EFFECT OF DIFFERENT TEMPERATURE ON REHYDRATION KINETICS OF CHICKEN BREAST MEAT CUBES

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***Abstract*— In the present research, it was aimed to understand the effect of different rehydration temperatures (80, 90 and 100°C) on rehydration kinetics of hot air dried chicken breast meat cubes. The rehydration rate increased with the increasing of temperature of rehydration water. ΔE and chroma values of the rehydrated samples at 90°C and 100°C samples were found statistically similar. To describe the rehydration kinetics, four different models, Peleg's, Weibull, first order and exponential association, were considered. Between these four models proposed Peleg's model gave a better fit for all rehydration conditions applied. The effective moisture diffusivity values of chicken meat increased as water rehydration temperature increased.**

***Keywords*— Chicken breast meat; Rehydration; Kinetic; Color; Modeling.**

I. INTRODUCTION

Like other animal origin foods, chicken meat shows superior nutritious properties in terms of high biological value protein, polyunsaturated fatty acid, significant amount of vitamins from group B and minerals especially iron and zinc (Barroeta, 2007; Milicevic *et al.*, 2014). Also, chicken meat is the cheapest and the most accessible meat source in recent years (Yıldırım and Ceylan, 2008). However, the chicken meat is very perishable to microbiological spoilage. So, the various techniques (drying, curing, canning, etc.) are applied both extend in order to shelf-life and to increase product range in chicken market (Babic *et al*., 2009). Drying is one of the efficient ways that improve the safety of food with regard to microbiological and chemical stability (Feng and Tang, 1998). Drying is an essential step to produce fermented, cured and powdered meat products. Dried chicken meat is used as an ingredient to various ready-to-eat foods such as soup, pizza, noodles, etc. (Başlar *et al*., 2014). However, the drying process generally can negatively affect the quality (loss of nutrients, color, texture, flavor, etc.) of the final product (Scala and Crapiste, 2008). So, rehydration is carried out to improve physical properties of dried product. Rehydration is a complex process used for restoration of dried foods treated with water (Falada and Abbo, 2007). The ability of a dried food material to rehydrate, or return to original weight when immersed in water, depends on its physical structure as well as its chemical properties (Farkas and Singh, 1991).

Many studies have been carried out dealing with rehydration of foods such as amaranth leaves (Mujaffar and Loy, 2016), broccoli floret (Sanjuan *et al*., 2001), strawberry (Meda and Rati, 2005), red bell pepper (Vega-Galvez *et al*., 2008), grapefruit (Martinez-Navarrate *et al*., 2019), pumpkin slices (Benseddik *et al*., 2019), as well as chicken meat (Schmidt *et al*., 2009), chicken breast meat (Mounir, 2015), chicken powder (Ran *et al.*, 2018), chicken cubes (Shiby *et al*., 2015).

The aim of this study was to investigate, rehydration kinetics of the dried chicken meat (50°C) at 80, 90 and 100°C and with two empirical models which are Peleg and Weibull. The empirical models described the rehydration process properly. In addition, color parameters (L*, a* and b*) were analyzed during rehydration process.

II. METHODS

A. Material

In this study, boneless and skinless fresh chicken breast meat was used which were obtained from a local poultry meat processing plant (Gedik Pilic Co.) in Usak, Turkey and it was transported to the laboratory in ice boxes and stored at 4°C until use.

B. Drying Process

Each of the drying process, 75±2 g chicken breast meat was used. They were cut in slices of 1 mm thickness, 1 mm of diameter and 1 mm of length with a sharp knife. Sliced samples were placed to the drying trays and then were carried out in a cabinet laboratory type drier at 50°C installed in the Food Engineering Department of Pamukkale University, Turkey. The dryer consists of a centrifugal fan to supply the air flow, an electric heater, and an electronic proportional controller (ENDA, EUC442, Istanbul, Turkey). The cabinet included four removable trays of 40 × 60 cm, which are made of stainless-steel gauze formed into a fine sieve.

During the drying process, after the samples were taken from the dryer at 30 min intervals, and weighed. The weight of the samples was measured using an analytical digital balance (model TP-3002, Denver Instruments, Gottingen, Germany). Drying experiments were carried out at a constant air velocity of 0.2 m/s and a constant relative humidity of 20% until targeted %35 final moisture content. The experimental results are expressed as mean ± standard deviation of duplicate measurements and the results were processed using Microsoft Excel.

