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Influence of hot-air drying on drying kinetics and some quality parameters of sliced chicken breast meat

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ABSTRACT

The present study investigated the influence of different drying temperatures (50, 60, and 70ºC) on the drying kinetics, drying rate, color, lipid oxidation, and protein oxidation of sliced chicken breast meat. In addition, color degradation, lipid oxidation, and protein oxidation kinetics during drying were also studied. The drying process takes place in a decreasing rate period at every drying temperature. Among the four tested kinetic models, the Page model showed the best fit to the experimental drying data. TBARS value was found to be lower due to the shortening of the drying time at high drying temperatures. Second-order and first-order kinetic models were fitted to lipid and protein oxidation respectively. Lipid oxidation occurs twice as fast as protein oxidation due to activation energy results. As the drying temperatures increased, the lightness values of the samples did not change, while the redness, yellowness, and browning index values increased, also whiteness index values decreased depending on the prolongation of the time.

KEYWORDS: Chicken, Drying kinetics, Color, Lipid oxidation, protein oxidation

1. INTRODUCTION

Chicken meats are extensively consumed in the world due to their low price and fat content, high protein content, and no cultural and religious restrictions furthermore ease of preparation, are quick and easy to serve, and have superior sensory properties. However, despite all these advantages, chicken meat is limited the shelf life due to large amounts of variable nutrients (proteins, essential amino acids, fatty acids, etc.) and high water activity, making it more susceptible to microbial, chemical deterioration, and negatively sensory properties (color, odor, flavor, texture, etc.) (Rahman et al., 2005; Traffano-Schiffo et al., 2014). Various preservation methods (chilling, freezing, salting, drying, smoking, etc.) have been used for ages to extend

shelf life and keep the quality of the chicken meats. Drying is one of the effective ways to prevent microbial spoilage and chemical changes in chicken meat by reducing water activity thereby decreasing costs of packaging and storage, transportation costs, etc. And also, the dried chicken meat slices are used to enhance the nutritional and sensory properties of the various food products such as instant soups, the pizza, and salad, pasta products, baby and pet foods, etc. (Aykın & Erbaş, 2016; Gatea, 2011; Gupta et al., 2011; Patel & Kar, 2012; Kelbaliev & Manafov, 2009).

Despite the fact that many methods (freezing, sun, microwave, etc.) are used for drying food, sun drying, which is the most common and oldest method of drying, is still used in most developing countries. Although one of the most prominent advantages of sun-drying has not any a capital investment in equipment, it is replaced by convective hot air drying recently. Convective drying is a simultaneous heat and mass transfer process where water is scavenged from the food into the drying medium by diffusion and exhausted into the air stream by convection (Kipcak & İsmail, 2021; Mousa & Farid, 2002; Tekin & Baslar, 2018).

During drying some physical and chemical changes occur which affect the quality of the product unfavorably. Because chicken meats particularly contain high amounts of essential fatty and amino acids, they are prone to oxidative damage. Lipids and proteins found naturally in meat reacting with oxygen in the air cause oxidation during the drying process, which adversely affects the sensory quality (color, odor, texture, etc.) and produces harmful compounds such as malondialdehyde. And also, nonenzymatic browning reactions can occur, and precursors can be formed that facilitate color changes during drying. If the drying process control and optimize, the oxidative and nonenzymatic browning reaction could be largely prevented in the final product (Alvarez et al., 2021; Babalis & Belessiotis, 2004).

The objective of this study is to determine the effect of different drying temperatures (50, 60, and 70°C) on the drying kinetic, drying rate, color, lipid oxidation, and protein oxidation of

sliced chicken breast meat. In addition, color degradation, lipid oxidation, and protein oxidation kinetics during drying were also investigated. The activation energy and other kinetic parameters of the sliced chicken breast meat were also calculated.

2. MATERIAL and METHODS

2.1. Material

The fresh chicken breast meat used in drying experiments was purchased from a local poultry meat processing plant. The purchased samples were placed into sterile plastic bags under aseptic conditions and brought to the Meat and Meat Product Laboratory (Pamukkale University, Denizli, Turkey) at 4ºC. Afterward, the samples were kept under refrigerated storage (<4ºC) until the drying process.

Before the drying process, the initial moisture content of the chicken breasts used in the experiments was determined in a vacuum drier at 70ºC, for 24 hours. Dry matter and initial moisture content of the chicken breast meat were 18.83% and 3.17 kg water/kg dry matter, respectively prior to the drying process.

2.2. Methods

2.2.1. Hot air drying of sliced chicken breast meat

Before the drying process, the chicken breast meats were taken out as a whole in the refrigerator (4ºC). The mean weight of the samples was approximate 100±5 g. Then, they were cut into thin strips of 1 cm width × 1±0.2 cm long × 1±0.2 cm thickness. Some of the sliced samples were used to determine the initial carbonyl, and dry matter content, TBARS, and color values of the samples. The remaining samples were spread on drying trays in one layer and dried in a drying cabinet (Yücebaş Machine, İzmir) in a laboratory which found Department of Food Engineering, Pamukkale University at three different drying temperatures (50, 60, and 70ºC) and a constant air velocity of 0.2 m/s. The weight of the chicken breast slices was measured every 30 min during the drying process, and the data obtained from the experiments were

recorded. The dried samples were cooled at 4ºC for 15 minutes, put in sealed polythene bags, and then frozen at -20ºC for further analysis. TBARS value, carbonyl content, and color measurements were performed on the sample's time interval of 30 minutes during the drying process. All drying experiments and physicochemical analysis (color, TBARS, and carbonyl content) were performed twice and repeated with two replications for each temperature also averages and standard deviations were calculated.

2.2.2. Analysis

2.2.2.1. Color measurement

This study was to investigate the effect of the drying process on the color change of sliced chicken breast meat. Color values (L*, a*, and b*) of sliced chicken breast meat, which were dried under three different temperatures (50, 60, and 70ºC) were measured by using a colorimeter (MiniScan XE, USA) at predetermined time intervals during the drying process.

