Araştırma Makalesi
Adıyaman Üniversitesi
Mühendislik Bilimleri Dergisi
23 (2024) 216-231

MODELING CHANGES IN THE QUALITY ATTRIBUTES OF COUSCOUS COOKED WITH OHMIC HEATING

Basri OMAC[1*], Ali GOKSU[2], Erdem ISIK[3], and Serdal SABANCI[4]

[1]Munzur University, Tunceli Vocational School, Department of Food Processing, Tunceli, 62000, Türkiye

[2]Munzur University, Faculty of Fine Arts, Design and Architecture, Department of Gastronomy and Culinary Arts, Tunceli, 62000, Türkiye

[3]Munzur University, Faculty of Engineering, Department of Mechanical Engineering, Tunceli, 62000, Türkiye

[4]Munzur University, Faculty of Health Sciences, Department of Nutrition and Dietetics, Tunceli, 62000, Türkiye

Geliş Tarihi/Received Date: 25.04.2024 Kabul Tarihi/Accepted Date: 12.08.2024 DOI: 10.54365/adyumbd.1473698

ABSTRACT

Kinetic studies on the quality alters of couscous are crucial to the suitable design of ohmic heating treatment. Hence, it has been targeted to build mathematical models to forecast the changes in quality attributes of couscous cooked using ohmic heating (OH) in the present study. In addition, the average power and total energy for cooking couscous with OH at a voltage gradient of 17 V/cm have been determined. Three dissimilar kinetic models—zero, first, and second—have been fitted to the data. Our findings have shown that, for the ohmic heating system, as cooking time increased, energy consumption increased while heating system efficacy declined. The best model to reflect the changes in color parameters has been the second-order model, while the zero-order model has provided the best fit for the experimental data observed for the cooking loss, moisture content, and weight increase (%). For all TPA parameters, however, neither model has yielded the greatest fit.

Keywords: *Pasta, texture, color, moisture content, cooking kinetics*

OHMİK ISITMA İLE PİŞİRİLEN KUSKUSUN KALİTE ÖZELLİKLERİNDEKİ DEĞİŞİKLİKLERİN MODELLENMESİ

ÖZET

Kuskusun kalite değişiklikleri üzerine yapılan kinetik çalışmalar, ohmik ısıtma işleminin uygun tasarımı için çok önemlidir. Bu nedenle, bu çalışmada ohmik ısıtma (OH) kullanılarak pişirilen kuskusun kalite özelliklerindeki değişiklikleri tahmin etmek için matematiksel modellerin oluşturulması hedeflenmiştir. Ayrıca 17 V/cm voltaj gradyanında OH ile kuskus pişirmek için gereken ortalama güç ve toplam enerji belirlendi. Üç farklı kinetik model (sıfır, birinci ve ikinci) verilerin modellenmesi için kullanıldı. Bulgularımız, ohmik ısıtma sistemi için pişirme süresi arttıkça enerji tüketiminin arttığını ve ısıtma sistemi etkinliğinin azaldığını gösterdi. Renk parametrelerindeki değişiklikleri en iyi yansıtan model ikinci dereceli model olurken, sıfır dereceli model pişirme kaybı, nem içeriği ve ağırlık artışı (%) için gözlemlenen deneysel verilere en iyi uyum sağlayan modeldir. Ancak tüm TPA parametrelerini için herhangi bir model tek başına en iyi uyumu sağlayamadı.

Anahtar Kelimeler: *Makarna, tekstür, renk, nem içeriği, pişirme kinetiği*

1. Introduction

Cooking dried pasta is a crucial step in the preparation of dishes because dried pasta can be produced with high quality, but its quality can be poor after the cooking process due to the incorrect cooking method [1]. Pasta is customarily cooked in boiling water for various times, which depends on the desired quality attributes, such as texture, color, and moisture content of the final product [2,3].

*e-posta[1] : basriomac@munzur.edu.tr ORCID ID: https://orcid.org/0000-0001-6956-2720 (Sorumlu Yazar)
e-posta[2] : aligoksu58@hotmail.com ORCID ID: https://orcid.org/0000-0003-2316-0704
e-posta[3] : erdem@munzur.edu.tr ORCID ID: https://orcid.org/0000-0003-4715-6582
e-posta[4] : serdalsabanci@hotmail.com ORCID ID: https://orcid.org/0000-0003-1630-0799

Heat energy must be produced externally for conventional heating methods, and it is subsequently transferred to the food material by radiation, convection, and conduction [4]. Due to this indirect heat transfer, energy loss is too high during conventional heating [5]. Also, the outer surface of food materials is exposed to excessive heat processing, causing the degradation of food quality [4]. Hence, innovative heating techniques, such as ohmic heating, should be considered as an option to conventional heating to perform rapid and uniform heating for the purpose of enhancing heating efficiency and decreasing quality losses [4,5].

Using an electric current to heat food materials, ohmic heating (OH) is one of the direct heating methods [6]. This method has several advantages [7,8]. First, uniform heating can be achieved using OH because the electrical resistance of the heating permits the food material to be heated at the same rate. Second, OH reduces energy losses due to direct heating, thus providing fast heating and saving costs [6,9,10]. For example, Goksu et al. [10] found that the OH reduced the overall energy used in bulgur cooking by around 80% in comparison to traditional methods. Lastly, it can reduce the degradation of food quality [11].

