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OPTIMIZATION OF BREAD BAKING CONDITIONS IN SUPERHEATED STEAM OVEN USING RESPONSE SURFACE METHODOLOGY

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Abstract

The objective of the study was to optimize the bread baking condition in superheated steam oven. Independent variables were the baking time (20, 25, and 30 min) and the baking temperature (180, 200 and 220°C). The bread quality parameter including moisture content, color and texture properties were measured. The response surface methodology was used for the optimization. The effect of baking condition on the parameters of bread were investigated using second- order central composite design. Baking temperature and time significantly affect moisture content and color of bread. Numerical optimization and superimposed contour plots suggested the optimum baking condition of bread to be 180 °C (temperature) and 20.77 minutes (time). The optimum moisture content, L and hardness value are predicted to be 38.52 %, 76.24 and 13.26 N of the baked bread respectively. Baking bread in these conditions produce high quality bread in terms of moisture content, color and texture properties*

Key words: bread, baking, superheated steam oven, optimization and response surface methodology.

INTRODUCTION

Superheated steam is a type of unsaturated steam generated by additional sensible heat to saturated or wet steam. The additional heat causes increasing of steam temperature above the saturation or boiling point at a given pressure. Superheated steam is using for drying products, it causes changes such as starch gelatinization, enzyme destruction, protein denaturation, color and texture changes and deodorization (Devahastin, Suvarnakuta, Soponronnarit, & Mujumdar, 2004), (Tang and Cenkowski, 2000), and (Tang and Cenkowski, 2000, 2001). Superheated steam in food processing not only used for drying but it is preferred for heat treatment of food products. Advantages of super-heated steam oven over conventional oven including air free environment, enhanced product quality, improved energy efficiency, higher drying rate, and reduced the impact of the environment when condensate is reused (Prachayawarakorn, et al 2004, 2006; Prachayawarakorn, et al, 2004), and Tang et al., 2005). Superheated steam helps in preventing oil oxidation whilst preserving nutritional components in food products (Sotome and Isobe, 2011). Food products have a better aroma when they dried with super heat steam. Furthermore, some valuable volatile organic compounds could be recovered and separated by the condenser (Karimi, 2010). Superheated steam has been applied to various kinds of food processing such

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as blanching, pasteurization, extraction, sterilization, and deodorization of the products (Van Deventer and Heijmans, 2001). Recently, it have been used for drying many kinds of food products such as potatoes (Caixeta, Moreira, and Castell-Perez, 2002), grains (Tang and Cenkowski, 2001) and soya bean (Prachayawarakorn et al., 2006).

Some heating methods were studied as alternative to conventional heating including infrared and hot air assisted microwave heating (Datta and Ni, 2002), microwave-hot air combination heating (Lu, Tang, and Liang, 1998), microwave-impingement combination heating (Walker et al., 1993) and halogen lamp-microwave (Keskin, Sumnu, and Sahin, 2004). Bread is an ancient and known staple food that consumed across the globe. Bread baking is the critical step in which the dough transformed into a light, porous, readily digestible and flavorful product, under impact of heat. Thus, the good quality bread production requires a carefully control baking process including the rate and amount of heat application and the humidity level in baking chamber and baking time. During baking process, the most apparent interactions of dough are volume expansion, crust formation, inactivation of yeast and enzymatic activities, denaturation of protein and partially starch gelatinization (Pyler, 1988). The effect of baking time and temperature on bread quality was studied in conventional oven. The end point of baking process depends on quality aspects which are critical in the acceptance of the bread consumer such as color with texture and flavor (Ahrné, et al, 2007); (Purlis and Salvadori, 2007). (Maleki et al, 1980) stated that bread with higher moisture content were initially softer and remain softer for three days than that one of low moisture content. (Patel, Waniska, and Seetharaman, 2005) observed that faster heating rate produced harder crumb bread, higher melting enthalpy of amylopectin and larger amount of leached amylase. (Borczak, et al, 2008) noticed that the duration of baking affected the degree of starch granules destruction. (Najafabadi, et al , 2014) observed that decreasing baking temperature with increasing baking time produced bread with high firmness and low moisture content. (Shittu et al, 2007) declared that increasing baking temperature and time increased the darkness of bread surface. In commercial baking technology, baking temperature and duration used are varied. In spite of technological advances and process automation, the bread baking is still traditional food process and largely depends on skilled technologist and long baking experience (Fahloul et al , 1994). Response surface Methodology (RSM) is statistical technique particularly appropriate for the development of products. RSM was successfully used for baked food (Smith et al., 1988) such as cake (Neville & Setser, 1986); (Vaisey-Genser, Ylimaki, & Johnston, 1987); (Turabi et al. 2008) and bread (Henselman et al. , 1974); (Ylimak et al. , 1988); (Demirekler et al., 2004); (Banu et al. , 2011). Processing techniques that based on various heating models are used in baking technology process. They are potentially resulting in improved quality products. Martin et al. (1991) noticed that breads that baked in an Electrical Resistance Oven (ERO) were staled more slowly than a conventional oven baked one. (Li and Walker, 1996) and (Yin and Walker, 1995) declared that improvements in bread and baked products quality by using impingement and hybrid microwave combination ovens as compared with conventional ones. Microwave baking of bread produced product with unacceptable texture (Ovadia and Walker, 1995) giving hard bread crust and crumb (Shukla, 1993).Whereas, Willyard (1998) stated slower staling of bakeries when baked with increasing microwave energy in combination with conventional baking.

