GIDA (2014) 39 (3): 131-138 *Research* / Araştırma
doi: 10.5505/gida.65265

MATHEMATICAL MODELING and THIN LAYER DRYING of CHICKEN MEAT ENRICHED BAGUETTE BREAD SLICES

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Received / Geliş tarihi: 24.10.2013
Received in revised form /Düzeltilerek Geliş tarihi: 14.01.2014
Accepted / Kabul tarihi: 24.02.2014

Abstract

The aim of this study is to determine thin layer drying behaviour of chicken meat powder (CMP) and chicken meat (CM) enriched baguette bread slices at 170, 190 and 210 °C in a convection oven for production of two new snacks. Only falling-rate period was observed for both of the snacks, however only for 10%-CMP enriched sample at 170 °C drying had a constant-rate period as well. Nine different mathematical models were fitted to experimental drying data and those tested models were compared based on the model selection criteria (highest $adj\text{-}R^2$, lowest χ^2 and RMSE) by using nonlinear regression analysis. Midilli et al. model was determined as the best model among all for predicting the moisture ratios of baguette slices with respect to time. Effective diffusion coefficient was found between 5.471×10^{-8}-8.308×10^{-8} m^2/s for CMP enriched baguettes, while it was between 4.458×10^{-8}-7.498×10^{-8} m^2/s for CM enriched baguettes. Also mathematical expressions were defined to explain the temperature dependency of effective diffusion coefficients..

Keywords: Drying, mathematical modeling, diffusion, activation energy

TAVUK ETİYLE ZENGİNLEŞTİRİLMİŞ BAGET EKMEĞİ DİLİMLERİNİN İNCE TABAKA KURUTULMASI ve MATEMATİKSEL MODELLEMESİ

Özet

Bu çalışmanın amacı, tavuk eti unu (CMP) ve tavuk eti (CM) ile zenginleştirilmiş baget ekmeği dilimlerinin 170, 190 ve 210 °C'de konveksiyonlu fırında ince tabaka kurutulması ve yeni iki atıştırmalık çerez üretilmesidir. Tüm çerezler için kuruma işlemi yalnızca azalan akı bölgesinde gerçekleşirken, %10-CMP ile zenginleştirilen çerezlerin 170 °C'de kurutulmasında azalan akının yanı sıra sabit akı bölgesi de gözlemlenmiştir. Dokuz farklı kuruma modeli deneysel kuruma verilerine uygulanmış ve verilen modeller model seçim ölçütüne göre (en yüksek düzeltilmiş belirleme katsayısı ile en düşük indirgenmiş ki-kare ve en düşük kök ortalama kare hatası) doğrusal olmayan regresyon analizi uygulanarak karşılaştırılmıştır. Midilli et al. modelinin, verilen modeller arasında baget dilimlerinin zamana bağlı nem oranını tahminlemekte en iyi model olduğu görülmüştür. Etkin difüzyon katsayısı CMP ile zenginleştirilen örnekler için 5.471×10^{-8}-8.308×10^{-8} m^2/s arasında değişirken, CM ile zenginleştirilen örneklerde 4.458×10^{-8}-7.498×10^{-8} m^2/s arasında olduğu bulunmuştur. Ayrıca etkin difüzyon katsayısının sıcaklığa bağımlılığını gösteren matematiksel eşitlikler tanımlanmıştır.