In the Hunter color system, the L* value indicates lightness, and it ranges from 0 to 100. The a* and b* values represent the redness (+60: red, -60: green) and yellowness (+60: yellow, -60: blue), respectively. Color measurements were taken at room temperature with illuminant D65 and a 0° angle observer on the outer surface of chicken breast slices from randomly chosen regions of the meat (Özünlü & Ergezer, 2020). Because Hunter L*, a*, and b* values obtained as a result of color measurements are not color phenomena directly perceived by both the buyer and seller in the market, color criteria appealing to people's color perception such as Chroma value, Hue Angle, total color change (ΔE), whiteness index (WI) and browning index (BI) were calculated according to Equations 1, 2, 3, 4 and 5 respectively. The Hue angle is defined as a color circle (0º to 360º), it causes some changes in the tonality on a color rotating counterclockwise from 0- 70º (red-violet), 240-120º (blue-green), to 60º (yellow). Chroma value indicates color saturation. Whereas chroma values decrease in drab colors, they increase in vivid colors.

124 $$Hue\ Angle = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (1)$$

125

126 $$Chroma = \left(a^{*2} + b^{*2}\right)^{1/2} \quad (2)$$

127

128 $$\Delta E = \sqrt{\left(L^*_0 - L^*\right)^2 + \left(a^*_0 - a^*\right)^2 + \left(b^*_0 - b^*\right)^2} \quad (3)$$

129 $$WI = 100 - \left(\left(100 - L^*\right)^2 + a^{*2} + b^{*2}\right)^{1/2} \quad (4)$$

130 $$BI = \left[100\left(x - 0.31\right)\right]0.17 \quad (5)$$

131 Where, $x = \left(a^* + 1.75L^*\right)\left(5.645L^* + a^* - 3.012b^*\right)$

132 Before each session, the colorimeter was calibrated on the CIE color system using standard
133 black and white tile. The color measurements of sliced chicken breast meat were performed at
134 three points on the sample surface, and they were evaluated by taking the average of the
135 obtained values.

136

137 **2.2.2.2. Lipid oxidation (TBARS value)**

138 TBARS were determined using the extraction method described by Witte et al. (1970) with
139 slight modifications. 20 g of sliced chicken breast meat was homogenized with an ultraturrax
140 in 50 ml of 4 °C extracting solutions containing 20% trichloroacetic acid in 2 M phosphoric
141 acid. The resulting slurry was transferred quantitatively to a 100 ml volumetric flask with 40
142 ml of water. The sample was diluted to 100 ml with water and homogenized again. A 50 ml
143 portion was filtered through Whatman No. 1 filter paper. 5 ml of filtrate was transferred to a
144 test tube followed by 5 ml of 2-thiobarbituric acid (0.02 M in distilled water). The tube was
145 stoppered and the solution was mixed by shaking and kept in a boiling water bath for 35 min.
146 Thiobarbituric extracts of each sample were used for measuring the absorbance at 532 nm. 1,

147 1, 3, 3, tetraethoxypropane was used as a standard for TBARS assay. TBARS numbers were
148 calculated as mg of malonaldehyde per kilogram of meat (mgMA/kg meat).
149

150 **2.2.2.3. Protein oxidation**

151 Protein oxidation, as measured by the total carbonyl content, was evaluated by derivatization
152 with DNPH as described by Oliver et al. (1987) with slight modifications. Sliced chicken breast
153 meat (1 g) was minced and then homogenized 1:10 (w/v) in 20 mM sodium phosphate buffer
154 containing 6 M NaCl (pH 6.5) using an ultraturrax homogenizer for 30 s. Two equal aliquots
155 of 0.2 mL were taken from the homogenates and dispensed in 2 mL Eppendorf tubes. Proteins
156 were precipitated by cold 10% TCA (1 mL) and subsequent centrifugation for 5 min at 4200×g.
157 One pellet was treated with 1 mL 2 M HCl (protein concentration measurement) and the other
158 with an equal volume of 0.2% (w/v) DNPH in 2 M HCl (carbonyl concentration measurement).
159 Both samples were incubated for 1 h at room temperature. Afterward, samples were precipitated
160 by 10% TCA (1 mL) and washed three times with 1 mL ethanol: ethyl acetate (1:1, v/v) to
161 remove excess DNPH. The pellets were then dissolved in 1.5 mL of 20 mM sodium phosphate
162 buffer containing 6 M guanidine HCl (pH 6.5), stirred, and centrifuged for 2 min at 4200×g to
163 remove insoluble fragments. Protein concentration was calculated from the absorption at 280
164 nm using BSA as standard. The number of carbonyls was expressed as nmol of carbonyl per
165 mg of protein using an absorption coefficient of 21.0 nM^{-1} cm^{-1} at 370 nm for protein
166 hydrazones.

167 **2.2.2.4. Mathematical modeling of drying curves**

168 Mathematical modeling has been widely and effectively used for the analysis of drying many
169 food products. Theoretical and empirical thin layer equations have been investigated to
170 represent the drying kinetics of different kinds of foods (Erbay & Icier, 2009). Many authors

171 used simple empirical models to simulate the drying curves of foods. Among them, Page,
172 Henderson and Pabis, Lewis, and Logarithmic equations (6)–(9) are widely used.

173 $$MR = \exp(-kt^n) \quad (6)$$

174 $$MR = a\exp(-kt) \quad (7)$$

175 $$MR = \exp(-kt) \quad (8)$$

176 $$MR = a\exp(-kt) + c \quad (9)$$

177 The moisture ratio of sliced chicken breast meat during drying was calculated using Eq.
178 (10).

179 $$MR = \frac{M - M_e}{M_i - M_e} \quad (10)$$

180 Where MR is the moisture ratio, M is the moisture content at a specific time (kg water kg^{-1} dry
181 matter), M_i is the initial moisture content (kg water kg^{-1} dry matter), M_e is the equilibrium
182 moisture content (kg water kg^{-1} dry matter) (AOAC, 1990).
183 The coefficient of determination (R^2), root mean square error (RMSE), and reduced chi-square
184 (χ^2) was used as the primary criterion to select the best equation expressing the convective
185 drying curves of sliced chicken breast meat. RMSE gives the deviation between the predicted
186 and experimental values. The lower values of RMSE and χ^2, the better goodness of the fit. On
187 the other hand, the value for R^2 determines the fitting ability of the equation, and it is required
188 to reach 1 for the best results (Erbay & Icier, 2009). These parameters can be calculated as
189 follows:

190 $$\text{RMSE}=\left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2\right]^{1/2} \quad (11)$$

191

192 $$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (12)$$

193 where $MR_{exp,i}$ is the *i*th experimentally observed moisture ratio, $MR_{pre,i}$ is the *i*th predicted
194 moisture ratio, *N* is the number of observations and *z* is the number of constants.
195
196 **2.2.2.5. Kinetic Models of Protein Oxidation, Lipid Oxidation, and Color**
197 **Degradation**
198 The oxidation of protein, lipid, and degradation of color in sliced chicken breast meat during
199 drying was calculated by using the standard equation for zero, first and second-order reactions
200 and degradation rate constants were determined by fitting Eqs. (13), (14), and (15) to
201 experimental data.

202 $$C = C_0 + k_0 t \quad (13)$$

203 $$C = C_0 \exp(k_1 t) \quad (14)$$

204 $$\frac{1}{C} = \frac{1}{C_0} + k_2 t \quad (15)$$

205
206 where C is the studied parameter (Protein and lipid oxidation, ΔE) at any given drying time, C_0
207 is the initial values of untreated samples, and k_0, k_1, and k_2 are rate constants.
208 The Arrhenius equation is the most widely accepted method of accounting for the temperature
209 dependence of the rate constant in food systems. The temperature and the rate constant are
210 related according to the Arrhenius equation (Eq. (16)):

211 $$k = k_a \exp(-\frac{E_a}{RT}) \quad (16)$$

212 where k is the rate constant at temperature T (K), k_a is the frequency factor, E_a is the activation
213 energy (kJ/mol), and R is the universal gas constant (8.314 J/molK).
214 The coefficient Q_{10} is another way to characterize the effect of the temperature on the rate of a
215 reaction and it was calculated by Eq. (17).

$$Q_{10} = (k_2/k_1)^{10/(T_2-T_1)} \quad (17)$$

where k_1 and k_2 are reaction rate constants at temperatures T_1 and T_2, respectively (h^{-1}). The experimental results are expressed as mean ± standard deviation of triplicate measurements and the results were processed using Microsoft Excel.

2.2.3. Statistical Analysis

The data obtained as a result of the experiments carried out in two parallels and two replications were analyzed by using the SPSS statistical package program. The level of difference between the means was determined using the Duncan multiple comparison test (p <0.05).

3. RESULTS and DISCUSSION

3.1. Effect of drying temperature on sliced chicken breast meat

Sliced chicken breast meat samples were initially dried from an average moisture content of 3.17 kg water/kg dry matter to 0.1 kg water/kg dry matter moisture content. When the findings were examined, it was observed that the drying temperature had a significant effect on the drying rate. The graphs of the drying rate changing with the moisture content of sliced chicken breast meat samples are given in Figure 1. As can be seen from Figure 1, there is no constant drying rate and the whole drying process takes place in the decreasing rate period. This reveals that only diffusion in the sample affected drying. In the decreasing rate period, the drying rate decreases with the decrease in the moisture content in the product.

Hii et al. (2014) dried chicken meat, which they bought from a local market and cut into 20 mm × 20 mm × 7 mm, at 60°C, 70°C, and 80 °C. They stated that the drying process took place in the decreasing rate period. In another study, Elmas et al. (2020) dried the turkey breast meats at 60, 75, and 90°C after slicing and stated that the drying process took place at a decreasing

rate period. Similar studies were also found by the researchers with different materials and it was found that the drying rate revealed a decreasing trend with the moisture content.

3.2. Mathematical modeling

Sliced chicken meat samples dried in a hot air dryer were dried at three different temperatures. Experimental data, including the variation of moisture content with drying time, were applied to four different thin-layer drying models by nonlinear regression analysis. Coefficients in all models were calculated by nonlinear regression analysis using the SigmaPlot 11.0 (Systat Software Inc., USA) program. The coefficients (*a*, *k,* and *n*) in the models are given in Table 1 for chicken breast meat samples dried at different temperatures. When the statistical values in Table 1 are examined, it is seen that the R^2 values are in the range of 0.8465-0.9989, and the χ^2 values are in the range of 0.000008-0.049203, and the RMSE (root-mean-square error) values are in the range of 0.002760-0.216472. It has been seen that the model that the best compatible experimental data is the "Page" model, which gives the highest R^2 and the lowest RMSE and χ^2 values. In addition, it was determined that the decrease in the experimental moisture content values during the drying process was compatible with the “Page” model at all drying temperatures. Dominguez-Nino et al. (2020) dried chicken breast meat at 45, 55, and 65°C after slicing. It was determined that Page, Modified Page, and Logarithmic models were the models best adapted to the decrease in experimental moisture content values. Aykın-Dinçer et al. (2020) dried the beef samples in a vacuum dryer after slicing and defined their drying characteristics. As a result of the modeling, it was determined that the Page model gave the best fit to the experimental results. In another study, Elmas et al. (2020) dried turkey breast samples at different temperatures (60, 75, and 90°C) and reached similar results. Thus, it was determined that the most proper models were Logarithmic and Page. Similar results were obtained from the modeling performed during the drying of other foods. For example, in thin-layer drying modeling, Page's model was stated to fit the experimental results best in carrots (Doymaz, 2004)

heat-treated at 100°C for 5 minutes and without pretreated garlic (Demiray & Tulek, 2014) and tomato slices.

3.3. Effect of drying on the TBARS values of sliced chicken breast meat

TBARS (Thiobarbituric acid reactive substances) is a measure of secondary products of lipid peroxidation, mainly malondialdehyde, which may contribute off-flavor to oxidized meat products (Jo & Ahn, 1998). The maximum TBARS limit value for meat products is 2 mg malondialdehyde/kg product (Greene & Cumuze, 1982).