Most of the studies on the effect of baking temperature and time have been done using the conventional oven for baking and some others heating methods such as infrared, combination heating and microwave oven. Superheat steam is not introduced for baking process. Such study will assist in the design and development of successful implementation of commercial baking technology. The objective of the present study was to optimize the baking condition based on the moisture content, color and textural properties of bread baking in superheated steam oven using response surface methodology (RSM).

MATERILS AND METHODS

Materials: Wheat flour, salt and dry yeast were obtained from the market, Penang, Malaysia. The chemicals of analytical grade were obtained from School of Industrial Technology, Universiti Sains Malaysia, Malaysia

Bread Preparation and Baking Test: Straight dough method was used for preparing the bread dough according to Badi and colleagues (Badi et al., 1978) with some modification, using the following formula: Flour=250gms, Dry yeast=2.5gms, Salt=2.5gms, Ascorbic acid=8O ppm and water =165 ml. All ingredients were mixed by a mixer (Spar Food Machinery MFG model 800 - C) for 5 minutes then the dough was placed into incubator (Broofer Bakbar E81) at 30° C and medium relative humidity for fermentation. After 20 min. the dough was taken out of the incubator, punched, divided into rounded dough balls and placed into the incubator again for another 20 min under the same condition. The dough was divided into 120 g pieces after fermentation. Each piece was shaped and placed in baking tin into the incubator for the final proof for 15 min under the same incubation condition for fermentation. The baking was performed using super heated steam oven (Healsio, AV-1500V, SHARP) in super heated steam model and conventional model (normal without steam). Preheated was carried out to reach the specific oven temperature then, the fermented dough samples were baked at 180, 200 and 220° C for 20, 25 and 30 min for each temperature. Three breads were baked at a time.

Moisture content: Moisture content was determined according to the Association of Official Analytical Chemistry Method (Association of Official Analytical Chemistry 2000).The moisture content percentage was calculated according to the following equation:

Moisture content (%) = ((wet weight – dry weight)/ Dry weight) * 100

Color measurement: Crust color of the bread samples was measured using a Minolta color reader (Minolta CM- 3500D colorimeter) after calibration against white and black glass standard. Color was expressed in CIELAB color values (L*, a*, and b*). The L* value represents the lightness to darkness, the a* value represents the greenness to redness spectrum, while the b* value represents the blueness to yellowness. Six reading were carried out from different positions of the bread crust, and then the mean value was calculated.

Texture measurement: Hardness and springiness of bread were measured using texture analyzer (CNS, Farnell, UK) bread was compressed for 50% using 75 mm cylindrical probe. Six readings were carried out of each type of bread.

Experimental design and data analysis for optimization: The central composite face centre design (CCD) was used for selecting baking condition. The independent variables were temperature (X1) and time (X2). Three levels for baking temperature and time were 180, 200, and 220°C and 20, 25 and 30 minutes respectively. The experimental design (the coded and actual values) was presented in Table 1.