Anahtar kelimeler: Kurutma, matematiksel modelleme, difüzyon, aktivasyon enerjisi

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INTRODUCTION

Increasing life standards impose people to change their eating habits and promote them to consume unhealthy, high energy, high fat, and sugar containing fast foods and snacks. It was stated that 30.3% of people reported that they are consuming fast food on a typical day (1). But appropriate snacking can help to maintain healthy body weight and encourage people for consumption of healthy choices on daily diet (2). Also certain populations in the world may not be receiving adequate levels of nutrients, may be experiencing nutritional deficiencies, and may be in environments in which disease or other adverse conditions affect their metabolic states (3). For eliminating these negative effects, some strategies are developed, such as enrichment of frequently consumed foods to regulate the nutrient intake in daily diet. Especially increasing protein content of widely consumed bread is one of the major concerns in most researches (4-7). However these types of enriched breads are susceptible to chemical, physical, and sensorial deteriorations as well as microbiological instabilities with their high moisture contents (up to 40%). Removal of that excess water from food can help to give a longer shelf life without any spoilage and increase stability of food during storage (8).

Drying is one of the oldest food preservation methods for decreasing available water in food materials and increasing shelf life of foods. This process involves simultaneous heat and mass transfer, however due to the complexity of this process, some researchers developed semi-theoretical models derived from Fickian diffusion approach to explain the water movement within the solid food materials (9). In these models, thin layer structure is assumed to simplify the Fick's second law and based on the solution of partial differential equations, extensive body of literature has been arisen for demonstrate the theoretical drying of several agricultural materials and food products. However the high energy intensity of drying process encourages food scientists to understand, model and optimize the whole process for each of new developed foodstuffs.

The objectives of this study is to produce new, rusk like, protein enriched snacks by adding chicken meat powder and chicken meat into baguette bread formulations and determine the drying mechanism of these snacks with increasing drying temperature. Also thin layer modeling of the drying process to predict and simulate the drying behaviour of these new snacks was studied. For this purpose, nine different thin layer drying models were fitted to experimental drying data and applicability of the models was compared according to statistical parameters.

MATERIALS and METHODS

Materials

The white wheat flour (type 650) was obtained from Yuksel Tezcan Gida A.S. (Turkey). The industrial chicken meat powder and raw whole chicken were supplied from Banvit A.S. (Turkey) and Keskinoglu A.S. (Turkey), respectively. EMCE gluten plusP baking improver (ABP Mühlenchemie A.S., Turkey) with a rate of 0.3% (on flour basis) were blended with dry ingredients. Other ingredients were obtained from a local market.

Production of Chicken Meat Enriched Baguette Breads

The raw whole chicken was first boiled in tap water until its cold point temperature exceeds 70 °C. Then skin and the bones were removed and the cooked chicken meat was grounded into small pieces in a blender (Waring Blender, USA) to produce final chicken meat enrichment source.

The bread production was optimized using traditional French baguette processing as stated in the study of Baardseth et al. (10) with slight modifications. The level of chicken meat powder (CMP) and chicken meat (CM) - between 0-30% - were determined from a series of sensory analysis. At the first step of sensory analysis, there was no statistical difference observed ($P<0.01$) in overall acceptance between samples as stated in the study of Cakmak (5). At the second step, the chosen bread formulations (three lowest level of enrichment) were flavoured with 1% spice mix (22.5% tomato powder, 17.5% red pepper powder, 17.5% coriander powder, 15% thyme, 15% cumin and 12.5% black pepper) and 2% virgin olive oil and according to the overall acceptance scores of second step, again no statistical difference observed ($P<0.01$). Finally 10% level of enrichment was selected for both of baguette breads (5). The detailed formulations of these baguettes were given in Table 1.

Table 1. Enriched baguette bread formulations

Ingredients (g)	CMP-enriched baguette	CM-enriched baguette
White flour	900	900
Chicken meat powder	100	-
Chicken meat	-	100
Yeast	27	27
Salt	10.8	10.8
Baking improver	2.7	2.7
Spice mix	9	9
Virgin olive oil	18	18
Water[1]	680	540

[1]Determined from farinograph at 500 BU.

