	0.930
7	8 (+1)	1400 (+1)	1 (0)	31.29	0.875
8	4 (0)	0 (-1)	0 (-1)	34.23	0.927
9	8 (+1)	700 (0)	0 (-1)	34.06	0.924
10	4 (0)	0 (-1)	2 (+1)	31.32	0.874
11	4 (0)	1400 (+1)	2 (+1)	30.53	0.841
12	8 (+1)	0 (-1)	1 (0)	32.68	0.897
13	4 (0)	700 (0)	1 (0)	31.64	0.874
14	4 (0)	700 (0)	1 (0)	31.69	0.874
15	8 (+1)	700 (0)	2 (+1)	30.21	0.852

Figure 2 showed the analysis of variance (ANOVA) of RSM on decreasing moisture rate. It also shows a 3D plot of the moisture content as a function of the electrical field, magnetic field, and treatment time of the bread. The plot shows the decreasing rate of moisture content decreased in the higher electric field. In the higher electric field, the moisture content decrease has a coefficient of determination (R^2) of 0.9854, suggesting that the model accurately represents the relationship between the two parameters. The error analysis indicates that the lack of fit is insignificant ($p>0.05$) (Mason, Gunst & Hess, 1989). The model *F*-value (37.56) implied that the model was significant. The relationship between electric field (KV), magnetic field (mT) and treatment time (hr.) on the decreasing rate of moisture content was shown in regression equation (2). The predicted second-order polynomial model was:

Effect of electric field and magnetic field on moisture content

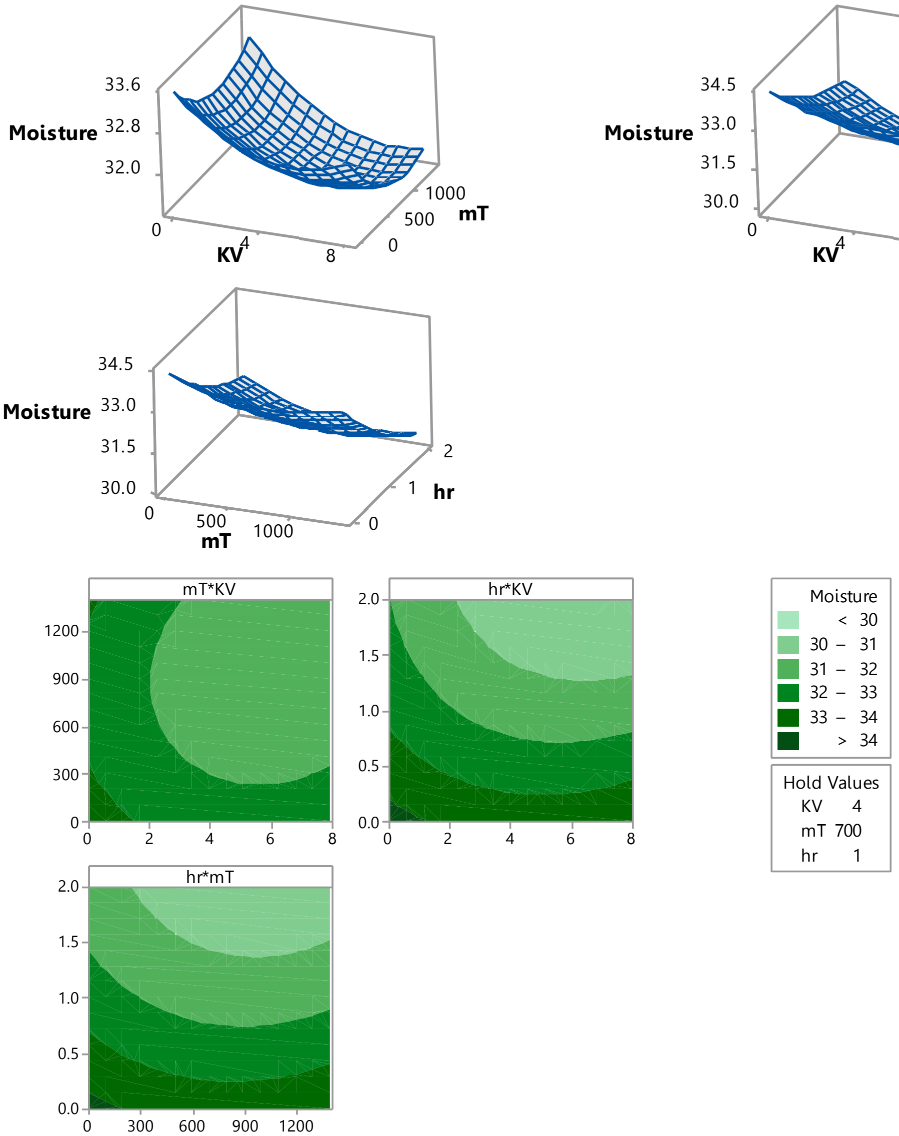

Figure 2 Response surface and contour plots for the effect of electric field (X_1) magnetic field (X_2) and treatment time (X_3) on moisture content.

$$\text{Moisture content} = 34.911 - 0.2951KV - 0.001579Magnet - 1.787\,Time + 0.03661KV*KV + 0.000001Magnet*Magnet + 0.398Time*Time - 0.000068\,KV*Magnet - 0.1019\,KV*Time - 0.000254Magnet*Time \qquad R^2 = 0.9854 \qquad (2)$$

From equation (2), the coefficient of electric field (KV) and treatment time (hr.) were 0.2951 and 1.787 respectively which indicates electric field (KV) and treatment time (hr.) had a significant the effective on the decreasing rate of moisture content (p<0.01). According to electric field strengths cause water dissociation in liquid water. Water dissociation is caused by strengths in electrical fields in liquid water. (Cassone et al., 2014; Saitta, Saija & Giaquinta, 2012). However, with lower fields (10^5 V m^{-1}) encouraging ice formation in supercooled water (Wei et al., 2008) by weakening the hydrogen-bonding. Hydrogen-bonding can become bent or broken when water molecules align with the electrical field. The bias of the balance between hydrogen bonding and van der Waals dispersion attractions towards van der Waals attractions gives rise to a reduction in cyclic hydrogen-bonded clustering.

The relationship between the treatment time (hr.) and electric field (KV) was a co-factor, with a coefficient of -0.1019. In addition, the increasing of magnetic field (mT), electric field (KV) and treatment time (hr.) significantly affected the moisture content (p<0.05). The time treatment was the main factor that affected the decrease of moisture content in bread in the order to the differential between the relative humidity of air and water activity of bread.

Magnetic field (mT) was the factor which affected the decreasing rate of moisture content. The coefficient of magnetic field was -0.001579. It could indicate that magnetic field was the least effective factor to moisture. Other studies demonstrated an increase in liquid water cluster size caused by magnetic fields (Wang et al., 2013). However, magnetic fields (0.16-0.53T) have been shown to reduce the friction coefficient of water in thin films. This may indicate that the hydrogen bond strength has been reduced (Cai et al., 2009).

Figure 3 showed a three-dimensional plot of the amounts of the water activity in the bread as a function of electric field, magnetic field and treatment time. The coefficient of determination (R^2) of the model was 0.9737 indicating that the model adequately represented the real relationship among the parameters chosen. Furthermore, the results of the error analysis indicated that the lack of fit was insignificant (p>0.05) (Mason, Gunst & Hess,1989). The model F-value (20.58) implied that the model was significant. The relationship between electric field (KV), magnetic field (mT) and treatment time (hr.) on the water activity was shown in regression equation (3).