Table 1: Central composite experimental design for baking bread using superheated steam

Experiment	Temperature(C,X1)		Time (min, X2)	
No	Coded	Actual	Coded	Actual
1	0	25	0	200
2	1	30	0	200
3	0	25	0	200
4	0	25	-1	180
5	1	30	1	220
6	1	30	-1	180
7	0	25	0	200
8	0	25	0	200
9	-1	20	-1	180
10	-1	20	0	200
11	0	25	0	200
12	0	25	1	220
13	-1	20	1	220

The responses (dependent variables) including moisture content, color and textural properties. The association of dependent variables to independent variables by polynomial by means of the model for predicting the quality of bread (response variable) was expressed as

$$Y= B0+B1X1+B2X2+B12X1X2+B11X1^2+ B22X2^2$$

Where, Y represents the response variable; B0 is constant; B1 and B2 are linear coefficients; B12 is interaction coefficient and B11 and B22 are quadratic coefficients. ANOVA was carried out and then the determination of regression coefficient of quadratic, linear and interaction was done. The model adequacy was performed using model analysis, goodness of fit test and determination coefficient (R^2). F value showing the significance at probability less than 0.05 (Zaibunnisa, Norashikin, Mamot, & Osman, 2009). Three dimensional plot of the regression models were used for performing contour plot and graphic interaction between variables which is recommended by (Vining, 2003) and (Mason, Gunst, & Hess, 2003). The statistical analysis was performed using Design-Expert software version 6.0 (Stat-Ease, Inc., USA).

RESULT AND DISCUSSION

The experimental values of moisture content (MC), color values (L*, a*, and b*), textural properties including hardness and springiness of baked bread are given in Table 2. The quadratic model was fit for MC, color values (L*, a*, and b*), hardness and springiness on the basis of p- value, lack of fit and determination coefficient (R^2). Table 3 shows the analysis of variance result for the tested quality parameters of the quadratic model of response surface methodology.

The linear term, quadratic term and the cross product one are important for MC, color values (L*, a*, and b*), hardness and springiness. Statistical parameters that gained from ANOVA are presented in table 3. The adjusted R^2 were 0.98, 0.96, 0.92 and 0.85 for moisture content, L*, a* and b* color values respectively. The R^2 were 0.99 for moisture content, 0.98 for L*, 0.95 for a* color value and 0.91 for b* value in the equation and lack of fit being insignificant ($p>0.05$). The CV is the ratio of standard error to the observed response (the mean value) and it's measured as percentage. Generally, the reasonable reproducible model when it's CV is not more than 10%. The CV values obtained from the statistical analysis are less than 10%.

Table 2: Experimental values of moisture content (%), L*, a* and b* color values, hardness and springiness of baked bread using superheated steam oven

Run No.	MC	L*	a*	b*	Hardness	Springiness
1	**37.25**	**72.49**	**2.29**	**27.20**	**14.32**	**0.95**
2	**34.42**	**70.29**	**5.76**	**30.09**	**13.48**	**0.95**
3	**37.25**	**72.49**	**2.29**	**27.20**	**14.32**	**0.95**
4	**38.27**	**75.21**	**0.73**	**24.27**	**13.11**	**0.95**
5	**32.67**	**63.76**	**10.27**	**32.82**	**13.33**	**0.96**
6	**35.96**	**72.09**	**3.83**	**28.58**	**14.42**	**0.95**
7	**37.25**	**72.49**	**2.29**	**27.20**	**14.32**	**0.95**
8	**37.25**	**72.49**	**2.29**	**27.20**	**14.32**	**0.95**
9	**38.39**	**76.25**	**0.74**	**23.91**	**13.34**	**0.94**
10	**38.72**	**74.71**	**2.37**	**26.85**	**14.28**	**0.93**
11	**37.25**	**72.49**	**2.29**	**27.20**	**14.32**	**0.95**
12	**37.24**	**64.13**	**8.88**	**33.01**	**14.28**	**0.95**
13	**38.77**	**69.08**	**4.74**	**28.60**	**14.54**	**0.96**

The significant effect of baking temperature and time on the tested quality parameters are presented in Table 3. Both baking temperature and time significantly ($p<0.05$) affected the MC, color values (L*, a*, and b*). The results are agreed with (Shittu et al., 2007), (Keskin et al., 2004) and (Therdthai et al., 2002) who stated that baking temperature and time significantly affected the moisture content and color values, and hardness of bread.