All the ingredients were mixed with an adequate quantity of water, which was determined according to the farinograph water absorption levels at 500 BU and kneaded in a spiral mixer (ISM-10, Inoksan, Turkey) to get dough of a moderately stiff consistency. The dough was then placed in a fermentation chamber (FGM 100, Inoksan, Turkey) for 30 min at 30 °C and 75% RH. After manual aeration of dough for 1 min, they were divided into 400 g portions, rolled into the baguette shape before placing in baking pans and allowed to rest in the same fermentation chamber for 45 min. After the proofing period, the baguettes were baked at decreasing temperatures from 250 °C to 220 °C in a preheated rotary oven (FD-200, Fimak, Turkey) for 15 min and to avoid dryness of the bread crusts, steam was injected for the first 30 sec of baking. Then baked baguettes were subjected to a 4 hour cooling period at room temperature before performing of all analyses. Initial moisture contents of enriched baguette breads were determined according to AOAC 934.01 vacuum oven method (11).

Drying of Baguette Slices

Baguette samples were first sliced into 5 mm thickness with an electric slicer prior to drying. Convection oven (Inoksan FBE 010, Turkey) was preheated until the set temperatures of 170, 190 and 210 °C have been reached with lowest fan speed (up to 1 m/s). Samples were uniformly placed into the aluminium oven tray (32x34 cm) in the middle rack position and the trays were weighed every 2 min until constant weight was observed. All drying tests were performed at least in triplicate.

Mathematical Modeling of Drying

Fick's second law of diffusion is generally used to describe moisture diffusion in a solid particle;

$$\frac{\partial M}{\partial t} = D_{eff}\frac{\partial^2 M}{\partial x^2} \quad (1)$$

where M is local moisture content on dry basis, D_{eff} is effective diffusion coefficient, t is time and x is spatial coordinate (12). The diffusion equation for the falling-rate drying period for a slab can be derived assuming that the initial moisture distribution is uniform, zero volume change (no shrinkage), and external mass transfer resistance is negligible and moisture is migrating only by diffusion (13). Solution of this equation for an infinite slab can be calculated according to the following formula;

$$MR = \frac{M-M_e}{M_0-M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} exp\left[(2n+1)^2\frac{\pi^2}{4}\frac{D_{eff}t}{L^2}\right] \quad (2)$$

where MR is the dimensionless moisture ratio, M_0 is initial moisture content (kg water/kg dry solid) at t=0, M_e is equilibrium moisture content (kg water/ kg dry solid), M is the moisture content at time t (kg water/kg dry solid) and L is the thickness of the slab (m) for the solids when evaporation occurs from only one face (14). At sufficiently large drying times (D_{eff} xt/L^2>0.1), only the first term in the series of expansion is taken into account to calculate the effective diffusion coefficient (15);

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}t}{4L^2}\right) \quad (3)$$

Nine different thin layer drying models which are often used in literature were tested to choose the best model representing the oven drying of enriched baguette slices (Table 2). These expressions were tested in MATLAB software version 7.7.0 (MathWorks Inc., USA) using curve-fitting tool box. To evaluate the goodness of fit, regression analysis was performed. Adjusted R-square (*adj-R^2*) was chosen as the primary indicator of the fit quality of the tested models, because this parameter is an improved estimation of multiple correlation coefficient (R^2). In addition to *adj-R^2*, reduced chi-square (χ^2) and root mean square error (RMSE) were determined and calculated according to the following equations;

$$adj - R^2 = 1-(1-R^2)\frac{N-1}{N-m-1},$$

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i-MR_{pre,i})\cdot\sum_{i=1}^{N}(MR_i-MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{N}(MR_i-MR_{pre,i})^2\right]\cdot\left[\sum_{i=1}^{N}(MR_i-MR_{exp,i})^2\right]}} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i}-MR_{pre,i})^2}{N-n} \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i}-MR_{pre,i})^2\right]^{1/2} \quad (6)$$

where $MR_{pre,i}$ expresses the predicted moisture ratio, $MR_{exp,i}$ expresses the experimental moisture ratio, N is the number of observations, m is number of regression parameters, and n is the number of constants. Reduced chi-square was calculated by using Microsoft Excel. The model having the highest $adj\text{-}R^2$, with the lowest χ^2 and $RMSE$ was chosen as the best fitting model explaining the drying behaviour of enriched baguette bread slices.