Effect of electric field and magnetic field on water activity

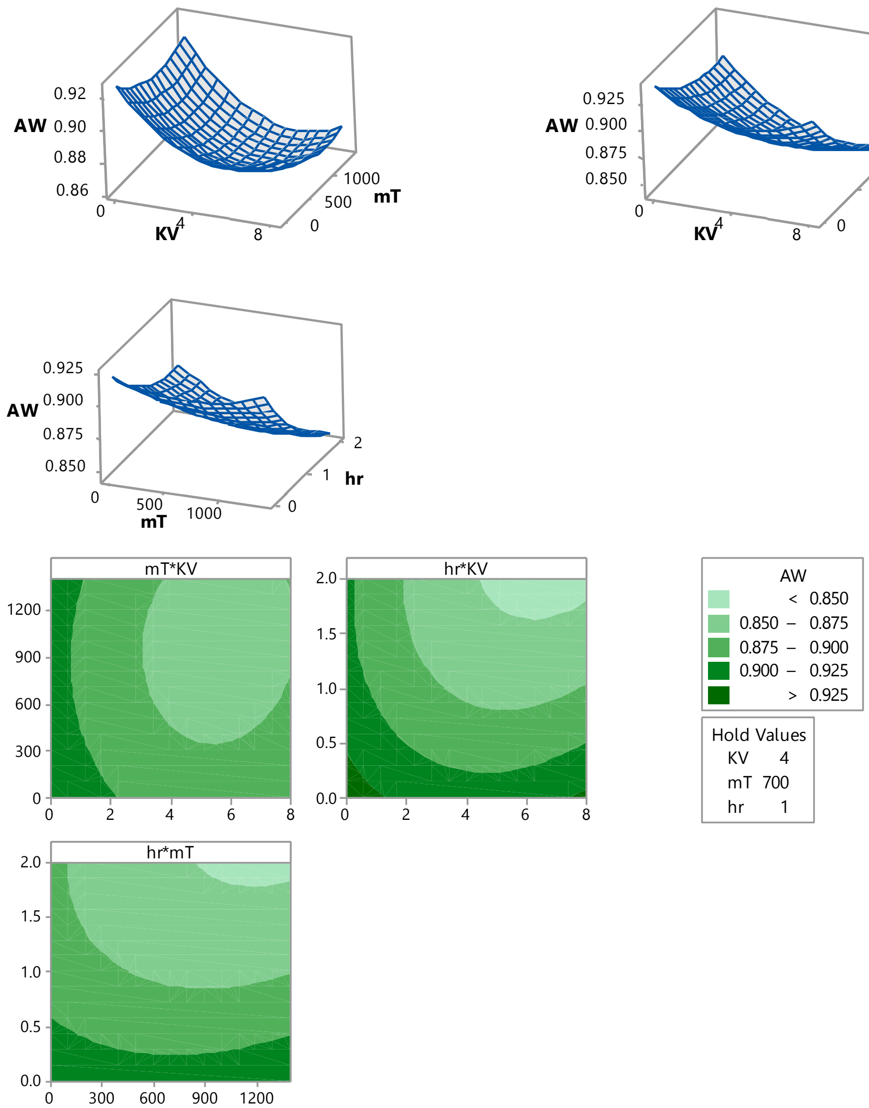

Figure 3 Response surface and contour plots for the effect of electric field (X_1) magnetic field (X_2) and time treatment (X_3) on water activity.

Water activity = 0.94513-0.01159 KV–0.000024Magnet-0.0304 Time+0.001398 KV*KV + 0.000000Magnet*Magnet + 0.01138 Time*Time - 0.000001KV*Magnet - 0.00319 KV*Time - 0.000013 Magnet*Time R^2 = 0.9737 (3)

From equation (3), the coefficient of the treatment time was minimum at -0.0304, indicating that the treatment time was the most effective factor in decreasing the water activity. Electric field also influenced the decreasing rate of water activity, which had the coefficient at -0.01556. The relationship between the electric field (KV) and treatment time (hr.) was the contributing factors for the decreasing rate of water activity with a coefficient at -0.00319. An interaction between the electric field with treatment time had a significant effect on the decreasing rate of water activity more than interaction between the magnetic field with treatment time and interaction between the magnetic field with electric field (p<0.05) (coefficient 0.00319, 0.000013 and 0.000001 respectively). Water activity provided valuable information about microbial spoilage, physical and chemical stability. Water activity and moisture content together provide a complete moisture analysis. When equilibrium (constant mass) was reached, by sorption or desorption, the water content at equilibrium was represented as a function of ERH or water activity (a_w = ERH/100).

