Hindawi
Journal of Food Quality
Volume 2018, Article ID 4186050, 14 pages
https://doi.org/10.1155/2018/4186050

Research Article

Optimizing Physiochemical and Sensory Properties of Infrared-Hot Air Roasted Sunflower Kernels Using Response Surface Methodology

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Received 14 May 2018; Accepted 25 July 2018; Published 12 September 2018

Academic Editor: Giuseppe Zeppa

Roasting sunflower kernels is a key process in production of nuts. In this study, the effect of roasting conditions, including hot air temperature (120–160°C), infrared (IR) power (400–600 W) and roasting time (3–10 min) on energy and specific energy consumption, color parameters (L^*, a^*, b^*, ΔE, BI, SI, WI, and h°), texture, moisture content, chemical properties (pH and total phenolic contents, peroxide value (PV), and sensory properties of sunflower kernel were investigated. In addition, the best models for the responses were obtained, and the proper roasting conditions were determined using response surface methodology (RSM). A quadratic model was proposed for color change (L^*, ΔE, SI, and WI), moisture and total phenol contents, linear relation for a^*, b^*, h°, and 2FI for BI, texture, PV, and pH. Roasting at 425.7 W IR power and 124.3°C for 3.7 min was found to be convenient or proper roasting conditions.

1. Introduction

Sunflower (*Helianthus annuus* L.), an annual plant, is grown in temperate and subtropical climate [1]. The sunflower seeds are rich in unsaturated fatty acids, proteins, fiber, and vitamins (such as B1, B5, and B6), phosphorus, copper, manganese, folate, iron, zinc, amino acids, and low-carbohydrate diets. They are consumed as snack products, either alone or in the blends of different nuts and other components [2].

Roasting is the key process in the production of value-added nuts having better taste, aroma, and a crunchy texture and exhibit enhanced crispiness. One of the common treatment methods is dry roasting. In this process, the nuts are heated applying the conventional thermal treatment, such as air convection and pan or sand roasting at 250–300°C for a short time [3–6]. In dry roasting, some novel thermal treatments could be used applying irradiation of microwave, infrared (IR), and radiofrequency [7]. In the conventional heating method, the outer surface of the seeds can be overroasted, whereas the core of them is not completely processed. This causes uneven roasting, burnt surface, and development of the undesirable aroma and flavor. Roasting of grains and legumes leads to the gelatinization of starch and denaturation of proteins, too [8]. On microwave roasting, the temperature on lower surface of the food, rather than its inner parts, causes over- or underroasted food [9].

IR heating has many advantages over the conventional method such as (1) production of the high-quality food due to consistent and uniform distribution of IR energy; (2) high energy efficiency as a result of direct radiation transferring from IR emitters to the surface of product, without requiring any heating medium; (3) short process time; (4) precise controlling the IR heating process; (5) compact design and

difference in types of IR emitters; and (6) environment-friendly energy [10].

Although IR heating is a new promising approach, it is limited because of its low penetrating power. Combination of two convection (hot air (HA)) and radiation heat transfer mechanisms is important to increase the thermal efficiency of dryers [11, 12].

IR heating was applied lonely or in combination with hot air in roasting of several products like almonds [13], pistachios, coffee [14], tea [15, 16], peanuts [17], pecans [18], hazelnuts [7, 19], cereal grains [20], and sesame seeds [21, 22]. There are only a few reports on the roasting sunflower kernels. Most of the previous studies on roasted sunflower kernels investigated the influence of various factors such as change of molecular species of triacylglycerols during microwave roasting [23], color, texture firmness, moisture, percentage of extracted oil, acidity, peroxide, sensory properties, and fatty acid composition sunflower kernels were roasted under two different conditions, i.e., by microwave and electrical oven [24].

The aim of this study was to investigate the effect of power, temperature, and time of combined IR-HA roasting method on some physicochemical properties of the sunflower kernels. The proper conditions for IR-HA roasting were also determined using response surface method (RSM).