And they were dried to 0.040±0.001 g water/g dry matter and 0.031±0.002 g water/g dry matter average, respectively at given drying conditions. The samples had reached this equilibrium moisture contents between 20 and 32 minutes depending on the drying temperature. For all of the samples, increasing air temperature caused a decrease in drying time to reach the equilibrium moisture content. The experimental drying rates versus moisture contents are shown in Figure 1 and 2.

Table 2. Mathematical models fitted to drying data

Model no	Model name	Model expression	Reference
1	Lewis	$MR = \exp(-kt)$	(16)
2	Henderson and Pabis	$MR = a\exp(-kt)$	(17)
3	Modified Henderson and Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(18)
4	Logarithmic	$MR = a\exp(-kt) + c$	(19)
5	Page	$MR = \exp(-kt^n)$	(20)
6	Two term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	(21)
7	Two term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	(22)
8	Parabolic	$MR = a + bt + ct^2$	(23)
9	Midilli et al.	$MR = a\exp(-kt^n) + bt$	(24)

Determination of Effective Diffusion Coefficient and Activation Energy

When the time is plotted against the logarithm of free moisture content, a straight line will be obtained (15) and the effective diffusion coefficient (D_{eff}) was calculated from the slope of that line as shown in below equation;

$$K = [(\pi^2 D_{eff}) / (4L^2)] \quad (7)$$

The moisture diffusion in a solid is a function of temperature and moisture content (25). The temperature dependency of effective diffusion coefficient (D_{eff}) is often described by Arrhenius equation as follows;

$$D_{eff} = D_0\exp(-E_a/RT) \quad (8)$$

where E_a is the activation energy (kJ/mol), T is the absolute temperature (K), D_0 is a reference diffusion coefficient (m^2/s) and R is the universal gas constant (8.314 kJ/mol.K) (26). The activation energy can be determined from the plot of ln (D_{eff}) versus $1/T$.

RESULTS and DISCUSSION

Drying Kinetics

The initial average moisture content of 10%- CMP enriched baguette bread was 0.564±0.002 g water/g dry matter while it was 0.542±0.001 g water/g dry matter for 10%- CM enriched baguette bread.

Only falling-rate period was observed for both of the enriched baguettes at all drying air temperatures, however only for 10%-CMP enriched sample at 170 °C drying had a constant-rate period as well. This shows that there was no sufficient free water available on the surface of samples, since there was no constant rate period observed. In drying of many food materials, the motion of water inside solid material during falling rate period occurs by diffusion (27). The thickness of both samples during drying was decreased less than 4%, so the assumption of negligible shrinkage was confirmed for the simplification of diffusion equation as similarly reported by Xu and Kerr (28).

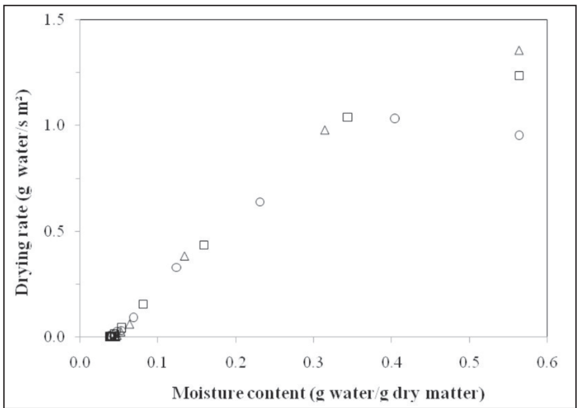

Figure 1. Experimental drying curves of 10%-CMP enriched baguette slices at 170 °C (o), 190 °C (□), 210 °C (∆).