In the analyzes performed before starting the drying process, the TBARS value was determined 0.520±0.08 mg MDA/kg product in sliced chicken breast meat. In a similar study, Ortiz et al. (2013) reported that the TBARS value in Atlantic salmon fillets before drying was 0.240±0.02 mg MDA/kg product.

It was observed that TBARS values decreased with increasing drying temperature in samples dried at 50, 60, and 70°C. As shown in Table 2, the TBARS value increased from 0.52±0.08 mg MDA/kg product value to 1.43±0.05 mg MDA/kg product value in the drying process at 50°C for 12 hours. On the other hand, it increased to 1.09±0.03 mg MDA/kg product value in the drying process at 70ºC for 8 hours. It is clearly seen that the minimum drying time of the product at a high drying temperature is effective in decreasing the TBARS values. However, drying chicken breast meat slices to 0.1 kg water/kg dry matter moisture content at low drying temperature caused high TBARS values due to the long drying time. After drying with hot air, it is seen in Table 2 that all TBARS values are at a safe level, with the highest TBARS value at 50°C and the lowest at 70°C. When the literature is examined, a similar result has been observed in drying Atlantic salmon fillets with hot air. For example, Ortiz et al. (2013) dried Atlantic salmon fillets at 40, 50, and 60°C. At the end of the drying process, the TBARS value of the samples dried at 40°C was determined 2.01±0.04 mg MDA/kg product, and the samples dried at 60°C as 1.47±0.05 mg MDA/kg product.

290 During the drying process, sampling was carried out once an hour, which would serve as a basis
291 for the kinetic calculations to determine the change in TBARS values. The losses are calculated
292 for each drying temperature. As can be seen from Table 3, the variation of TBARS values in
293 sliced chicken breast meat during drying was in accordance with the second-order kinetic model
294 (Figure 2). When the kinetic data is analyzed (Table 4), it is seen that the rate of change of
295 TBARS values increases as the temperature rises, as expected. For example, while the reaction
296 rate constant was 0.1084 in the drying process at 50ºC, this value increased to 0.1316 kg/(mg
297 MDA)(h) at 70ºC.
298 The obtained findings were tried to be compared with the literature data, but no study was found
299 expressing the changing kinetics of the TBARS value during the drying of any meat product.
300 In most of the studies in the literature, it has been observed that the TBARS value during the
301 storage of dried meat products is related to the determination of the kinetics of change. For
302 instance, Wenjiao et al. (2014) stored pork sausages at different temperatures and examined the
303 change in TBARS value. At the end of the study, they stated that the change in TBARS values
304 fit the first-order kinetic model. In another study, they stored rabbit meat at four temperature
305 levels (4, -4, -12, and -18˚C) (Wang et al., 2020). The TBARS values of the samples were
306 determined during the storage process. As a result of the kinetic modeling, they stated that the
307 kinetics of change of TBARS values during the storage of the samples were compatible with
308 the first-order reaction model.
309

310 **3.4. Effect of drying on protein oxidation level of sliced chicken breast meat**

311 Protein oxidation occurs during the drying process of meat depending on drying time and
312 temperature and affects the meat quality including color, firmness, aroma, flavor, etc. Heat
313 treatment has a negative impact on the natural antioxidant defense system of meat so reactive
314 oxygen species and the free radicals such as alkyl, alkoxyl, and peroxyl that are produced by

315 lipid oxidation can easily accumulate and attack proteins and initiate protein oxidation. The
316 carbonyls are the main end products of protein oxidation and are used to detect the level of
317 protein oxidation (Soladoye et al., 2015). In this study, the carbonyl content of dried chicken
318 breast meat slices was found significantly higher than compared raw meat and gradually
319 decreased with increasing drying temperature. As can be seen in Table 2, the carbonyl content
320 of samples increased from 1.38±0.04 to 5.79±0.05 nmol carbonyl/mg protein during the drying
321 process at 50°C for 12 hours. Also, it increased to 5.54±0.03 nmol carbonyl/mg protein in the
322 drying process that lasted for 8 hours at 70°C. It is thought that the decrease in carbonyl content
323 with increasing drying temperatures is due to the shortening of the drying time. Considering
324 that the realization of a chemical reaction depends on the activation energy, it is seen that lipid
325 oxidation occurs faster than protein oxidation in this study. When the activation energy values
326 in Table 4 are compared, 8.90 kJ/mol of energy is required for lipid oxidation occurrence and,
327 17.90 kJ/mol of energy is required which is twofold this value, for protein oxidation occurrence.
328 Therefore, free radicals and malondialdehydes formed as a result of lipid oxidation are thought
329 to trigger protein oxidation.
330 To the best of our knowledge, there are limited studies on the progression of protein oxidation
331 during drying in different meat sources. It was determined that the carbonyl content increased
332 in parallel with the increase in salt concentration in chicken meat dried at different drying
333 temperatures (40, 50, and 60 ºC) and salt concentrations (3, 6%), and they emphasized that salt
334 accelerates protein oxidation with the effect of temperature (Qu et al., 2020). In another study,
335 it was observed that the carbonyl content of minced pork slices, dried at 55 °C, and 30%
336 humidity increased compared to the raw samples, similar to this study (Xu et al., 2018).
337 The carbonyl content was determined in the samples taken every hour as a basis for the kinetic
338 calculations. As can be seen from Table 3, the change of carbonyl content in chicken breast
339 cubes during drying was in accordance with the first-order kinetic model (Fig. 3). Considering

340 the kinetic data in Table 4, the reaction rate constants at 50, 60, and 70 °C were calculated as
341 0.1182, 0.1438, and 0.1743, respectively. And also, Q_{10} values in Table 4, it is seen that there
342 is no difference between increasing the temperature from 60 °C to 70 °C with the effect of
343 increasing the temperature from 50 °C to 60 °C.
344 It has been stated above that there is no study expressing the kinetic changes of TBARS values,
345 which are the indicators of lipid oxidation during the drying of meat and meat products.
346 Similarly, there is no scientific study on the kinetic changes of carbonyl contents, which is an
347 indicator of protein oxidation, as literature searched. Additionally, the absence of a study
348 expressing the carbonyl content kinetics changes during the storage of dried meat products is
349 thought to add originality to the study.