2. Materials and Methods

2.1. Sample Preparation. Sunflower seeds (Slatki variety) were obtained from the agricultural farm (KhanBebin, in Golestan Province). The seeds were manually cleaned and deshelled. The percent of kernel recovery was 39.3%. The seeds were sorted to obtain the uniform size and defect-free ones. Then, they were kept at 4°C until using in experiments. Before roasting process, sunflower kernels were soaked in 25% (w/w) salt solution for 30 min. Then, the excess water of sieved seeds was removed using cloth.

2.2. Experimental Design. The results were analyzed using RSM based on the performed pretests, the independent variables were IR power (*A*) (400–600 W), temperature of HA (*B*) (120–160°C) having constant velocity (1 m/s), and roasting time (*C*) (4–10 min). The roasted samples were analyzed according to a central composite design (CCD). The experimental design consisted of 20 treatments including 6 center points and 14 noncenter points, as shown in Table 1.

2.3. Combined IR-HA Roasting Process. Roasting was performed in a combined IR-HA roaster equipped with a controller to adjust the air temperature and IR power of roasting. The apparatus consisted of heating elements (4 electrical elements with power 750 watts), scale, pitot unit, a centrifugal fan, infrared radiator (Far infrared lamp, 1500 W), and a roasting chamber (Figure 1). A single layer of the seeds was spread on aluminum trays. Finally, the processed kernels were kept at room temperature to cool (25 ± 2°C). Until performing the experiments, the samples were kept in polyethylene Zip-pack bag at room temperature (25°C).

Table 1: Experimental range levels of three independent variables: (*A*) IR Power (W), (*B*) air temperature (°C), and (*C*) roasting time (min).

Run number	Coded variables			Actual variables		
	A	*B*	*C*	*A*	*B*	*C*
1	+1	+1	+1	598	158.3	8.3
2	−1.68	0	0	334	140	6
3	0	0	+1.68	500	140	9.8
4	0	0	0	500	140	6
5	0	0	0	500	140	6
6	−1	−1	+1	401	121	8.3
7	+1	−1	−1	598	121	3.6
8	0	0	−1.68	500	140	2
9	0	0	0	500	140	6
10	0	0	0	500	140	6
11	0	+1.68	0	500	170	6
12	+1	−1	+1	598	121	8.3
13	0	0	0	500	140	6
14	+1.68	0	0	665	140	6
15	0	0	0	500	140	6
16	0	−1.68	0	500	109	6
17	−1	+1	−1	401	158.3	3.6
18	−1	−1	−1	401	121	3.6
19	+1	+1	−1	598	158.3	3.6
20	−1	+1	+1	401	158.3	8.3

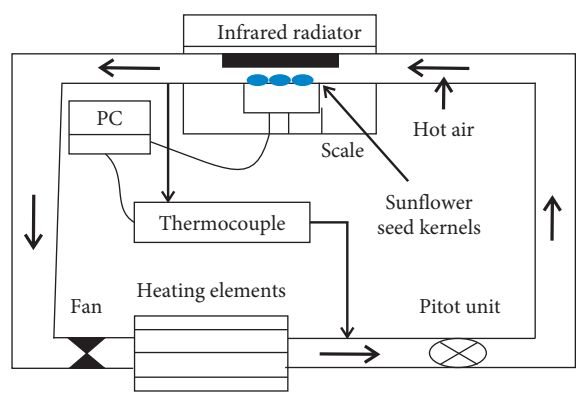

Figure 1: Schematic of combined infrared-hot air apparatus used for roasting of sunflower kernels.