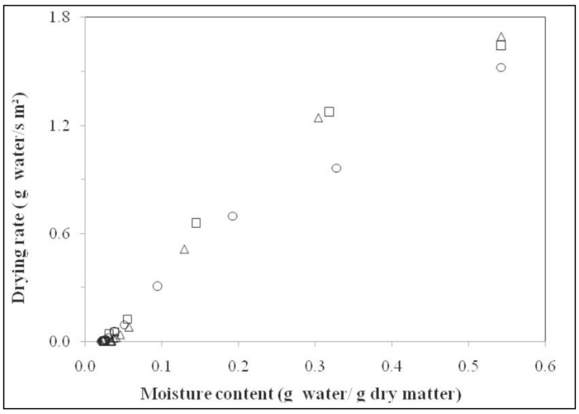

Figure 2. Experimental drying curves of 10%-CM enriched baguette slices at 170 °C (o), 190 °C (□), 210 °C (Δ).

Mathematical Modeling of Drying

The moisture contents of samples were transformed into dimensionless moisture ratio to perform modeling studies easily. The experimental moisture ratios were fitted to mathematical models shown in Table 2. These models were fitted to experimental data and obtained drying constants, *adj-R²*, χ^2 and RMSE are presented in Table 3 and 4. Those constants given in the tables will help the researchers to predict the drying behaviour of a similar food material without doing any experimental studies.

Most of the tested models had good correlations with the experimental data (*adj-R²*>0.99), however parabolic model with its comparably low correlation coefficient was insufficient to represent the drying data. But according to the model selection criteria, the highest *adj-R²*, with the lowest χ^2 and RMSE values were obtained for Midilli et al. model. Also the goodness of fit can be seen in Figure 3 and 4 with respect to time. This model is very successful for explaining drying kinetics of various agricultural and food products (29-31).

The comparison of the experimental and Midilli et al. predicted moisture ratios were shown in Figure 5 and 6. The predicted values were accumulated around a straight line, which was a strong proof of the chosen models suitability (24).

Effective Diffusion Coefficient and Activation Energy

Effective diffusion coefficients were calculated from Eq. 7, and the values of 10%-CMP enriched baguette slices were found as 5.471×10^{-8}, 6.181×10^{-8}, and 8.308×10^{-8} m²/s at 170, 190, and 210 °C drying temperatures, respectively. The effective diffusion coefficients of 10%-CM enriched baguette slices were found as 4.458×10^{-8}, 5.775×10^{-8}, 7.498×10^{-8} m²/s at 170, 190, and 210 °C

Table 3. Model parameters and statistical results of thin layer drying of 10%-CMP enriched baguette slices