Quantitative changes in quality attributes in thermal processes are crucial for the proper design of heat treatments, involving conventional or novel thermal processes, which need to deeply understand the thermal features of foods [5,12]. To minimize food quality degradation, the optimal process conditions should be selected. Therefore, many kinetic studies have been largely documented and discussed in the literature for conventional heat processes [1,5,12]. These models also contribute beneficial insights into understanding, forecasting, and managing food quality alterations throughout thermal processing [1,5]. Nevertheless, the research regarding the kinetic models developed for food products treated with ohmic heating is limited and most of them are about the kinetics of the quality of fruits and vegetables treated with this technology [13–15].

Therefore, the aim of the present study was (1) to develop kinetic models to conclude the alterations in quality characteristics of couscous cooked with ohmic heating (OH) depending on time; (2) to determine average power, current, and total energy values throughout the cooking process of dried couscous.

2. Materyal ve Method

2.1. Data

The data used in the present study was published in previous research [16]. Briefly, dried couscous was cooked in a 0.1% salt solution using an ohmic heating system. The cooking time started when the water started to boil. Following a specified cooking time (0, 4, 8, 12, and 16 min), the parameters of color, moisture content, texture profile analysis, total soluble solid content (TSSC), and weight gain (%) were determined by analyzing the samples. These parameters were selected based on studies already published [1-3,10].

2.2. Performance analysis

The general energy balance (E_{in}, Eq. 1) was applied to determine the energy input and output energy values throughout the cooking process [17].

$$E_{in} = E_{out} + E_{loss} \tag{1}$$

herein, the subscripts *in* and *out* represent input and output, respectively.

For the energy input in the cooking process, the ohmic energy (Q_{ohmic}), ohmic heating equipment ($Q_{eq,\,in}$), liquid ($Q_{L,\,in}$), and solid ($Q_{S,\,in}$) products in the cooking cell were considered as shown in Eq. 2.

$$E_{in} = Q_{ohmic} + Q_{S,in} + Q_{L,in} + Q_{Eq,in} \tag{2}$$

Also, the ohmic energy entering the cooking system was determined by using Eq. 3.

$$Q_{ohmic} = \sum[V \times I \times t] \quad (3)$$

herein, *V*, *I*, and *t* represent voltage (V), current (A), and time (s), respectively.

Then, Eq. 4 was applied to determine the output energy (E_{out}) value including removing water (Q_w), solid ($Q_{S,\,out}$) phase, and equipment ($Q_{Eq,\,out}$), such as an electrode, test cell, cover, etc.

$$E_{out} = Q_{S,out} + Q_w + Q_{Eq,out} \quad (4)$$

During the cooking process, the energy input and output energy of liquid and solid phases and equipment were calculated by using Eq. 5. The temperature of liquid and solid phases was determined using T-type thermocouples whereas the temperature of equipment was evaluated using a thermal camera (Testo 882, Germany). The C_p values of the liquid and solid phases throughout the process were computed with the equation of [18] as follows.

$$Q_i = m_i \times Cp_i \times (T - T_0) \quad (5)$$

herein, the subscript "i" represents the solid and liquid phases and equipment whereas the subscript "0" represents the death state.

During the ohmic and conventional cooking process, the energy efficiency (η) was calculated by using Eq. 6.

$$\eta\ (\%) = \frac{E_{out}}{E_{in}} \times 100 \quad (6)$$

2.3. Kinetic models

Several equations have been studied by researchers to find out the color and texture alterations of food materials as a function of process time [12,19,20]. The rate alteration of a quality factor *C* may be typically calculated by using Eq. 7.

$$\frac{dC}{dt} = -kC^n \quad (7)$$

herein, *k* symbolizes the kinetic rate constant, *c* symbolizes the concentration of a quality factor at a time (*t*), and *n* symbolizes the order of the reaction. Chemical and physical changes in foods during processing were modeled in accordance with zero-order (Eq. 8), first-order (Eq. 9), and second order (Eq. 10) kinetic models derived as follows.

$$C = C_0 - k \times t \quad (8)$$

$$C = C_0 \times \exp(-k \times t) \quad (9)$$

$$\frac{1}{C} = \frac{1}{C_0} + k \times t \quad (10)$$

where C_0 symbolizes the beginning value of the quality variable (before cooking), *C* symbolizes the value of the quality variable at a specific cooking time (*t*), and *k* represents the rate constant of the quality variable (min^{-1}). A positive value of *k* demonstrates a decrease whereas a negative value demonstrates an increase in the parameter throughout cooking.

The rightness of the three kinetic models was described by comparing the root mean squared errors (RMSE) and coefficient of determination (R^2), which were provided by the software, SigmaPlot for windows version (11.0.0.77). In addition, the Akaike information criterion (AIC, Eq. 11) considers sample size and number variables in a model [21]. Therefore, it was used to compare the models.

$$AIC = N \times \ln(\frac{SSE}{N}) + (2 \times (n+1) + (\frac{(2 \times (n+1) \times (n+2)}{N-n-2}) \quad (11)$$

herein, *N* represents the count of observations, *SSE* represents the sum of the square error, and *n* represents the count of variables in the examined model.