2.4. Physical Characteristics

2.4.1. Specific Energy Consumption. The energy consumption in each period of roasting was calculated using the following equation

$$E = \int_{t=0}^{t} Pt, \quad (1)$$

where E is the energy consumption (kW·h), P is the consumed power by the roaster system (W), and t presents the roasting time (min). Using (2), the specific energy consumption was calculated at different roasting conditions:

$$E_{kg} = \frac{E}{W_0}, \quad (2)$$

where E_{kg} and W_0 are the specific energy (kW·h/kg) and initial weight of the sample (kg), respectively.

2.4.2. Color Measurement. Color measurement of sunflower kernels was performed using image processing method. 40g of processed kernels were put on the surface of a scanner system (DCP8065DN brother). The taken images (600 dpi) were saved in the JPEG format. L^*, a^*, and b^* values were calculated by ImageJ software (version 1.46r). The L^* value represents lightness, and the $+a^*$ and $-a^*$ values represent redness and greenness, respectively. The $+b^*$ and $-b^*$ values represent yellowness and blueness, respectively. The parameter hue angle (h°) expresses the color tone and is defined as red-purple: 0°, yellow: 90°, bluish green: 180°, and blue: 270° [25]. Total color difference (ΔE), browning index (BI), saturation index (SI), h° and whiteness index (WI) were calculated using Equations (3)–(8) [26]:

$$\Delta E = \sqrt{\Delta l^{*2} + \Delta a^{*2} + \Delta b^{*2}}, \quad (3)$$

$$\mathrm{BI} = \frac{[100\,(X - 0.31)]}{0.17}, \quad (4)$$

$$X = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}, \quad (5)$$

$$\mathrm{SI} = \sqrt{a^{*2} + b^{*2}}, \quad (6)$$

$$\mathrm{Hue} = \arctan\left(\frac{b^*}{a^*}\right), \quad (7)$$

$$\mathrm{WI} = 100 - \sqrt{(100 - l^*)^2 + a^{*2} + b^{*2}}, \quad (8)$$

where L^*, a^*, and b^* refers to the difference between the color parameters of the fresh sunflower kernel and the treated one.

2.4.3. Texture Analysis. According to definition, texture hardness is the required force over compression test. The textural analysis of the sunflower kernels was performed using a TA.XT Plus Texture Analyzer (Texture Technologies Corp Surrey, UK TA-XT Plus, Stable, England). In texture profile analysis (TPA), 10 sunflower kernels were placed on the platform of the texture on the following settings as described by Soleimanieh et al. [24]:

Probe P/36R used a load cell 250 N, a diameter of 32 mm, a speed of 5 mm/min, and a penetration index of the probe was 50% of the kernel thickness. Textural properties were derived from the force time curves. To study the textural properties of the samples, hardness (maximum peak of first compression) measured.

2.4.4. Moisture Content. Moisture content of roasted kernels (10 g) was measured according to ISO665 [27] in oven drying method (103 ± 2°C) until a constant weight was reached, and results are expressed as % db.

2.5. Chemical Characteristics

2.5.1. Composition of Sunflower Kernels. Moisture, protein, fat, and ash contents of fresh kernels were determined according to AOAC [28].

2.5.2. pH. Powdered samples (2.5 g) of sunflower kernel as described by Bagheri et al. [29] were mixed with 50 mL of distilled water for 2 h at 80°C. The extract was filtered through filter paper (Whatman no. 40) and used for analysis of pH. The pH of the extract was measured using a pH meter (pH-lab, model 827, metrohm, Germany) with a glass electrode.

2.5.3. Total Phenolic Content (TPC). The TPC was determined based on the Folin–Ciocalteu colorimetric method with slight modification as described by Bagheri et al. [29]. 1 g of powdered samples of sunflower kernel was mixed with 10 mL hexane, and the phenolic compounds were extracted by 12 mL methanol/water (60:40, v/v) for 30 min. The mixture was filtered through a filter paper, and the extracts (both phases) were separated by centrifugation (at 3500 rpm for 10 min). An aliquot (0.2 mL) of the methanolic phase was diluted using water to a total volume of 2.5 mL, followed by the addition of 0.25 mL Folin–Ciocalteu reagent. After 3 min, 0.5 mL sodium carbonate solution (35%, w/v) was added to the reaction mixture, which was finally mixed and diluted with distilled water to 5 ml. The absorbance of the solution was measured after 2 h against a blank sample (methanol) by a spectrophotometer (UV1601, Shimadzu, Kyoto, Japan) at a wavelength of 760 nm. The concentration of total phenolic compounds was determined by comparison with the absorbance of gallic acid at different concentration as standard.