Model no	Temperature (°C)	Model constants	adj-R²	χ^2	RMSE
1	170	k=0.004391	0.9833	0.00146	0.03825
	190	k=0.005615	0.9902	0.00081	0.02846
	210	k=0.006403	0.9904	0.00099	0.03150
2	170	a=1.045, k=0.004549	0.9841	0.00139	0.03735
	190	a=1.025, k=0.005726	0.9901	0.00082	0.02859
	210	a=1.020, k=0.006500	0.9898	0.00105	0.03246
3	170	a=0.4704, k=0.004547, b=0.2837, g=0.004531, c=0.2891, h=0.004549	0.9777	0.00195	0.04420
	190	a=0.3143, k=0.005717, b=0.3967, g=0.005733, c=0.3136, h=0.005717	0.9857	0.00118	0.03437
	210	a=0.3335, k=0.006494, b=0.3792, g=0.006512, c=0.3063, h=0.006487	0.9816	0.00190	0.04356
4	170	a=1.056, k=0.004381, c= -0.0138	0.9843	0.00137	0.03706
	190	a=1.032, k=0.005596, c= -0.008187	0.9899	0.00083	0.02888
	210	a=1.032, k=0.006262, c= -0.01334	0.9898	0.00106	0.03251
5	170	k=0.004908, n=0.9783	0.9800	0.00175	0.04188
	190	k=0.01486, n=0.8202	0.9736	0.00218	0.04667
	210	k=0.01558, n=0.8364	0.9763	0.00245	0.04945
6	170	a=3.097, k_0=0.003667, b= -2.06, k1=0.003306	0.9849	0.00133	0.03645
	190	a=4.284, k_0=0.004009, b= -3.263, k1=0.003607	0.9922	0.00064	0.02535
	210	a= 3.854, k_0=0.01119, b= -2.859, k1=0.01506	0.9998	0.00002	0.00442
7	170	a=2.052, k=0.006854	0.9994	0.00005	0.00707
	190	a=2.004, k=0.008522	0.9997	0.00003	0.00529
	210	a=2.071, k=0.009926	0.9998	0.00002	0.00410
8	170	a=0.7962, b= -0.001495, c=6.242×10^{-7}	0.8424	0.01382	0.11760
	190	a=0.7396, b= -0.001525, c=6.913×10^{-7}	0.7838	0.01783	0.13350
	210	a=0.825, b= -0.00229, c=1.415×10^{-6}	0.8553	0.01491	0.12210
9	170	a=0.9997, k=0.0002916, n=1.483, b=1.429×10^{-6}	0.9998	0.00002	0.00428
	190	a=0.9998, k=0.0006441, n=1.401, b=1.788×10^{-6}	0.9998	0.00002	0.00390
	210	a=1.00, k=0.0006688, n=1.428, b=1.894×10^{-6}	0.9999	0.00001	0.00306

Table 4. Model parameters and statistical results of thin layer drying of 10%-CM enriched baguette slices

Model no	Temperature (°C)	Model constants	adj-R^2	χ^2	RMSE
1	170	k=0.005096	0.9966	0.00025	0.01571
	190	k=0.006811	0.9771	0.00193	0.04396
	210	k=0.007435	0.9790	0.00214	0.04624
2	170	a=1.015, k=0.005158	0.9966	0.00025	0.01574
	190	a=1.025, k=0.006936	0.9759	0.00214	0.04516
	210	a=1.021, k=0.007543	0.9772	0.00232	0.04821
3	170	a=0.3382, k=0.005159, b=0.3382, g=0.005158, c=0.3382, h=0.005158	0.9954	0.00034	0.01838
	190	a=0.3416, k=0.006935, b=0.3416, g=0.006935, c=0.3416, h= 0.006934	0.9638	0.00306	0.05531
	210	a=0.3406, k=0.007533, b=0.3406, g=0.007529, c=0.3406, h=0.007584	0.9590	0.00418	0.06469
4	170	a=1.017, k= 0.005111, c= -0.003058	0.9965	0.00026	0.01607
	190	a=1.03, k=0.006827, c= -0.005713	0.9740	0.00220	0.04688
	210	a= 1.03, k=0.007341, c= -0.009954	0.9752	0.00253	0.05034
5	170	k=0.00649, n=0.9428	0.9914	0.00063	0.02511
	190	k=0.01855, n=0.8098	0.9598	0.00340	0.05828
	210	k=0.01742, n=0.8175	0.9559	0.00450	0.06710
6	170	a=1.069, k_0=0.005152, b= -0.05693, k_1=0.005208	0.9961	0.00029	0.01692
	190	a=1.010, k_0=0.006939, b=0.01462, k_1=0.006491	0.9710	0.00245	0.04947
	210	a=1.019, k_0=0.007524, b=0.000011, k_1=0.009868	0.9707	0.00299	0.05467
7	170	a=0.8131, k=0.005305	0.9963	0.00027	0.01657
	190	a=1.00, k=0.006812	0.9752	0.00209	0.04576
	210	a=1.088, k=0.007488	0.9767	0.00237	0.04871
8	170	a=0.7094, b= -0.00127, c=5.031x10^{-7}	0.7802	0.01617	0.12720
	190	a=0.7146, b= -0.001609, c=7.911x10^{-7}	0.7208	0.02359	0.15360
	210	a=0.7886, b= -0.002253, c=1.414x10^{-6}	0.7848	0.02195	0.14820
9	170	a=0.9991, k=0.001863, n=1.183, b=1.766x10^{-6}	0.9992	0.00006	0.00789
	190	a=1.001, k=4.96x10^{-5}, n=1.963, b=4.553x10^{-6}	0.9948	0.00044	0.02090
	210	a=1, k=5.31x10^{-5}, n=1.974, b=5.588x10^{-6}	0.9977	0.00024	0.01540