Table 3: Analysis of variance (p- value) for moisture content (%), L*, a* and b* color values, hardness and springiness in response surface quadratic model of baked bread using superheated steam oven

source	MC	L*	a*	b*	Hardness	Springiness
Model	**<0.0001****	**<0.0001****	**0.0002****	**0.0015****	**0.0697**	**0.0599**
Temperature	**0.0002****	**<0.0001****	**<0.0001****	**0.0003****	**0.1897**	**0.0973**
Time	**<0.0001****	**0.0001****	**0.0007****	**0.0024****	**0.3239**	**0.0468**
(Temperature)2	**0.1763**	**0.0009****	**0.0129***	**0.2849**	**0.1879**	**0.0310***
(Time)2	**0.0001****	**0.5175**	**0.1035**	**0.4001**	**0.5719**	**0.7451**
Tem. X time	**<0.0001****	**0.4643**	**0.1965**	**0.8410**	**0.0151***	**0.3323**

*** Statistically significant at p<0.05**
**** Statistically significant at p<0.01**

Moisture content: The moisture content of bread is one of the important marketing tools that affect the consumer buying and slow down the firming process of bread (Cauvain and Young, 2003), (Kulp et al., 1981) and (He and Hoseney, 1990). Moisture content of bread baked in superheated steam ovens is shown in Figure 1.Regard to moisture content were presented to be a function of linear, quadratic and cross product being significant (p<0.05) effects of the baking temperature and time. The lowest moisture content value (32.67 %) observed at 220° C for 30 minutes whereas the highest value 38.77 % which observed at 220° C for 20 minutes (Table2). Moisture content of bread baked in superheated steam oven increased by increasing temperature at constant baking time and this was due to the degree of starch gelatinization and early formations of bread crust that causing more prevention of moisture evaporation of bread during baking. This trend was also observed by other researchers who stated that increasing baking temperature at constant baking time retains higher moisture content in bread where as increasing baking time causes reduction in moisture content of bread crumb (Shittu et al., 2007), (Faridi and Rubenthaler, 1984) and (He and Hoseney, 1990). Similarly, increasing baking time in the same baking temperature causes decrease in moisture content of bread in superheated steam ovens as can be seen in Fig (1) and this due to higher evaporation rate of water during baking process. This trend was also noticed by other researchers when they used conventional and some other heating methods as alternative to conventional heating including infrared and hot air assisted microwave heating (Datta and Ni, 2002) microwave-hot air combination heating (Lu et al., 1998), microwave-impingement combination heating (Walker et al., 1993) and halogen lamp-microwave (Keskin et al., 2004).The obtained result of moisture content is in agreed with that obtained by (Shittu et al., 2007) and (Wagner et al. , 2007) and (Faridi and Rubenthaler, 1984) found that the temperature and time of baking process affects the degree of starch gelatinization. Generally the gelatinization of starch absorbs moisture. The difference in moisture content due to baking time is more pronounced than that one of the temperate.(Keskin et al., 2004) noticed that bread baked using microwave oven lose more moisture than the conventional baked one.

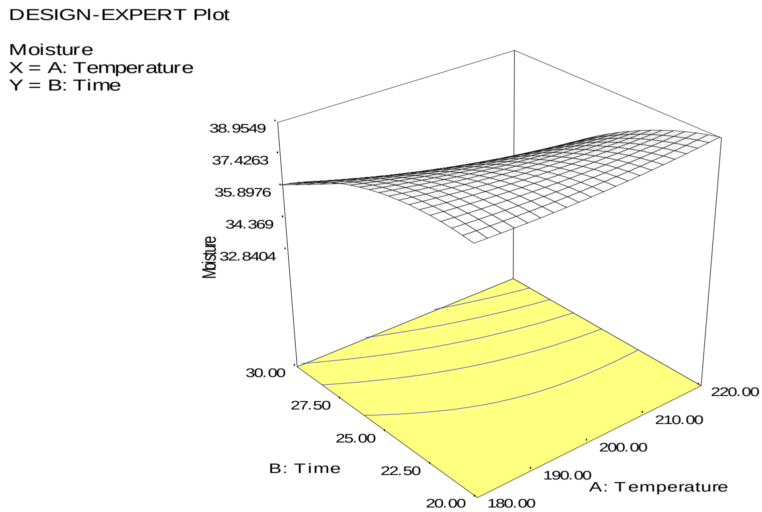

Fig. 1 : Moisture content of bread with increasing of baking time

Color: Color is one of the most important appearance quality attributes of food that influences consumer purchase. Generally consumers perceive pale bread as not well - cooked and easily undergoes microbial damage and staling while the dark one is over-cooked and burn bread. (Purlis and Salvadori, 2007) studied the development of browning during baking using nature and forced convection at 180, 200 and 220°C. They stated that good color of bread crust is yellow to gold in Argentina.