*2.5.4. Peroxide Value (*PV*).* Peroxide value (PV) was determined by the iodometric assay according to ISO3960 [30].

2.6. Sensory Analysis. Sensory attributes of roasted kernels including appearance, hardness, taste, aroma, and total acceptance were assessed by using a five-point hedonic scale (5 point: the best, 1 point: the worst). A panel consisting of 10 members (all food experts of the Golestan Standard Office), with sensory evaluation experience, was trained in descriptive evaluation of sunflower kernels. Mean values were calculated and used to determine the sensory attributes of the roasted sunflower kernels.

2.7. Statistical Analysis and Optimization. Design-Expert Software (Version 10.0.1.0, 2016, Stat-Ease, Inc., Minneapolis, MN) was employed to find the mathematical model for any response and to present the relationship between the dependent and independent variables as three dimensions'

curves. The analysis was performed individually for all the responses. Also, optimization of the process conditions was simultaneously performed using numerical and graphical optimization tool of Design-Expert software.

3. Results and Discussion

3.1. Energy Consumption and Specific Energy Consumption. The energy efficiency of the process and quality of roasted product are two key factors in food roasting. Figures 2(a) and 2(b) show the energy and specific energy consumption during roasting of sunflower kernels. The minimum and maximum values of specific energy consumption for roasting of sunflower kernels were 0.37 kW·h/kg in treatment 500 W, 140°C, 2 min and 1.50 kW·h/kg in treatment 500 W, 140°C, 10 min. Regression analysis indicated that the quadratic model ($R^2 = 0.9915$) sufficiently described the heat consumption (Equations (9) and (10)). Energy consumption increased with increasing power and time ($p < 0.05$), whereas no statistical difference in heat consumption was observed due to the temperature ($p > 0.05$).

$$E\,(\mathrm{kW{\cdot}h}) = -0.19317 + 2.94066A - 2.37940C + 1.91899, \tag{9}$$

$$E_{\mathrm{kg}}\,(\mathrm{kW{\cdot}h/kg}) = -0.96586 + 1.47033A - 0.11897C + 9.59495C^2. \tag{10}$$

Heat consumption of dried barley was compared under far infrared (FIR)–convection and convection alone. It was reported that the use of FIR radiation enhances the drying rate and the energy consumption was reduced considerably [31]. In another research, it evaluated the energy consumption during IR-HA roasting of peanut kernels and reduced the energy consumption up to 31% in the HA method [17]. Also, it was observed that in drying mushroom and pomegranate, using the combination of HA and IR decreased energy consumption relative to IR drying alone and increased it relative to HA drying [32, 33]. The use of IR method in drying persimmon sheet, drying time at three levels of 50, 60, and 70 degrees, respectively, decreased by 46.39%, 30.66%, and 22.38% [34].

3.2. Color Measurement. Visual color is an important quality criterion for roasted foods and may be assessed in terms of quantitative parameters such as L^*, a^*, b^*, color differences ($\Delta E*$), hue angle (h°), and saturation or chroma (SI) values. Color also is an important quality indicator in the case of roasted foods, and optimized color parameters may be used as quality control indicators during the roasting processes [25, 26].