3. Results and Discussion

3.1. Performance analysis

In this study, couscous, an important pasta product, was cooked using ohmic heating technology, and temperature change, current, performance values, and cooking degree characteristics during the cooking process were investigated. Time-dependent temperature and current changes throughout the ohmic heating-assisted cooking process are provided in Figure 1A. During the cooking of couscous, a 0.1% salt couscous solution was first heated from 20 °C to 100 °C, and then the cooking operation was carried out at 4-minute intervals up to 16 minutes. The ohmic heating-assisted cooking process took 545.9±18.6 seconds to heat up to 100 °C in a fixed voltage gradient (17 V/cm).

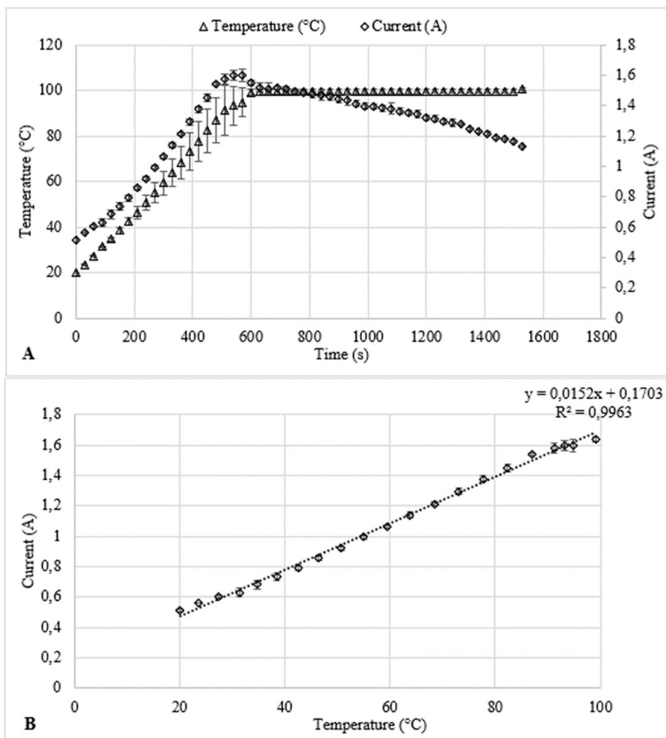

Figure 1. During ohmic heating assisted cooking (A): current and temperature change with time and (B): current change with temperature

The time-dependent current alteration throughout the ohmic heating-assisted cooking treatment is given in Fig. 1B. Electrical conductivity (EC) is one of the primary variables during the ohmic heating treatment. The EC value depends on the current, voltage gradient, distance between two electrodes (m), and electrode contact surface area (m^2). The distance and voltage gradient between the two electrodes was constant during ohmic heating-assisted cooking. However, electrode contact surface area (m^2) and current were not constant during ohmic heating-assisted cooking. There were several factors affecting the electrode contact surface area such as swelling of the baked product, evaporation, and change in the density of the water. Because of these changes in it, current values were investigated in place of electrical conductivity in the ohmic heating-assisted cooking treatment in the present study. The current values varied from 0.51 to 1.55 S/m when the temperature of the couscous specimens was altered from 20°C to 100°C while these values have been found to vary from 1.55 to 1.13 S/m for the samples cooked for 16 minutes at 100 °C, where the cooking treatment was started. In the ohmic heating-assisted cooking treatment, it has been found that the current value raised as the temperature raised throughout the heating stage and started to decline at the beginning of the cooking period. It has been found that the current value raised with the rise in molecular mobility as a result of the rise in temperature during heating. Due to the water being removed at the beginning of the cooking treatment, the molecular mobility in the product was limited and thus the current value was decreased. In studies where ohmic heating was used, it was observed that the current value enlarged as the temperature enlarged during the heating of products such as orange juice [22], grape juice [23], lemon juice [24], and sour cherry juice [6]. In addition, it has been published that the current value raised as a result of the rise in temperature in different food processing techniques such as thawing [9], evaporation [25], cooking [26], and extraction [7].

Also, it was discovered that temperature and current had a linear relationship that depended on the temperature rising throughout the ohmic heating-assisted cooking process (Fig. 2). When this relation was studied, it was noticed that the R^2 value was above 0.99. As a result of the literature review, a linear correlation between current (or EC) and the temperature has been reported during heating, especially in heating different juices and milk [22,24,25]. In addition, it has been reported that there was a linear correlation between temperature and current during different processes with ohmic heating such as evaporation [27,28], extraction [29] and thawing [30].

The total consumed energy (TCE), average power, and energy efficiency values depending on various process times during the ohmic heat cooking process are given in Table 1. As expected, TCE values raised as the process time raised. It has been found out that the increase in TCE value depended on the process time in the ohmic heating system. It has been found that the average power and TCE values altered with the change in the process time (Table 1). It has been found that the average power value is raised with increasing process time. Considering the energy efficiency values, it was determined that the holding time was adversely affected and decreased from 85.1% to 72.5%. It has been observed that significant losses in energy occurred with the increase in time for the heat transfer to the environment as a result of the raising holding time (Fig. 2). In addition, the current value decreased with the rise in the process time and the instant energy consumption was negatively affected due to this decrease. Similar energy consumption trends have been observed in different food ohmic-assisted heating applications such as evaporation [28], extraction [29], and thawing [30], and energy efficiency was adversely influenced by the rise in the processing time.