C. Rehydration

Rehydration processes were carried out at three different temperatures (80, 90 and 100 ºC) in distilled water. A water bath (WB-11 Model, Wisd Laboratory Instruments,

Table 1. Mathematical models applied to rehydration curves of dried chicken meat cubes.

Models	Model Equation	References
Peleg	$M = M_0 + \frac{t}{k_1 + k_2 t}$	Peleg, 1988.
Weibull	$M = M_e + (M_0 - M_e)\exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right]$	Goula and Adamopoulos, 2009.
Exponential	$M = M_e[1 - \exp(-Ht)]$	Kaptso *et al*., 2008.
First Order	$M = M_e + (M_0 - M_e)\exp(-Kt)$	Apar *et al*., 2009

Wertheim, Germany) was used for rehydration process. Before the rehydration process beginning, the temperature of the water bath was set according to the required rehydration temperature (80, 90 and 100 ºC). Glass containers were placed in water bath. Afterwards, 150 ml of distilled water was added to glass containers with 250 ml capacity and it was checked whether the temperature of the distilled water in the glass container reached the desired working temperature with the aid of a thermometer. Approximately, 8±0.50 g the dried sample was rehydrated by immersion in 150 mL of distilled water (80, 90 and 100 ºC) and the evaluation of sample moisture over the time was determined by mass balance. At 30 min intervals, the samples taken from water bath superficially dried with paper towel to remove superficial water on the surface and weighed. The rehydration process was stopped when the weight of the samples stabilized. The weights of samples were measured with an analytical digital balance (model TP-3002, Denver Instruments, Gottingen, Germany) having a sensitivity of 0.01 g. Each rehydration experiment was performed by duplicate.

D. Rehydration kinetics modeling

During three different rehydration temperature (80, 90 and 100°C), rehydration kinetic models of the dried chicken breast meat were evaluated using appropriated mathematical models. The rehydration models used commonly in literature are given in Table 1. The Peleg model, consists of two parameter equation generally used in rehydration of many dried foods (Dadali *et al*., 2008; Goula and Adamopoulos, 2009; Bilbao-Sainz *et al*., 2005; Planinic *et al.*, 2005).

$\boldsymbol{M_0}$ is the initial moisture content expressed as dry basis [(kg water) (kg dm)$^{-1}$] and $\boldsymbol{M}$ is the moisture content at any time [(kg water) (kg dm)$^{-1}$]. $\boldsymbol{t}$ is the rehydration time (min), $\boldsymbol{k_1}$ is the Peleg rate constant (min [(kg water) (kg dm)$^{-1}$)], $\boldsymbol{k_2}$ is the Peleg capacity constant [(kg water) (kg dm)$^{-1}$] (Peleg, 1988). If the time of rehydration is long enough, the equilibrium moisture content ($\boldsymbol{M_e}$) [(kg water)(kg dm)$^{-1}$] is given in Table 1.

In the literature, many researchers accepted that the Weibull model is the most suitable model to explain the rehydration behaviors of dried foods among other rehydration models (Diaz *et al*., 2003; Garcia-Pascual *et al*., 2006; Marquez *et al*., 2009). α is the shape parameter, β is the rate parameter, M is the moisture content at time t. $\boldsymbol{M_0}$ is the initial moisture content, and $\boldsymbol{M_e}$ is the equilibrium moisture content. H is the rehydration kinetic constant (min^{-1}) and K is the rehydration kinetic constant (min^{-1}).

Diffusion, observed during drying of foods and rehydration of dried foods is a complex phenomenon. While a rapid mass transfer occurred at the beginning of the drying and rehydration process, the rate of mass transfer decreased towards the end of the process. Consequently, the diffusion of water decreased (Resio *et al.*, 2006; Markowski *et al*., 2009).

The effective diffusivity coefficients (D_{eff}), depending on the temperature during rehydration, are calculated by using the Fick's second law (Markowski *et al*., 2009; Kaymak-Ertekin, 2002). Some assumptions were made in this law.

- The initial moisture content of rehydrated sample is uniform.
- During the rehydration, the food protects original shape.
- Moisture intake from the food surface begins by immersing the food in the rehydration medium.
- Heat and mass transfers are neglected factors that will be outside the conditions specified for rehydration.
- The effective diffusivity coefficient is constant during the rehydration.
- Volumetric changes of rehydrated food are neglected throughout the rehydration (Maldonado *et al.*, 2010).