Figures 3(a) and 3(b) show the degree of lightness change (L^*) during roasting of sunflower kernels. The result showed that the highest value for L^* was observed in raw kernels (66.55) (Table 2), and power, temperature, and time of thermal processing had significant effect ($p < 0.05$) on L^*, but temperature and time had no interaction effect on it ($p > 0.05$). A quadratic model ($R^2 = 0.9733$) was applied between different parameters as

$$L^*\ \text{value} = +49.90091 + 0.19814A - 0.42057B + 1.19482C + 5.09717AB - 6.55813AC - 2.66228C^2. \tag{11}$$

As shown in Figures 4(a), 4(b) and 5, there was a linear relation ($p < 0.05$) between used power, time, and temperature and the changes in a^* and b^*:

$$a^*\ \text{value} = -10.36174 + 0.011369A + 0.032051B + 0.48566C \quad R^2 = 0.7669,$$
$$b^*\ \text{value} = +23.34206 - 0.011465A + 0.31727C \quad R^2 = 0.5594. \tag{12}$$

The value L^*, a^*, and b^* of roasted kernels were 43.75–61.34, −0.56–5.61, 13.44–20.8, respectively. a^* value or the amount of redness of treatments increased by increasing the roasting variables ($p < 0.05$). Also, according to Figure 5, unlike the temperature of heating that had not significant effect ($p > 0.05$), the different amounts of power and time of roasting had significant effects ($p < 0.05$) on b^* value or degree of yellowness of treatments.

The result of model fitting for ΔE compared with fresh samples (Table 2), SI, BI, h°, and WI of roasted kernels by RSM are given in Figures 6–10. ΔE, SI, and WI changes were described by a quadratic model and BI by two factor interaction (2FI) model and h° by a linear relation (Equations (13)–(17)). The values ΔE, SI, BI, h°, and WI of roasted sunflower kernels were in the range of 6.38–23.20, 13.93–21.20, 28.67–51.93,72.17–89.84, and 42.29–57.95, respectively

$$\Delta E\,(\%) = +22.96943 - 0.15342A + 0.20253B - 1.16329C - 5.98460AB + 4.87283AC + 2.40754A^2 \quad \left(R^2 = 0.9706\right), \tag{13}$$

$$\mathrm{SI} = -3.17090 + 0.084435A + 0.084435B \quad \left(R^2 = 0.8157\right), \tag{14}$$

$$\mathrm{BI} = +16.67685 + 0.059942A - 0.14282B - 0.010352AC + 0.053792BC \quad \left(R^2 = 0.8154\right), \tag{15}$$

$$h^\circ = +124.69235 - 0.043578A - 0.10471B - 1.21931C \quad \left(R^2 = 0.8491\right), \tag{16}$$

$$\mathrm{WI} = +89.75183 - 0.27457A + 0.029266B + 2.40837C + 6.76245AB - 4.61709AC + 2.38087A^2 \quad \left(R^2 = 0.9724\right). \tag{17}$$

L^*, b^*, and a^* values of roasted sunflower kernels by electrical oven and microwave method for both treatments