Owing to the lack of an opaque white center—a sign that the cooking process is finished—the couscous samples treated with OH required 12 minutes to cook [31]. Therefore, the conventional cooking process was implemented for 12 min. The energy required for couscous cooking with the conventional cooking technique was determined as 871.2±46.8 kJ. This value was approximately 5 times higher than that consumed in the OH. In addition, the average power value of OH was 126.7 W whereas the value of the conventional method was 671±36 W. Moreover, the energy efficiency of the conventional heating method (12 min) was 13.1% while it was calculated as 72.5% for OH for 12 min. Overall, the total energy consumed, average power, and energy efficiency of the conventional and OH treatments were significantly different for 12 min of cooking time ($p < 0.05$).

Some of the energy generated by ohmic heating during the cooking process was lost as a result of the heat transfer between the container and the environment. Throughout the cooking treatment, the average temperature of the container increased with the rising cooking time. Thus, the amount of energy loss increased since the average temperature raised with increasing cooking time as seen in Fig. 2. In accordance with the outcomes acquired in the current study, the efficacy of ohmic heating reduced when the cooking time was increased because the energy loss between the container and environment was increased. Similarly, Goksu et al. [10] reported that during the pectin production by using ohmic heating at several voltage gradients (10, 13, 16, and 19 V/cm), the heat losses occurring on the surface of electrodes and containers were increased when the processing time was raised. As a result, the efficacy of ohmic heating systems during the heating process is reduced with increasing cooking time or temperature.

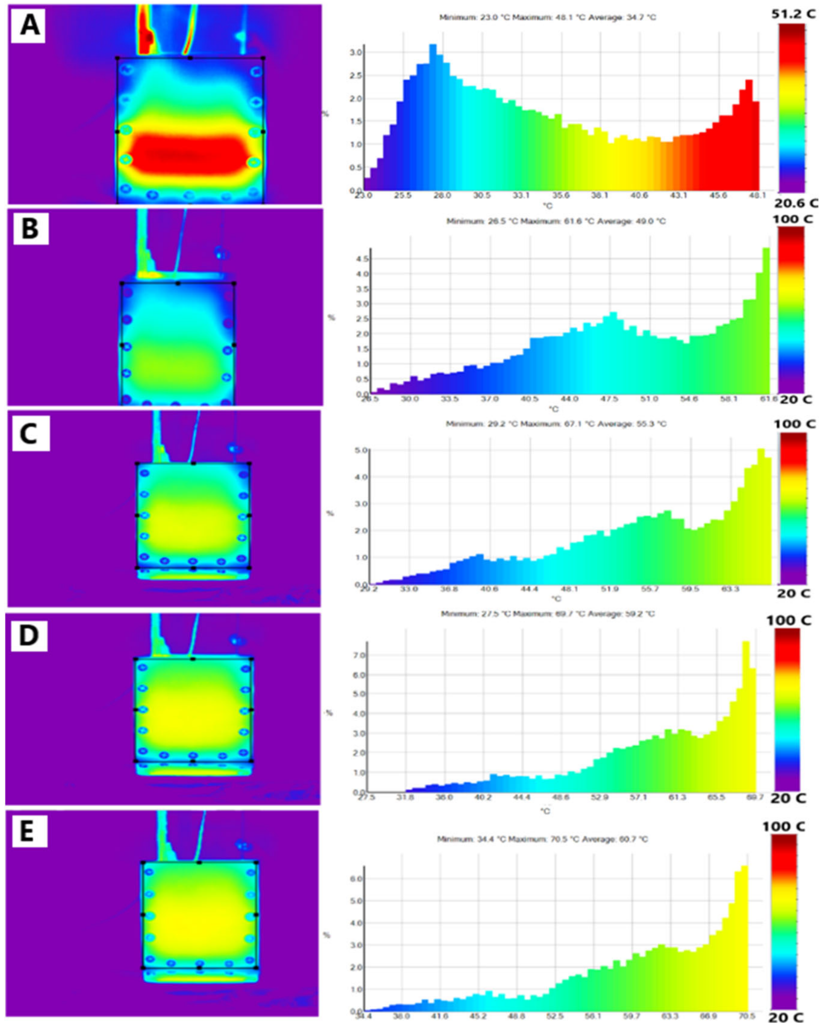

Figure 2. Thermal camera images and surface temperature distributions of the ohmic system cell at different times (A: 0 min, B: 4 min, C:8 min, D: 12 min. E:16 min)

3.2. Kinetic models

The experimental color values of the couscous, such as L, a, b, chrome (C), total color change (ΔE), and browning index (BI) obtained from each cooking time, was fitted to zero order (Eq. 8), first order (Eq. 9), and second order (Eq. 10) models (Fig. 3). Kinetic parameters for color evolution of the couscous treated with ohmic heating at 17 V/cm are shown in Table 2. The model with the highest coefficient of determination (R^2) and the least values of the Akaike information criterion (AIC) and root mean square error (RMSE) was chosen as the best one to describe the color change kinetics of the data. Overall, the second-order model is the best model based on R^2, RMSE, and AIC. On the other hand, Badin et al. [32] pointed out that a*, L, and L-ascorbic acid values of crushed tomato samples due to the thermal degradation tracked the first order kinetic model, but they did not used the second order model, which may be better than the first order model. Furthermore, Gull et al. [33] found that color changes for pasta during

Table 1. Total consumed energy (TCE), average power, and energy efficiency values at different processing times during ohmic heating-assisted cooking

Processing Time (min)	TCE (kJ)	Average Power (W)	Energy Efficiency (%)
0	57.3^{a} (3.7)*	105.1^{a} (0.0)	85.1^{a} (4.6)
4	91.6^{b} (3.2)	116.7^{b} (0.0)	74.3^{b} (2.6)
8	126.0^{c} (0.8)	122.9$^{b, c}$ (0.0)	74.6^{b} (0.5)
12	160.2^{d} (3.1)	126.7^{c} (0.0)	72.5^{a} (1.5)
16	193.1^{e} (3.8)	128.3^{c} (0.0)	72.5^{a} (1.4)

$^{a, b, c, d, e}$ Significant differences exist between the values in a column that has a different lowercase letter. ($p < 0.05$).