350 **3.5. Effect of drying on color values of sliced chicken breast meat**

351 The measured CIE color parameters of fresh chicken breast meat and chicken breast slices dried
352 at different temperatures with hot air are given in Table 5. It is seen that the measured color
353 values of fresh chicken breast meat are compatible with the studies in the literature. Babic et al.
354 (2009) determined the L^* color value in a fresh form as 50.33±1.26, a^* value 1.73±0.47, and
355 b^* value 9.21±0.94 of breast meat slices of broiler chickens to which freeze-drying will be
356 applied.
357 As can be seen from Table 5, it was detected that the L^* value of the fresh chicken breast meat
358 slices, which expresses the color lightness, and the values of the dried products were different
359 from each other (p <0.05). As a result of the statistical analysis, it was detected that there was
360 no difference between the L^* values of the samples dried at 50 and 60°C (p >0.05). During all
361 drying processes, both a^* and b^* values increased with time without a clear trend. The
362 proportional increase in myoglobin concentration with the decrease in moisture content can be
363 considered the reason for the increase in the redness of chicken breast meat slices during drying.
364 It is seen that the results obtained are compatible with the studies in the literature. For example,

Nathakaranakule et al. (2007) dried chicken meat to be used as an ingredient in ready-to-eat pasta in a superheated steam dryer combined in different ways. They stated that the redness of the dried products increased depending on the drying temperature. Researchers reported that this change in the product's color occurred due to browning reactions occurring at high drying temperatures. In another study, researchers determined that the b^* value of dried meat slices increased (Aykın-Dinçer, 2018). It is stated that this increase was due to the lightening of the colors of the dark pigments formed during drying by being exposed to more oxygen with high air velocity. Xu et al. (2018) reported that there might be an increase in the b^* value due to the oxidation of divalent iron ions.

Total color change (ΔE), a critical color characteristic, represents the color change between fresh chicken breast meat slices and dried samples. When the ΔE values in Table 5 were examined, it was observed that there was a statistically significant difference between the samples dried at all temperatures (p <0.05). The results obtained are similar to the data in the literature. For example, the researchers dried chicken breast meat at 60, 70, and 80°C after slicing it at a certain thickness and detected that ΔE values increased with the increase in drying temperature (Kumar et al., 2019). In another study, Ortiz et al. (2013) calculated the ΔE values as 9.27, 12.37, and 19.31, respectively, after drying Atlantic salmon at 40°C, 50°C, and 60°C. The researchers stated that the calculated ΔE values were statistically different (p <0.05).

While the measured L^*, a^*, and b^* values give information about the basic components of the product color, they do not fully represent the color perception of the consumer. Instead of these values, *Hue angle* and *chroma* values calculated from the values better represent the color perception of the consumer. *Hue angle* is defined as a color circle, and red-violet colors are between 0°-360° angle values, the yellow color is 90°, and the bluish-green color is between 180°-270° angle values. In the study, the *Hue angle* of the fresh samples was calculated as 81.02°±2.00. *Hue* angle of the samples dried at 50, 60, and 70°C was calculated as 63.21°±1.14,

390 66.71°±1.65, and 72.55°±1.84, respectively. *Hue* angle of fresh samples was found to be
391 statistically different from dried samples (p <0.05). The results found are similar to the studies
392 in the literature. For example, the researchers calculated the *Hue* angles of chicken breast meats
393 dried at 60, 70, and 80°C as 64.70°, 66.77°, and 70.53°, respectively (Kumar et al., 2019). While
394 the *chroma* value decreases in dull colors, it increases in vivid colors. When the *chroma* values
395 in Table 5 are examined, it is seen that the *chroma* values of the fresh samples are different
396 from the dried samples (p <0.05). The *chroma* value for the fresh samples was determined as
397 13.54±1.16. The *chroma* values of the samples dried at 50, 60, and 70°C were calculated as
398 16.52±0.73, 20.29±1.40, and 26.36±0.23, respectively. Here, the higher *chroma* value indicates
399 the brightness of the orange-yellow color observed in the dried samples. When the browning
400 and whiteness index values of the dried chicken breast meat slices are examined, it can be seen
401 from Table 5 that the fresh sample is statistically different. While the browning index is lowest
402 in the fresh sample, it is highest in dried samples at 70°C. The browning index of the product
403 also increased with the increase in drying temperature. When looking at the whiteness index
404 values of the dried samples in Table 5, contrary to the browning index values, the drying
405 temperature decreased as the drying temperature increased.
406 No apparent increase or decrease in color values other than ΔE values was determined during
407 all drying processes. Kinetic calculations could only be made for this color value since the net
408 trending increase was determined in ΔE values. When the kinetic data of the ΔE value in Table
409 3 is examined, it will be seen that the ΔE value fits the zero-order kinetic model. Figure 4 shows
410 that the ΔE values obtained from the drying processes of chicken breast meat slices with hot air
411 at different ambient temperatures are compatible with the zero-order kinetic model. The
412 findings obtained in the study are compatible with the literature data. For example, Hosseinpour
413 et al. (2013) reported that the ΔE value change fits the zero-order kinetic model in shrimp. In
414 another study, Kong et al. (2007) applied heat treatment to salmon at different temperatures

(100, 111.1, 121.1, and 131.1°C). They stated that the change in ΔE value in the samples is compatible with the zero-order kinetic model. In addition, they calculated the activation energy value of this change as 99.46 kJ/mol. In this study, the activation energy value of the ΔE value change as a result of the drying process was calculated as 48.97 kJ/mol. When the Q_{10} values are examined, it can be seen from Table 4 that there is no significant difference between increasing the temperature from 60ºC to 70ºC with the effect of increasing the temperature from 50ºC to 60ºC.