Accordingly, the effective diffusivity coefficients of the dried chicken breast meat (at 50°C) slices during the different rehydration temperatures are used in Eq. (1).

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

D_{eff} is explained as effective moisture diffusivities (m^{2}s^{-1}) and M is the moisture content at any time [(kg water) (kg dm)$^{-1}$]. M_0 expresses the initial moisture content non-rehydration expressed [(kg water) (kg dm)$^{-1}$, M_e is equilibrium moisture content (kg water/kg dm), MR is non-dimensional moisture content/amount, t is rehydration time (min), L is the half-thickness of the used samples (m) (Tütüncü and Labuza, 1996).

The slope (k) is calculated using Eq. (1) when the time-varying graphs of the amount of dimensionless moisture calculated for dried chicken breast slices rehydrated in three different temperatures are plotted to have semi logarithmic coordinates.

$$k = \frac{\pi^2 D_{eff}}{4L^2} \quad (2)$$

In the study, the effective diffusivity coefficients with the rehydration process at three different temperatures were calculated using the slopes.

E. Color measurement

The color values of samples were performed with colorimeter (Hunterlab Miniscan XE Plus, USA). Before each session the colorimeter (aperture size of 25mm) was calibrated on the CIE color space system using a black and white tile. The L* value indicates lightness (L* = 0 darkness, L* = 100 lightness); a* value indicates redness (+ 60 = red, − 60 = green) and b* value indicates yellowness (+ 60 = yellow, − 60 = blue). Color measurements were taken at room temperature with illuminant D65 and a 0°

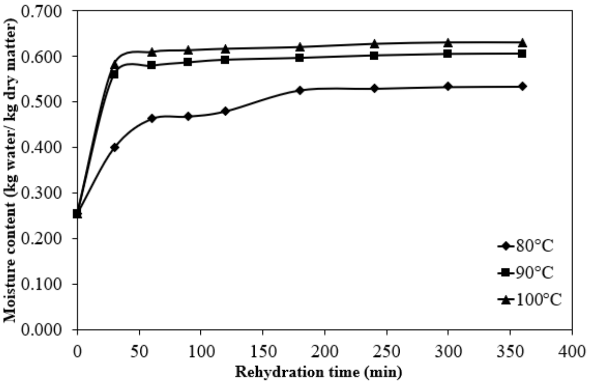

Figure 1. Time versus weight of slices of rehydrated chicken meat at three different temperatures (80, 90 and 100°C).

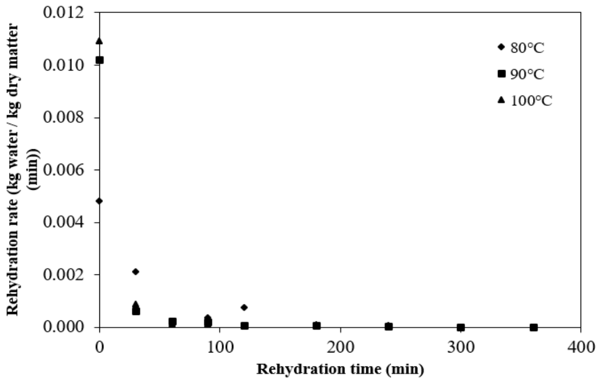

Figure 2. Time versus rehydration rate of slices of rehydrated chicken meat at three different temperatures (80, 90 and 100°C).

angle observer on the outer surface of chicken breast meat from randomly chosen regions of the meat. Hue angle (°), Chroma, and total color difference (ΔE) of dried chicken cubes were calculated as given in Eq. 3 through Eq. 5 (Topuz *et al*., 2009).

$$Hue = Arctan\left(\frac{b}{a}\right) \quad (3)$$

$$Chroma = \sqrt{(a^2 + b^2)} \quad (4)$$

$$\Delta E = \sqrt{(L0 - L)^2 + (a0 - a)^2 + (b0 - b)^2} \quad (5)$$

F. Statistical analysis

Compliance with the experimental rehydration curves of the rehydration models used in the study were determined by nonlinear regression analysis using Microsoft Excel (Microsoft Office, version 2013) program. To evaluate the goodness of each model fit, the coefficient of determination, R^2, root mean square error ($RMSE$) and chi-square (χ^2) values were calculated using Eq. (6) and (7) (Sacilik *et al*., 2006).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=|}^{N}\left(M_{expect,i} - b_{experim,i}\right)^2} \quad (6)$$

$$\chi^2 = \frac{\sqrt{\sum_{i=|}^{N}\left(M_{expect,i} - b_{experim,i}\right)^2}}{N-m} \quad (7)$$

III. RESULTS

A. Rehydration process and color value

Dried chicken breast meat cubes were rehydrated at three different rehydration temperature (80, 90 and 100°C), to investigate the effect of rehydration temperature on rehydration kinetics of dried meat cubes. During the rehydration process, water absorption of the samples performed. During the rehydration process lasting 6 hours, the moisture content of the samples increased from 0.255 to 0.606±0.05 kg water/kg dry matter. Results of the moisture content (kg) with rehydration time (min) are obtained for each set of temperatures are given in Fig. 1.