* Standard deviation.

storage followed zero order kinetic. Similarly, Olivera and Salvadori [34] stated that the alterations in the color of lasagna throughout storage were expressed from zero order kinetics. The difference between these studies and our results may be due to the thermal treatment used in the present study.

Figure 4 displays alters in TPA characteristics of the samples, including resilience, gumminess, chewiness, adhesiveness, hardness, and springiness. Kinetic parameters for TPA parameters of the couscous cooked with ohmic heating at 17 V/cm are displayed in Table 3. In terms of RMSE values, the zero, first, and second order did better in 29%, 14%, and 57% of the curves (7). In addition, when comparing the discrepancy in R^2 value between Eq. 8, Eq. 9, and Eq. 10, the first (Eq. 9), and second order (Eq. 10) models fitted better one (14%) and six (86%), respectively, out of 7 curves. It is well recognized that when comparing models, the RMSE and R^2 are typically not the best indicators [35]. Therefore, the values of the AIC criterion were calculated for comparing models used in the present study. The zero order (Eq. 8) and second order (Eq. 10) models were suitable for fitting the experimental data of springiness, cohesiveness, resilience and hardness, adhesiveness, gumminess, and chewiness, respectively, although neither model regularly generated the best fit to all TPA parameters on the basis of the Akaike information criteria (AIC) values. Gomez et al. [36] found that a linear model could be suitable to fit some TPA parameters, such as firmness, cohesiveness, springiness, curves of white bread, but it was not good for other TPA parameters such as resilience and gumminess.

Figure 5 shows the total soluble solid content (TSSC) values that entered the boiling water at different cooking durations (4, 8, 12, and 16 min). The models` parameters and statistical results are summarized in Table 4. Similarly, the percentage in weight increase and moisture content demonstrated a similar trend with TSSC (Fig 5). According to the models' results, the zero-order (Eq. 12) model was the better model to represent the alterations in TSSC, moisture content (%), and weight increase (%) during the cooking times (Table 4).