The analysis of bread color is measured using L*, a* and b* color system. The L*, a* and b* color values stand for lightness, redness and yellowness of the color components respectively. The result of color of bread using various baking temperature and time is provided in Figure (2, 3, and 4).

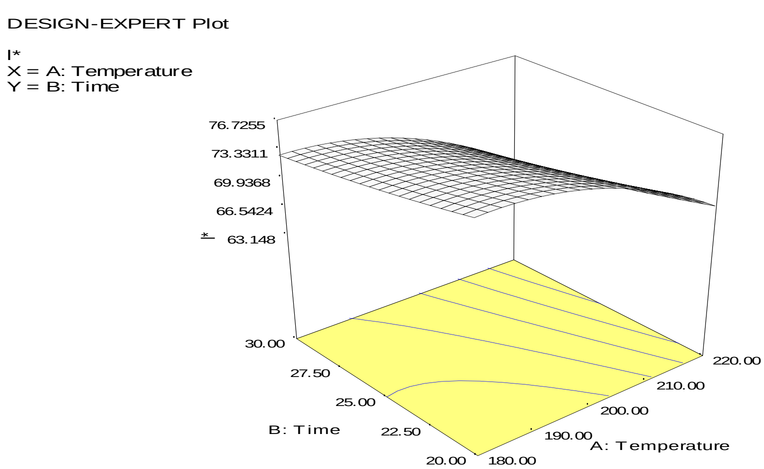

Fig. 2 **Bread color using various baking temperature and time**

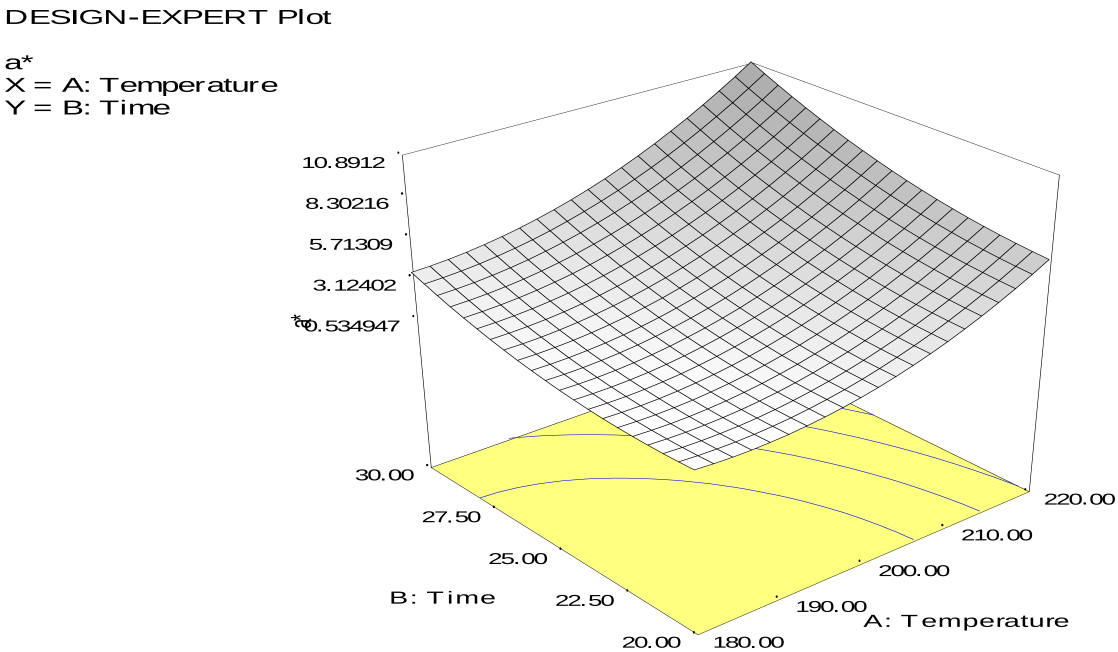

Fig. 3 **Bread color using various baking temperature and time**

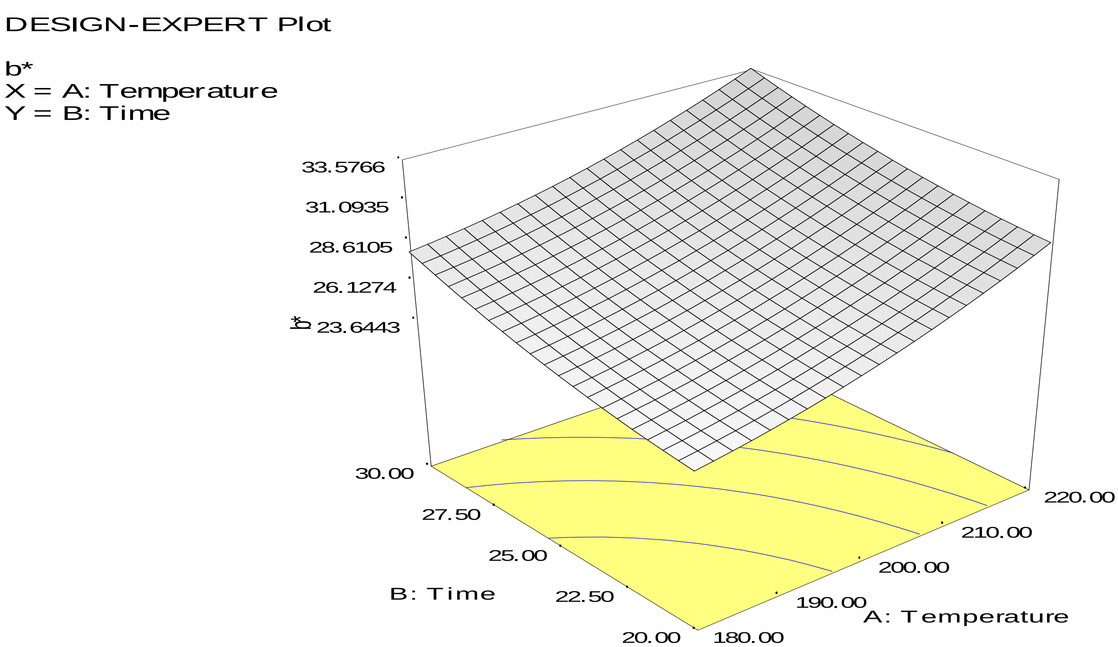

Fig. 4 **Bread color using various baking temperature and time**

Results on color was found to be a function of linear, quadratic and cross product were significant ($p<0.05$) effects of baking temperature and time. Both baking temperature and time significantly affected the color of bread. Baking temperature and time have negative linear relationship with L*color values of bread. The result showed that increasing in baking temperature and time caused reduction in L* values and darkens the crust of bread. This result is agreed with that obtained by (Shittu et al., 2007) (Keskin et al., 2004) and (Therdthai et al., 2002). The factors that governed the color of bread are the moisture evaporated of dough and the Millard reaction during the baking process. As baking time increased, the temperature inside the super heated steam increased that causing high temperature at bread surface which is required for Millard reactions. Millard reaction is non enzymatic browning between carboxyl groups of simple sugars and amino groups of amino acids. (Sumnu, 2001) observed minimum difference in color between bread baked in conventional and combined ovens. Super heated steam baked breads were light and bright, the result is agreed with other authors who observed the good color for the drying products when using super heated steam. In the experimental design, the lowest L* value (63.76) was observed at 220° C for 30 minutes whereas the highest value 76.25 which observed at 180° C for 20 minutes. Increasing temperature and time caused increasing in a* and b* values of color. As can be seen in table 2, bread that baked at 180° C for 25 minutes had the lowest a* value (0.73) whereas bread baked at 220° C for 30 minutes had the highest a* value (10.27). The lowest b* found at 180° C for 20 minutes whereas the highest one at 220° C for 25 minutes (23.91 and 33.01 respectively). Super heated steam brings changes such as starch gelatinization, enzyme destruction, protein denaturation, color and texture changes and deodorization (Devahastin et al., 2004), (Tang and Cenkowski, 2000) and (Tang and Cenkowski, 2001). Superheated steam in food processing not only used for drying but it is preferred for heat treatment of food products and this is due to the advantages of super heated steam oven over convection oven including enhance product quality and preserving nutritional components in food products (Sotome and Isobe, 2011).