The temperatures of water used for rehydration process have significant effect on water absorption of the samples. As can be seen from Fig. 2, the rehydration rate increased with the increasing of temperature of rehydration water. Moreover; while the rehydration rate found fairly high at the initial stage of the rehydration process, followed by a slower absorption rate in the final stage of the process. This typical rehydration behavior was observed by many researchers. For example, Muñoz *et al.* (2012) was to study the rehydration kinetics at two temperatures (5 and 15 °C) of salted ground pork, (2% or 4% NaCl) dried to different water contents, (10%, 20% and 35%) and they stated that the rehydration rate of samples increased with the increasing of salt concentration however, weight of samples rapidly increased at the beginning of the rehydration process. And also, they determined that rehydration was faster at 15°C than at 5°C.

Color is one of the most important quality characteristics of foods in terms of consumer acceptance. However, several physicochemical reactions occurred in foods associated with color changes. When protein fraction of the chicken meat exposed to heat during drying process, the color changes could be attributed to denaturation of myoglobin to metmyoglobin and Maillard browning reactions. The color values of slices of chicken breast meat dried and rehydrated at 50°C are given in Table 2. The L* values of dried chicken meat cubes varied with different rehydration temperature ($p<0.05$), where re-hydrated at 90°C samples had significantly higher L* values, while rehydrated at 80°C samples had the low-est L* values (Table 2). Rehydrated at 90°C samples had obviously higher a* and b* values than the other samples. In terms of the a* values, no significant differences were observed rehydrated at 80°C and 100°C samples ($p>0.05$). Moreover, b* values of rehydrated at 90°C and 100°C samples were not significantly differences ($p>0.05$). A decrease in L* value and increase in a* value indicated both increase of browning discoloration and oxidation reaction.

ΔE and chroma values of the rehydrated samples at 90°C and 100°C samples were found statistically similar ($p>0.05$), rehydrated at 80°C samples were lower than the other samples ($p<0.05$). In terms of hue angle, all the samples were significantly different ($p<0.05$). In a study, microwave-dried amaranth leaves rehydrated at three different temperatures (35, 50, and 60°C) and the color difference (ΔE) between fresh leaves and leaves rehydrated at 35°C was found significantly higher than other samples (Mujaffar and Loy, 2016).

B. Modeling of rehydration kinetics

At 30 min intervals, dried chicken meat cubes which are rehydrating removed from glass containers, superficially

Table 2. Color values of slices of chicken breast meat dried and rehydrated at 50°C

Cases	L*	a*	b*	*ΔE*	*Chroma*	*Hue Angle*
Dried at 50°C	72.62±0.51[a]	-0.83±0.11[a]	11.11±0.52[a]	0.00	11.16±0.87[a]	94.91±0.85[a]
Rehydrated at 80°C	67.34±0.60[c]	-0.30±0.08[b]	18.88±0.33[b]	9.07±0.74[a]	18.91±0.51[b]	90.89±0.47[c]
Rehydrated at 90°C	72.92±0.35[a]	-1.25±0.16[c]	20.04±0.40[c]	9.56±0.24[b]	20.08±0.16[c]	93.49±0.20[a]
Rehydrated at 100°C	70.14±0.42[b]	-0.35±0.05[b]	19.97±0.22[c]	10.09±0.36[b]	20.05±0.24[c]	96.15±0.41[b]

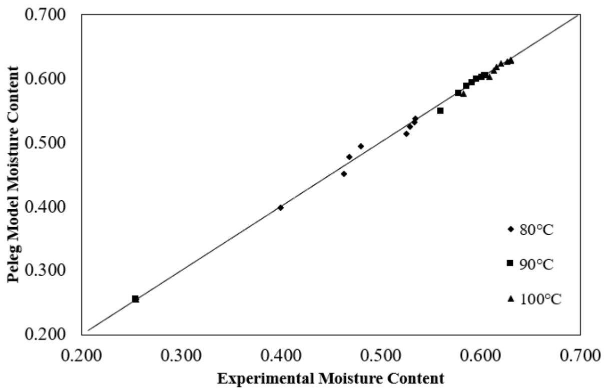

Figure 3. Experimental moisture content versus Peleg model moisture content of slices of rehydrated chicken meat at three different temperatures (80, 90 and 100°C).

dried with paper towel, were weighted and were examined the weight changes. This process has been continued for 6 hours. The data of the weight changes are used for the modeling regarding rehydration kinetics given in Table 1.