4. CONCLUSIONS

Dried chicken breast meat is a high protein and low in fat food and can be used mixed with other dried foods, rehydrated and cooked directly or it can be consumed as a snack food with some flavorings. The findings from the present study revealed that the best model describing the drying kinetics was the PAGE model, and short-term drying at high temperature was more effective in keeping the quality characteristics of chicken breast meat slices. The TBARS value, carbonyl content, and color properties were significantly affected by drying time and temperature. According to the oxidation process which is indicated by activation energy showed that lipid oxidation generates faster than protein oxidation and products of lipid oxidation accelerate the protein oxidation. In conclusion, the results of this study indicate that the kinetics of drying, lipid oxidation, protein oxidation, and color supported by quality parameters of the sliced chicken breast meat could be used to improve the final properties of such meat products.

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AUTHOR CONTRIBUTIONS

Engin Demiray, Conceived the idea, supervised the analytical work, statistical analysis and formatted the manuscript

Haluk Ergezer, Literature review, statistical analysis, wrote the manuscript

Orhan Özünlü, Literature review, carried out experimental work, statistical analysis

Ramazan Gökçe, Literature review, carried out experimental work, statistical analysis

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from thecorresponding author upon reasonable request.

FIGURE CAPTIONS

Figure 1. The variation of the drying rate values of sliced chicken breast meat samples dried at different temperature values and 20% relative humidity with moisture content.

Figure 2. Kinetics of TBARS value changes at sliced chicken breast meat samples at different drying temperatures.

Figure 3. Kinetics of protein oxidation changes in sliced chicken breast meat samples at different drying temperatures.

Figure 4. Kinetics of ΔE values change at sliced chicken breast meat samples at different drying temperatures.

TABLES

Table 1. Statistical results obtained from the selected models for convective drying of sliced chicken breast meat.

Table 2. TBARS and protein oxidation values in fresh chicken breast meat and hot air-dried chicken breast meat slices.

Table 3. The kinetic parameters of zero, first and second-order models for *TBARS, Protein oxidation,* and *ΔE* at different drying temperatures.

Table 4. Kinetic parameters of TBARS, protein oxidation, and ΔE values of chicken breast meat slices dried at different temperature values in hot air drying.

Table 5. Color values of fresh chicken breast meat and dried chicken breast meat slices dried with hot air.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Figures

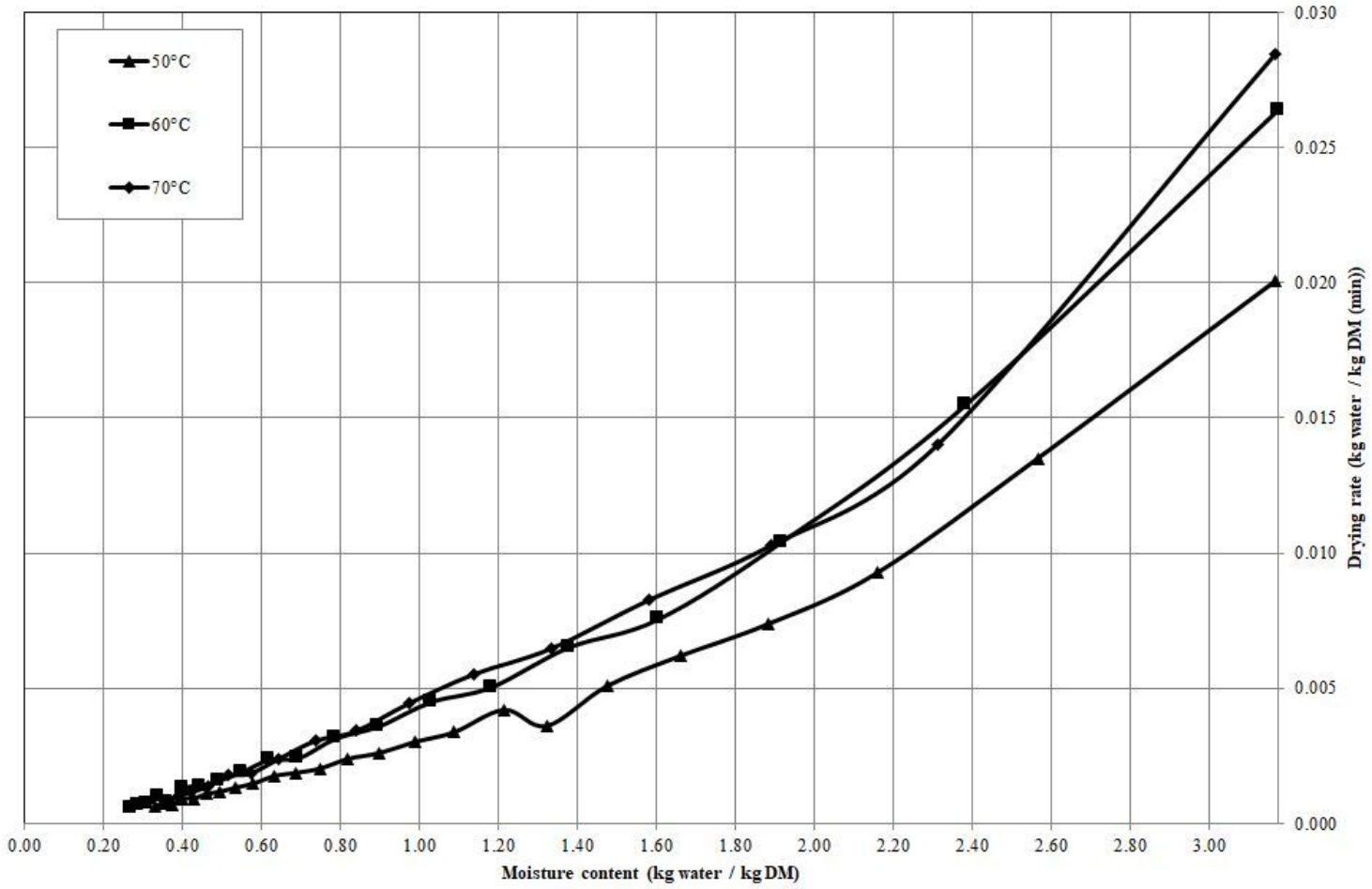

Figure 1

The variation of the drying rate values of sliced chicken breast meat samples dried at different temperature values and 20% relative humidity with moisture content.