Texture: The texture as function of baking temperature and time is given in Fig (5 and 6**.** The lowest hardness value (13.11 N) was obtained at 180°C for 25 min. whereas the highest value (14.54 N) was observed at 220°C for 20 min. The difference observed in bread hardness is affected by the heating rate and time during baking process in super heated steam oven. Bread hardness values increased by increasing baking temperature and time in most bread baked using superheated steam oven (Figure 5). Various thermal conditions affect the starch properties including starch gelatinization, starch retro gradation amylase solubility, pasting viscosity and recrystalization of amylopectin. These various properties are affecting the crumb hardness of bread. (Keskin et al., 2004) found that increasing baking temperature and time causes increasing in bread firmness and the highest baking temperature produced the firmest bread. (Zhang et al., 2007) noticed that an early formation of crust bread limit the expansion and produce bread with intensive structure that causes bread firming. Springiness of bread for most heat treatment of bread was almost the same for superheated steam ovens as provided in table 2. Patel and colleagues noticed that the combination of convective heating and microwave one gives a small difference in crispiness when compared with convective one (Patel et al., 2005). Crumb structure of bread is a critical and important factor that determining the sensorial quality attributes as cans quantified texture and crispiness as well as storage and staling properties of the end product (Mondal & Datta, 2008).

Optimization of baking conditions: The response surface methodology and contour plots for moisture content, color value including L*, a* and b* and textural properties; hardness and springiness of baked bread using superheated steam baking are shown in Figure 1, 2, 3, 4, 5 and 6. Contour plots give the responses towards independent variables to get the optimum point of specific parameter (Liu et al., 2011). There was a specific point in each response surface plot giving the optimum value position within the range of the experimental data. The optimum baking conditions including temperature and time were determined for the optimum response of baked bread. The optimum responses determination was done using numerical optimization and contour plots for analysis the baking temperature and time. The optimum baking conditions were 180 °C and 20.77 min with 92 % desirability. The optimum moisture content, L* and hardness value are predicted to be 38.52 %, 76.24 and

13.26 N of the baked bread respectively. The desirability function of response surface methodology and the validity is given in figure 7 and table 4. Each model predictive quality was tested at the optimum conditioned that suggested. The lack of perfect fitted models and errors of the experiment show the deviations between experimental value and predicted value (Mendes et al., 2001). The result of responses values that obtained were closer to the predicted ones and suited the fitted model.

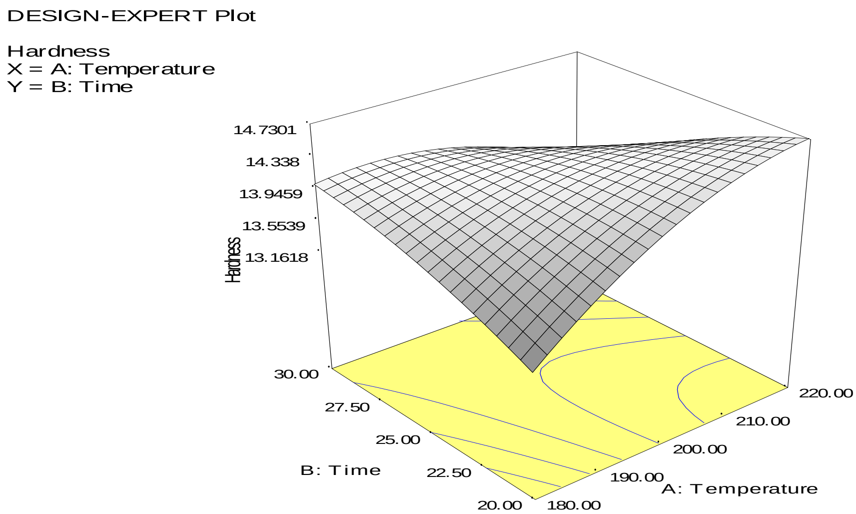

Fig. 5 Bread texture as function of time and temperature (Hardness).