drying temperatures, respectively. Those values were calculated with high multiple correlation coefficients, and they were R^2>0.94 for 10%-CMP enriched and R^2>0.99 for 10%-CM enriched baguette slices. Above given values are consistent with the other agricultural and food products that are reviewed by Erbay and Icier (9). It was stated by Chen (13) that, the diffusivity of bread having moisture content between 0.1-0.75 kg water/kg dry matter were given between 2.8x10^{-9} to 9.6x10^{-7} m^2/s while Tong and Lund (32) found between 2.5x10^{-9} to 5.5x10^{-7} m^2/s for bread having moisture of 0.1-0.7 kg water/kg dry matter for temperatures between 20-100 °C, which are consistent with our present study. Xu and Kerr (28) reported slightly lower values for tortilla chips for comparably low drying temperatures; however the structure of the tortilla chips were probably different than our samples which influences the moisture distribution and movement inside the material, and so changing the mechanism of drying.

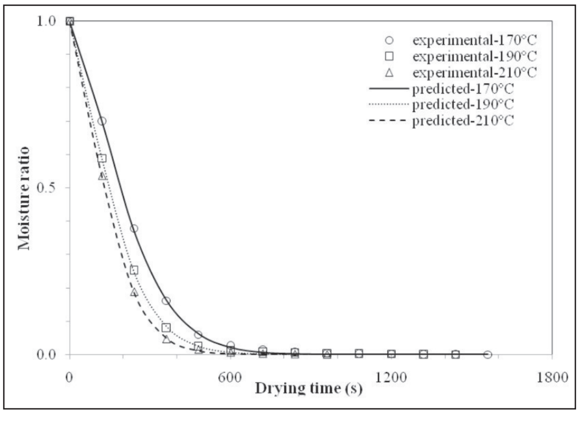

Figure 3. Variation of experimental and Midilli et al. predicted MRs of 10%-CMP enriched baguette slices at 170 °C (o), 190 °C (□), and 210 °C (Δ).

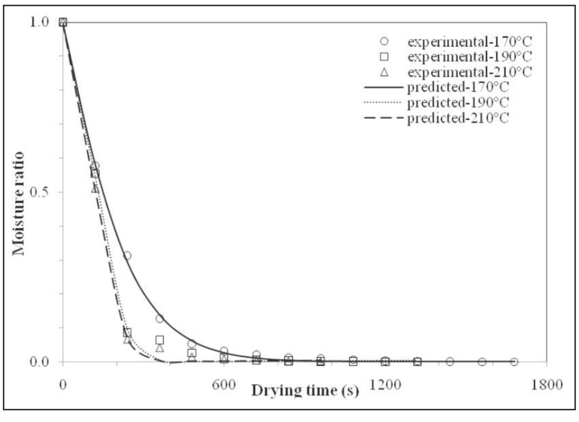

Figure 4. Variation of experimental and Midilli et al. predicted MRs of 10%-CM enriched baguette slices at at 170 °C (o), 190 °C (□), and 210 °C (Δ).