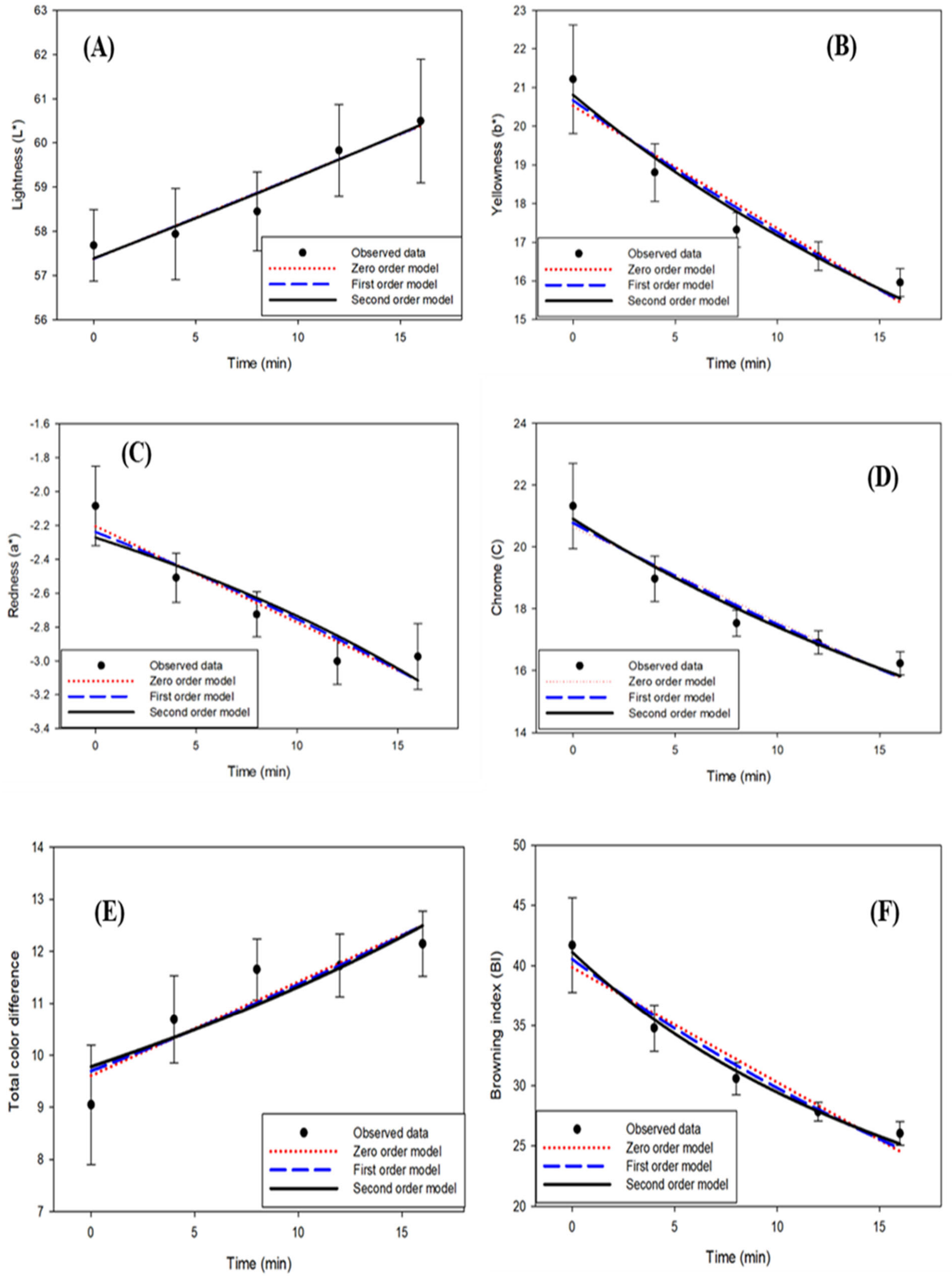

Figure 3. Kinetic change of color parameters (A) lightness (L*), (B) yellowness (b*), (C) redness (a*), and (D) chrome (C), (E) total color difference (ΔE), and (F) browning index (BI)

Table 2. Color kinetic parameters

Model	Parameter	Lightness (L*)	Redness (a*)	Yellowness (b*)	Chrome (C)	Total color difference (ΔE)	Browning index (BI)
Zero order (Eq. 8)	[a]C_0	57.37 (0.61)*	-2.204 (0.24)	20.52 (1.18)	20.64 (1.15)	9.604 (0.96)	39.84 (3.17)
	[b]k	-0.188 (0.06)	0.057 (0.02)	0.317 (0.12)	0.306 (0.12)	-0.181 (0.10)	0.96 (0.32)
	[c]RMSE	0.350	0.138	0.681	0.667	0.556	1.831
	[d]R^2	0.94	0.90	0.92	0.92	0.85	0.94
	[e]AIC	-1.01	-10.29	5.65	5.45	3.62	15.54
The first order (Eq. 9)	C_0	57.38 (0.59)	-2.239 (0.26)	20.67 (1.06)	20.77 (1.05)	9.695 (0.10)	40.532 (2.48)
	k	-0.003 (0.001)	-0.02 (0.01)	0.018 (0.006)	0.017 (0.006)	-0.016 (0.01)	0.031 (0.01)
	RMSE	0.342	0.158	0.585	0.580	0.601	1.331
	R^2	0.94	0.87	0.94	0.94	0.82	0.97
	AIC	-1.23	-8.98	4.14	4.04	4.42	12.35
Second order (Eq. 10)	C_0	57.47 (0.92)	-2.272 (0.32)	20.79 (1.89)	20.92 (1.86)	9.775 (2.33)	41.152 (4.06)
	k	-0.00005 (0.00)	0.007 (0.004)	0.001 (0.00)	0.001 (0.00)	-0.001 (0.00)	0.001 (0.00)
	RMSE	0.335	0.175	0.486	0.489	0.644	0.818
	R^2	0.94	0.84	96	0.96	0.80	0.99
	AIC	-1.45	-7.90	2.28	2.34	5.09	7.48

* Standard deviation.
[a]C_0: the initial value of the color parameter (before cooking)
[b]k: the rate constant of the color parameter
[c]RMSE: root mean square error
[d]R^2: the coefficient of determination
[e]AIC: the Akaike information criterion