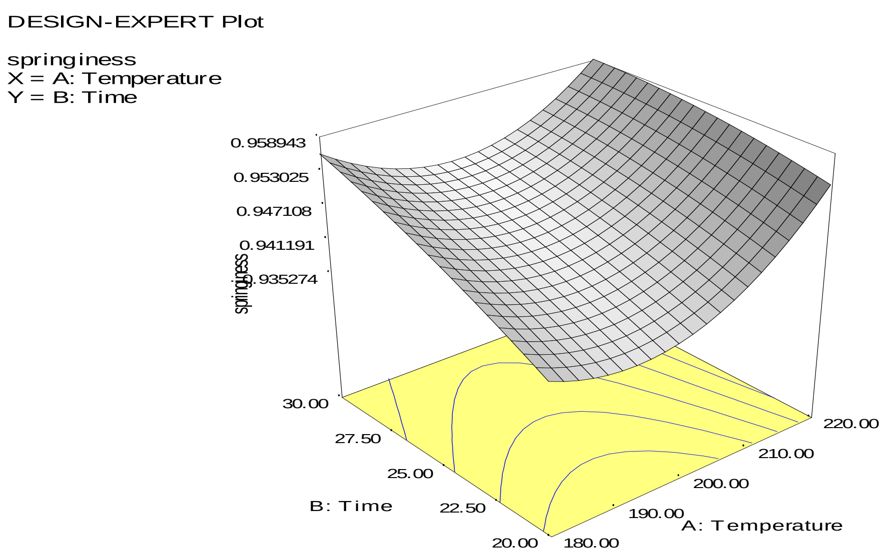

Fig. 6 Bread texture as function of time and temperature (springiness)

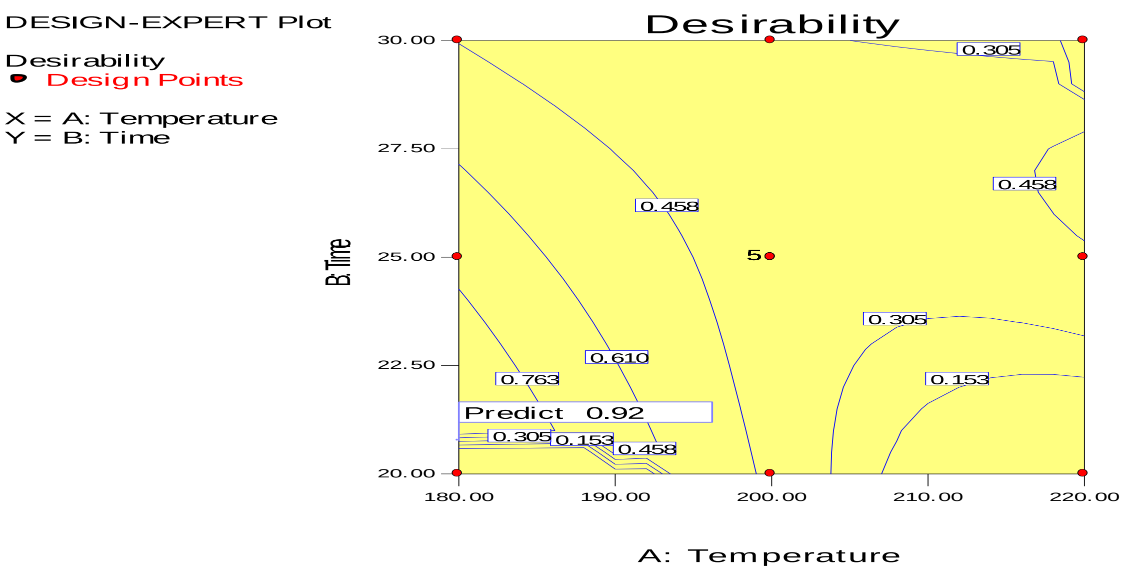

Fig.7: The desirability function of response surface and the validity

CONCLUSION

Optimization of bread baking condition in superheated steam oven was carried out using response surface methodology (second- order central composite design). Baking time used in the study were 20, 25, and 30 min and the baking temperature 180, 200 and 220°C were the independent variables. Moisture content, color and texture properties were evaluated. Both baking temperature and time significantly affect moisture content, color in bread. Numerical optimization and superimposed contour plots suggested the optimum baking condition of bread to be 180 °C for temperature and 20.77 minutes for time. These conditions for bread baking produce high quality bread in terms of moisture content, color and texture properties.

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