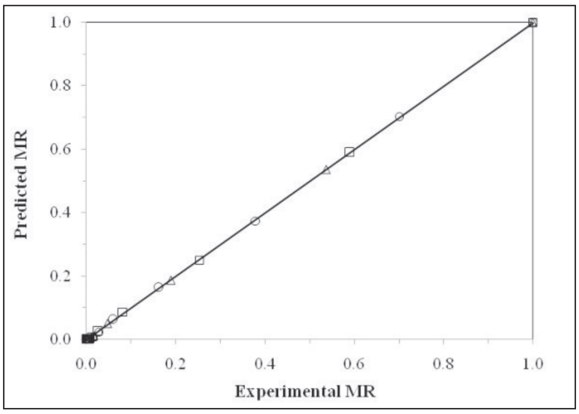

Figure 5. Experimental versus predicted MRs of 10%-CMP enriched baguette slices at 170 °C (o), 190 °C (□), 210 °C (Δ).

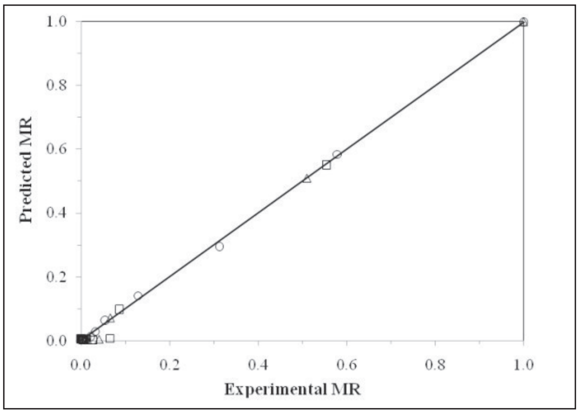

Figure 6. Experimental versus predicted MRs of 10%-CM enriched baguette slices at 170 °C (o), 190 °C (□), 210 °C (Δ).

As effective diffusion coefficients are strongly correlated with drying temperature, Xanthopoulos et al. (33) were suggested developing a mathematical model to relate the temperature dependency, treating the effective diffusion coefficient as the dependent variable and temperature as the independent variable. The following expressions were determined according to aforementioned study for both of the baguette samples by regression analysis;

$$D_{eff}\,(\text{CMP}) = 5.984 \times 10^{-5} \exp\left(-3166/T\right) \quad (9)$$

$$D_{eff}\,(\text{CM}) = 2.433 \times 10^{-5} \exp\left(-2795/T\right) \quad (10)$$

where T refers to the drying temperature (K). $Adj\text{-}R^2$ and RMSE were found as 0.8846 and 5.015×10^{-9} for CMP enriched baguettes, while for CM enriched baguettes they were 0.9986 and 5.791×10^{-10}. Those values testify the accuracy of derived expressions.

The activation energies were calculated as 18.47 kJ/mol for CMP enriched samples, and 23.12 kJ/mol for CM enriched samples, respectively. This shows that temperature sensitivity of the activation energy of CM enriched baguette bread slices were higher than the CMP enriched baguette bread slices. These values are rather lower than the values for bread, biscuit and muffin where the diffusion coefficient dependency expressed as a function of both temperature and moisture content (32).

CONCLUSION

The thin layer drying behaviour of chicken meat powder and chicken meat enriched baguette bread slices at 170, 190 and 210 °C in convection oven were studied. The samples had reached the equilibrium moisture contents (0.031 and 0.040 g water/g dry matter) between 20-32 min. Only falling-rate period was observed for all samples; however 10%-CMP enriched sample at 170 °C drying had a constant-rate period as well. Drying rate was significantly affected by increasing drying temperatures. Nine different mathematical models were tested and, Midilli et al. model was found satisfactory to represent the drying behaviour of these snacks. Also depending on the activation energies, chicken meat enriched samples were found to be more heat sensitive than chicken meat powder enriched samples.

ACKNOWLEDGEMENT

This research is fully funded by TUBITAK with project no: 110-O-030.

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