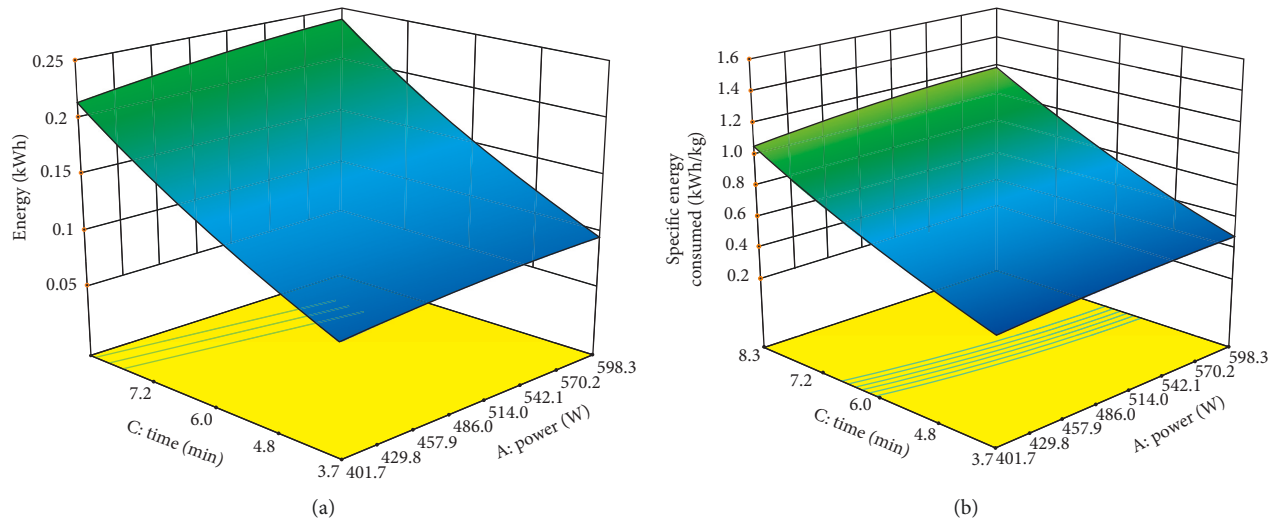

Figure 2: The effect of IR power and time of roasting on energy (a) and specific energy consumption (b) during IR-HA roasting of sunflower seed kernels.

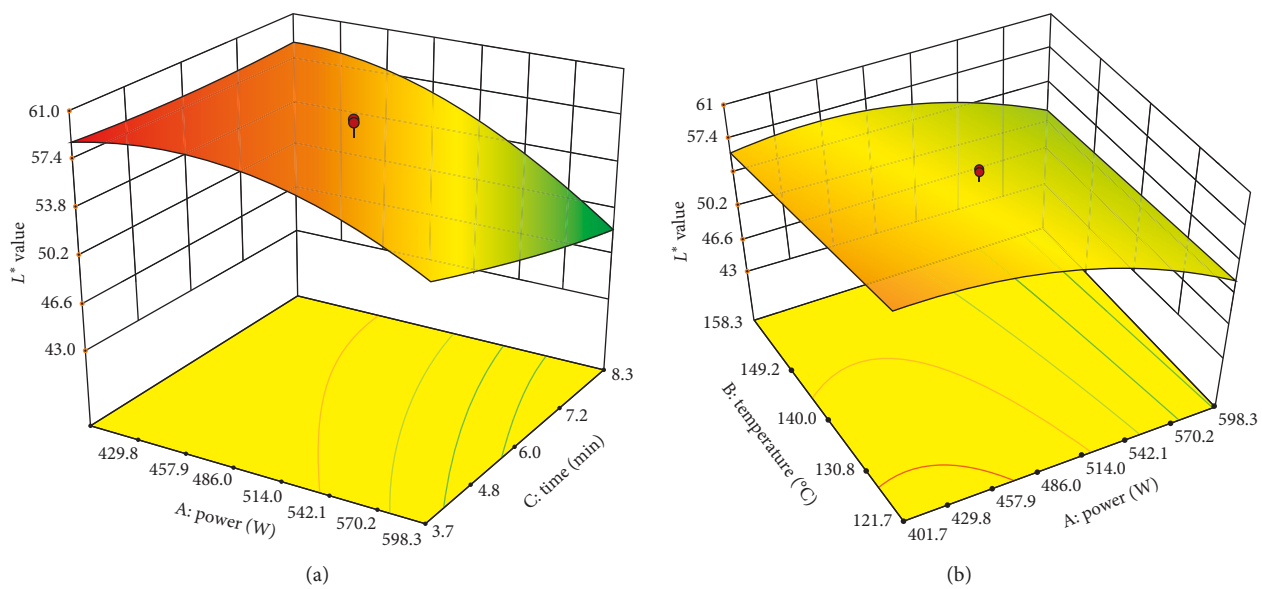

Figure 3: The effect of IR power and time (a) and IR power and temperature (b) of roasting on the L^* value of sunflower seed kernels.