Optimization

Table 3 Regression coefficients of the second-order polynomial model for the response variables.

Factor	Estimated coefficients	
	Moisture content	Water activity
Constant	34.911***	0.94513***
Linear		
Electric field (KV)	-0.2951***	-0.01159***
Magnetic field (mT)	-0.001579**	-0.000024**
Time (hr.)	-1.787***	-0.03404***
Quadratic		
Electric field (KV)	0.03661**	0.001398***
Magnetic field (mT)	0.000001**	0.00000*
Time (hr.)	0.398**	0.01138**
Interaction		
Electric field (KV) x Magnetic field (mT)	-0.000068^{ns}	-0.000001^{ns}
Electric field (KV) x Time (hr.)	-0.1019**	-0.00319**
Magnetic field (mT) x Time (hr.)	-0.000254^{ns}	0.000013*
R^2	0.9854^{ns}	0.9737^{ns}

* Significant at p<0.10

** Significant at p<0.05

*** Significant at p<0.01

A three-level and three-variable Box-Behnken design with RSM was used to investigate the effects of the electric field (KV), magnetic field (mT) and treatment time (Time) on moisture content. Using the least square technique, the regression coefficients of the intercept, linear, quadratic and interaction terms of the model were calculated (Table 3). All independent variables showed significant effects on moisture content (*p*<0.10; *p* <0.05 and *p* <0.01). There were significant Linear (*p*<0.05) of magnetic field (mT) and significant linear (*p* < 0.01) of electric field (KV) and treatment time (hr.). It was related with water activity as the moisture content of bread. There was significant quadratic(*p*<0.05) of electric field (KV) and magnetic field (mT) for the moisture content. There was significant interaction (*p*<0.05) of Electric field (KV) x Time (hr.) for the moisture content. But There was significant interaction(*p*<0.05) of Electric field (KV) x Time (hr.) and significant interaction (*p*<0.10) of Magnetic field (KV) x Time (hr.) for the water activity.

Table 4 ANOVA of the regression models for various parameters.

Regression	Sum of square	R^2	F value	P
Moisture content				
Linear	23.8293	85.78	22.12	0.000
Quadratic	2.6108	9.40	0.38	0.769
Interaction	0.9347	3.36	0.13	0.942
Total model	27.3748	98.54	37.56	0.000
Water activity				
Linear	0.009799	71.98	9.42	0.002
Quadratic	0.002447	17.97	0.80	0.518
Interaction	0.001010	7.42	0.29	0.829
Total model	0.013256	97.37	20.58	0.002

With a regression coefficient of 0.9854 and 0.9737 respectively, the prediction model for moisture content and water activity was significant and had a good fit to pre-existing experimental data. The linear model was shown to be significant by the conical model (*p*<0.01), however the quadratic and interaction models were non-significant. Table 4 shows that the factor-analysis of electric field, magnetic field, and treatment time on bread water activity and moisture content were significant (*p*<0.01). By superimposing the contour plots of all three responses, the optimum conditions by which bread moisture content and water activity using electrical and magnetic fields was determined. If the rate of decrease of the moisture content and water activity were sufficiently low, the final condition could be considered optimum. The water activity (Figure 3), and moisture content (Figure 2) were selected due to their status as important indexes of the physical and chemical properties of bread. The main factors were the electric field and magnetic field. The optimum conditions were determined using the Minitab 17–statistical software. The optimal conditions were 8 KV of electric field, 1400 mT of magnetic field and treatment time for moisture content and water activity.

Conclusion

The results presented in this study indicated the effect of electric field, magnetic field and treatment time on moisture content and water activity. Moisture content and water activity (AW) were observed to be significantly influenced by electric field, magnetic field and treatment time. Electric field and magnetic field can be employed for the decreasing of moisture content and water activity without any effect on chemical and physical properties of bread.

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