Kinetic models relevant to the coefficients of each model were determined by using Microsoft Excel. Moreover, statistical parameters concerning models were calculated and the best rehydration model fitted to experimental data was determined (Table 2). The coefficient of determination (R^2) is an important statistical parameter for determining the most appropriate model. Calculating χ^2 and RMSE values for each model as well as R^2 contributed to determining the most appropriate model. As a result; the highest value of R^2, the lowest values of the χ^2 and RMSE are expressed as the most appropriate model.

Peleg's model was used to describe the rehydration kinetics of dried chicken meat cubes, due to the highest values of the coefficient of determination (R^2), the lowest χ^2 and RMSE values in this study. During the rehydration process, increment of moisture content of samples which is experimentally determined gave a better fit in the Peleg's model for all rehydration conditions. Fitness of experimental and calculated by Peleg model moisture content data for different temperatures are shown in Fig. 3.

Similar results were reported by some researchers on rehydration kinetics of various foodstuffs. Dadalı *et al.* (2008) stated that Peleg model was the most fitted model for rehydrating of microwave dried spinach at different temperatures. Both Peleg and Weibull models were found most appropriate models to describe the rehydration kinetics of vacuum-microwave dried potato cubes (Markowski *et al.,* 2009).

C. Calculation of the Effective Moisture diffusivity

To calculate the effective moisture diffusivity of the rehydrated samples at 80, 90 and 100°C, the logarithm of non-dimensional moisture content versus rehydration time (t) were plotted. By using the method of slopes the effective moisture diffusivity was calculated and given in Table 3.

Table 3. Calculated effective moisture diffusivity of samples at different rehydration temperature

Rehydration Temperature (°C)	Effective moisture diffusivity ($m^2\ s^{-1}$)
80	1.69×10^{-11}
90	3.38×10^{-11}
100	8.45×10^{-11}

The water absorption increased as water rehydration temperature increased (Table 3). Consequently, the effective moisture diffusivity increased as well. Similar results have been reported by other researches. The effective moisture diffusivity of dried of mango slices rehydrated at 25 and 40°C calculated as $1.24x10^{-10}$ m^2s^{-1} and $1.60x10^{-10}m^2s^{-1}$, respectively (Maldonado *et al.*, 2010). In another study; Falade amd Abbo (2007), persimmon (*Phoenix dactylifera*) samples were dried with hot air between 50 and 80°C and the dried persimmons were rehydrated at three different temperature (15, 30 and 45°C) and also they found that the effective moisture diffusivity of the samples $1.80x10^{-10}$ m^2s^{-1}, $4.74x10^{-10}m^2s^{-1}$ and $1.15x10^{-9}$ m^2s^{-1}, respectively. At the end of the rehydration process, they stated that the effective moisture diffusivity increased with increasing rehydration water temperature.

IV. CONCLUSIONS

The aim of this study, was to investigate the effect of three different rehydration temperatures (80, 90 and 100°C) on the rehydration kinetics of dried chicken meat cubes at 50°C.

- It was determined that dried chicken meat cubes gained faster moisture as the temperature of rehydration water increased. With increasing of temperature of the rehydration water, kinetic energy of water molecules increased and this case led to acceleration of water diffusion to samples.
- As a result of sample weights, the Peleg's model gave a better fit under all conditions tested with higher R^2, lower χ^2 and RMSE values during rehydration process. Thus, it is stated that Peleg's model is the best model identified the rehydration kinetics of samples.
- Further work will be carried out to explore the changes in the chemical and sensorial properties, and texture of the other meats (etc. red meat) in order to clarify the effect of drying and rehydration on the nutritional value of the meat.

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Received: February 28, 2021
Sent to Subject Editor: March 18, 2021
Accepted: June 3, 2021
Recommended by Subject Editor Laura Briand