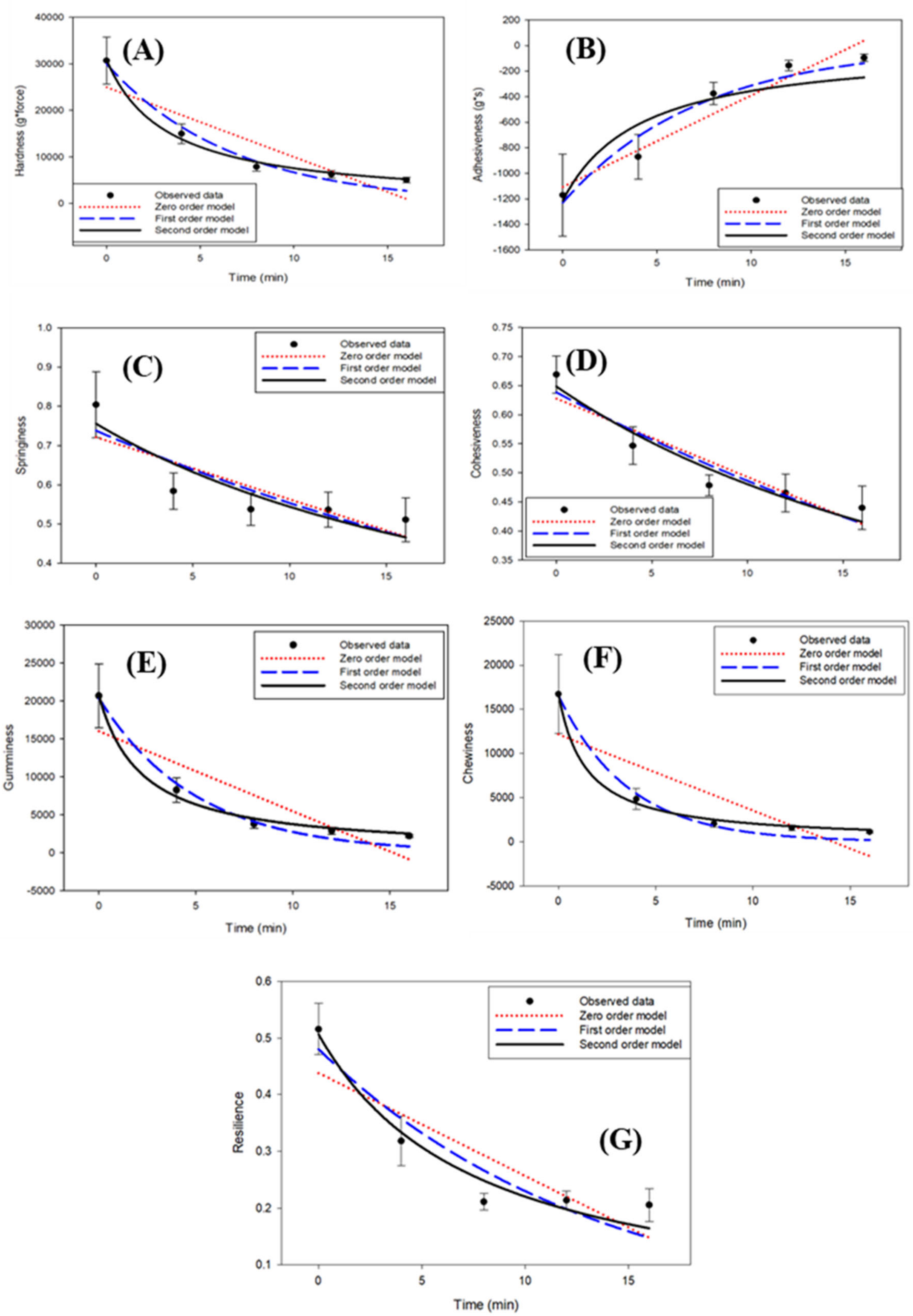

Figure 4. Kinetic change of (A) hardness, (B) adhesiveness, (C) springiness, and (D) cohesiveness, (E) gumminess, (F) chewiness, and (G) resilience

Table 3. Texture profile analysis (TPA) kinetic parameters

Model	Parameter	Hardness (g)	Adhesiveness (g*sec)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Zero order (Eq. 8)	[a]C_0	24963 (9581)*	-1107 (241.4)	0.721 (0.132)	0.628 (0.07)	15999 (7631)	12153 (3283)	0.438 (0.14)
	[b]k	1501 (977.9)	-71.63 (24.64)	0.016 (0.013)	0.014 (0.007)	1055 (778.9)	861.89 (335.1)	0.018 (0.01)
	[c]RMSE	5532	139.37	0.076	0.04	4406	4239	0.078
	[d]R^2	0.80	0.93	0.70	0.86	0.76	0.69	0.74
	[e]AIC	95.68	58.86	-16.26	-22.59	93.40	93.01	-16.00
The first order (Eq. 9)	C_0	29968 (4115)	-1230 (241.59)	0.738 (0.128)	0.638 (0.06)	20353 (2538)	16596 (864.8)	0.480 (0.11)
	k	0.150 (0.04)	0.137 (0.05)	0.029 (0.021)	0.027 (0.01)	0.2011 (0.023)	0.278 (0.03)	0.074 (0.04)
	RMSE	1916	113.49	0.069	0.035	1157	869.76	0.071
	R^2	0.97	0.96	0.75	0.90	0.98	0.99	0.87
	AIC	85.08	56.81	-17.20	-24.13	80.03	77.18	-19.34
Second order (Eq. 10)	C_0	30813 (2059)	-1250 (22360)	0.756 (23.61)	0.648 (38.22)	20715 (1235)	16743 (487.6)	0.507 (0.29)
	k	0.00001 (0.00)	-0.0002 (0.00)	0.051 (0.03)	0.054 (0.02)	0.00002 (0.00)	0.00004 (0.00)	0.257 (0.09)
	RMSE	925.20	195.99	0.061	0.028	695.05	424.70	0.035
	R^2	0.99	0.87	0.81	0.93	0.99	1.00	0.95
	AIC	77.79	62.27	-18.46	-26.16	74.93	70.01	-24.13

[*] Standard deviation.
[a]C_0: the initial value of the TPA parameter (before cooking)
[b]k: the rate constant of the TPA parameter
[c]RMSE: root mean square error
[d]R^2: the coefficient of determination
[e]AIC: the Akaike information criterion