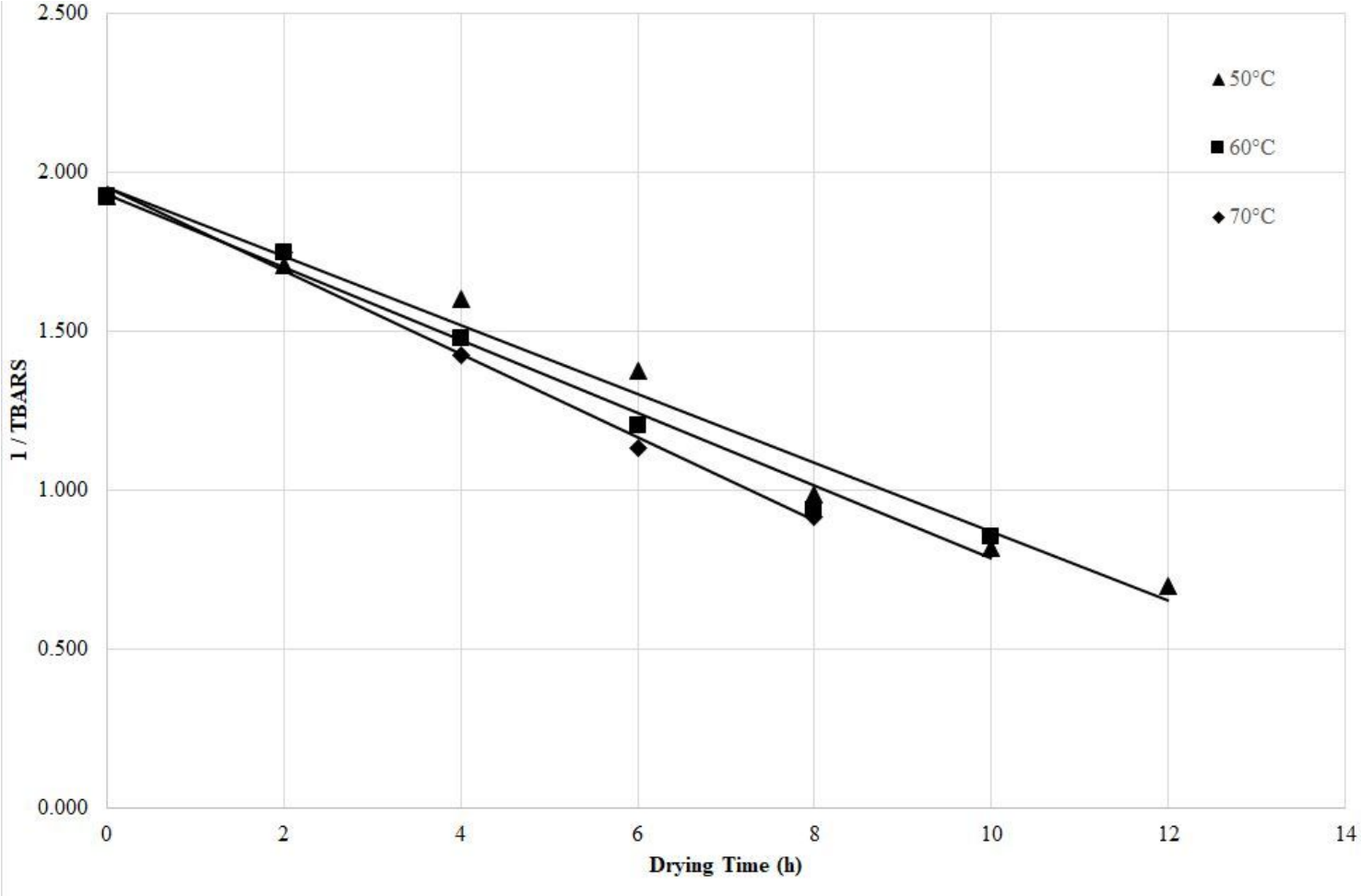

Figure 2

Kinetics of TBARS value changes at sliced chicken breast meat samples at different drying temperatures.