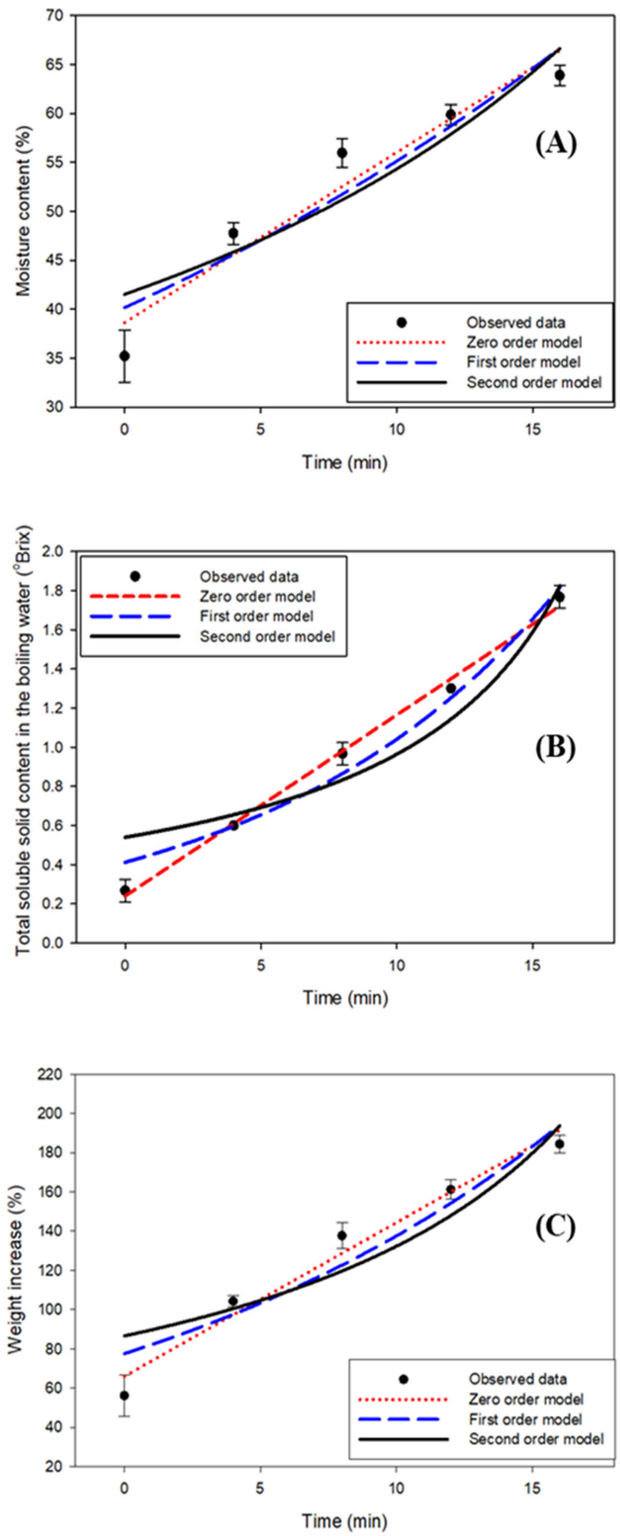

Figure 5. Kinetic change of (A) moisture content (MC), (B) total soluble solid content (TSSC), and (D) weight increase (WI)

Table 4. Kinetic parameters for weight increase (%), moisture content (%), and total soluble solid content (˚brix)

Model	Parameter	Moisture content (%)	Total soluble solid content (˚Brix)	Weight increase (%)
Zero order (Eq. 8)	[a]C_0	38.62 (5.89)[*]	0.24 (0.08)	65.92 (16.63)
	[b]k	-1.74 (0.60)	-0.09 (0.01)	-7.84 (1.70)
	[c]RMSE	3.40	0.04	9.60
	[d]R^2	0.93	1.00	0.97
	[e]AIC	21.73	-21.84	32.11
The first order (Eq. 9)	C_0	40.16 (6.78)	0.41 (0.13)	77.53 (24.30)
	k	-0.03 (0.01)	-0.09 (0.02)	-0.06 (0.03)
	RMSE	4.31	0.11	17.05
	R^2	0.89	0.97	0.91
	AIC	24.11	-12.61	37.85
Second order (Eq. 10)	C_0	41.49 (8.03)	0.54 (0.72)	86.21 (42.3)
	k	-0.0006 (0.00)	-0.082 (0.05)	-0.0004 (0.05)
	RMSE	5.09	0.20	22.60
	R^2	0.85	0.91	0.85
	AIC	25.77	-6.47	40.67

[*] Standard deviation.

[a]C_0: the initial value of the parameter (before cooking)

[b]*k*: the rate constant of the parameter

[c]RMSE: root mean square error

[d]R^2: the coefficient of determination

[e]AIC: the Akaike information criterion

4. Conclusion

Our finding revealed that it is likely to apply the ohmic heating method for the cooking of dried couscous in advance of consumption. During the ohmic heating treatment, the current value was increased from 0.51 A to 1.55 A when the temperature was escalated from 20 ˚C to 100 ˚C. Then, the current value decreased from 1.55 A to 1.13 A due to the restriction of molecular mobility. The consumption of energy increased with the rise in the cooking time for the ohmic heating-assisted cooking process. Similarly, the energy losses raised since the temperature difference between the container and environment increased with increasing the cooking time according to the thermal camera`s results. Thus, the efficacy of the ohmic heating-assisted cooking process was reduced with increasing cooking time.

In addition, the developed kinetic models can contribute to a deeper knowledge of the mechanism of the quality alterations throughout the ohmic heating process of couscous. These can be connected to physical-based models (such as heat and mass transfer) allowing the forecast of quality alterations throughout the ohmic heating process at 17 V/cm. Furthermore, the second order model was suitable to determine the color properties of couscous, whereas none of the models used in the present study were adequate alone for predicting all TPA parameters. Moreover, changes in TSSC, moisture content, and weight increase (%) can be defined using a zero-order model. Further studies are needed to determine whether changes in the voltage gradient have any effect on the best model used to represent the quality parameters of couscous.

Conflict Of Interest

The authors declare that they have no conflict of interest

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