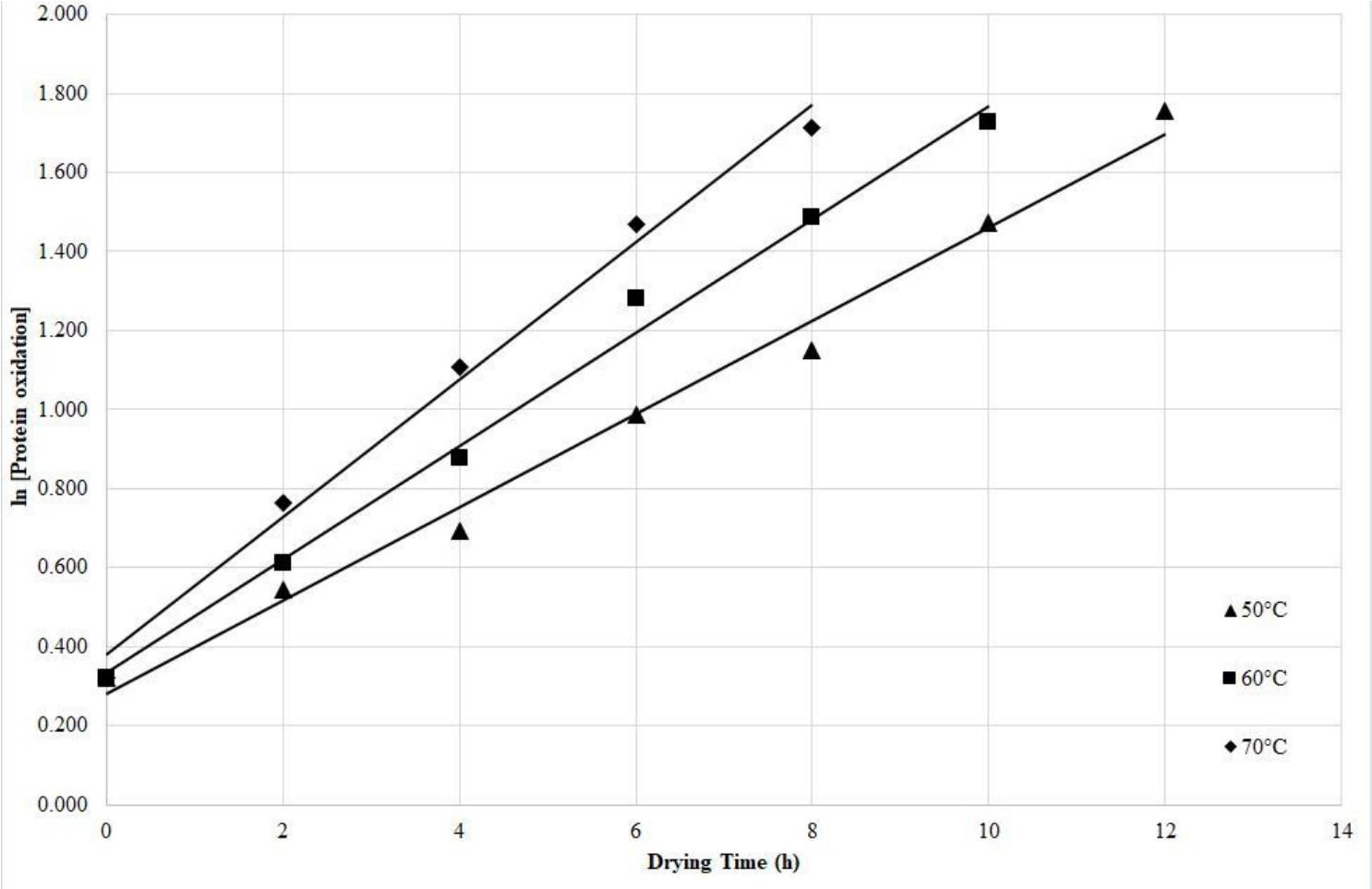

Figure 3

Kinetics of protein oxidation changes in sliced chicken breast meat samples at different drying temperatures.

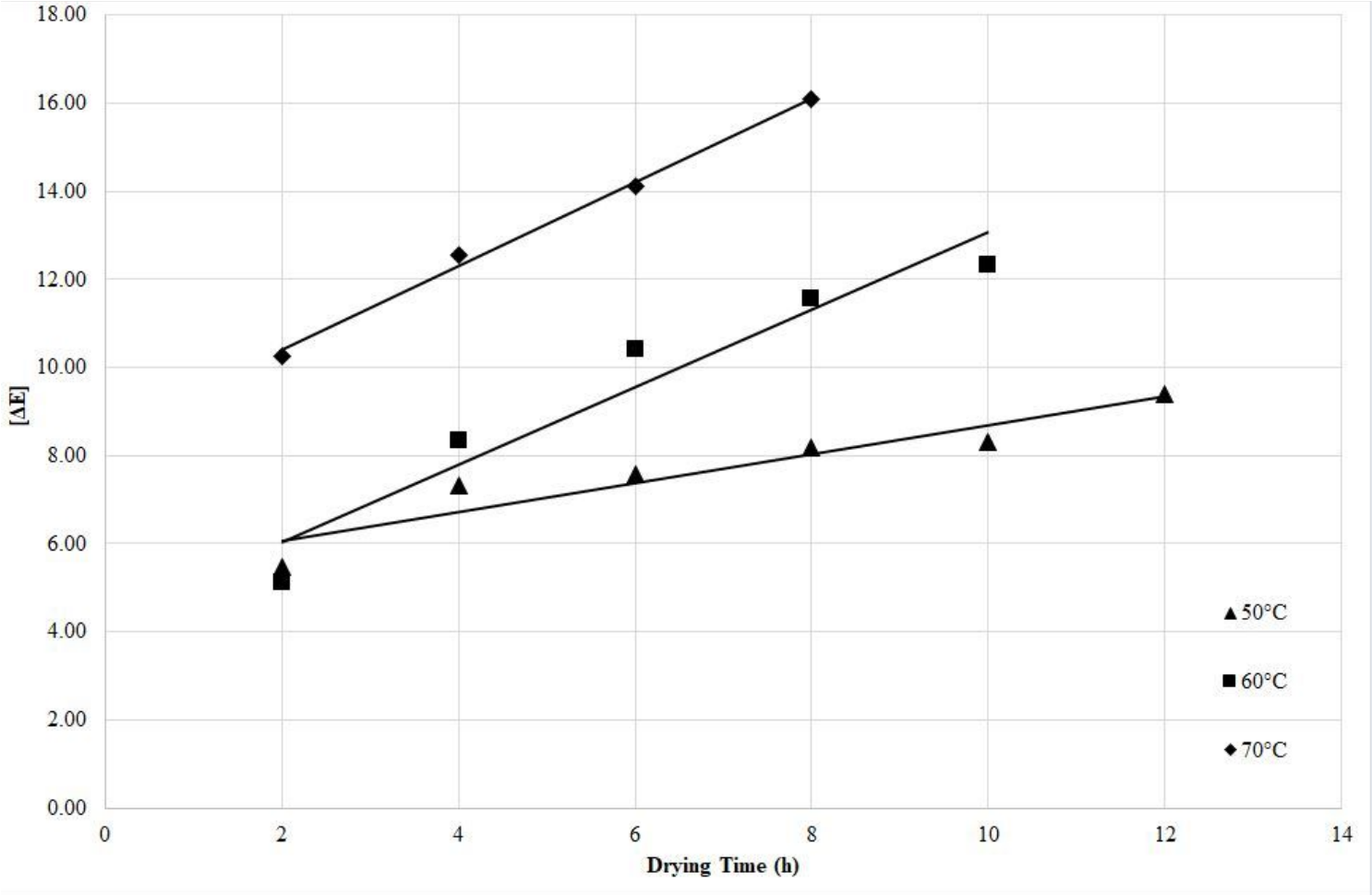

Figure 4

Kinetics of *ΔE* values change at sliced chicken breast meat samples at different drying temperatures.