Table 2: Composition of raw sunflower seed kernels.

Average of height seeds (mm)	Average of width seeds (mm)	Weight of 1000 of seeds (g)	Moisture content (%)	Ash (%)	Protein (%)	Fat (%)	pH	Total phenolic compounds (ppm)	Peroxide value (meq O_2/kg oil)	L^*	a^*	b^*
11.67 ± 1.02	5.048 ± 0.43	172.17 ± 12.29	5.45 ± 0.03	3.09 ± 0.04	28.61 ± 1.20	41.04 ± 1.28	5.58 ± 0.08	45.60 ± 0.1	3.0 ± 0.09	66.73 ± 0.79	−0.504 ± 0.09	14.45 ± 1.11

Mean value is the average of three replications.

as the time of roasting increased, L^* value decreased, whereas a^* value increased with the electrical oven. Also prolonged roasting time by microwave increased b^* value whereas it reduced b^* value for oven-roasted samples. In general, prolonged roasting time by both methods (oven and microwave) increased ΔE [24].

The results showed that increasing temperature and roasting time reduced b^*, L^*, h°, and WI and increased ΔE

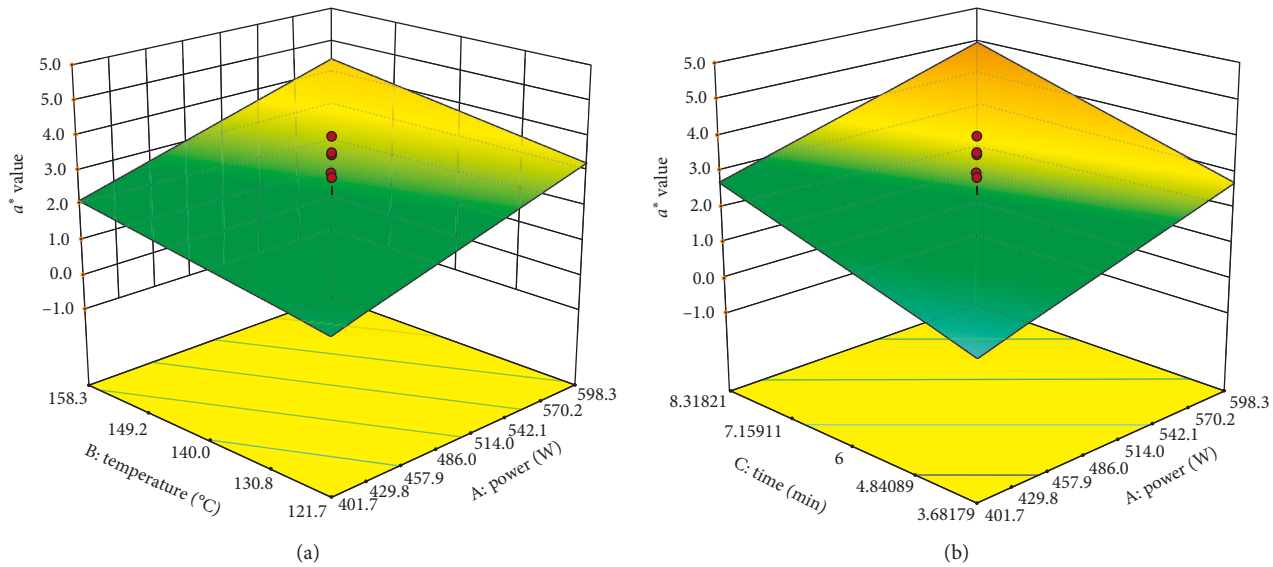

Figure 4: Response surface of color parameter (a^* value) of sunflower seeds kernels during IR-hot air roasting in relation to IR power and temperature (a) and IR power and time (b).

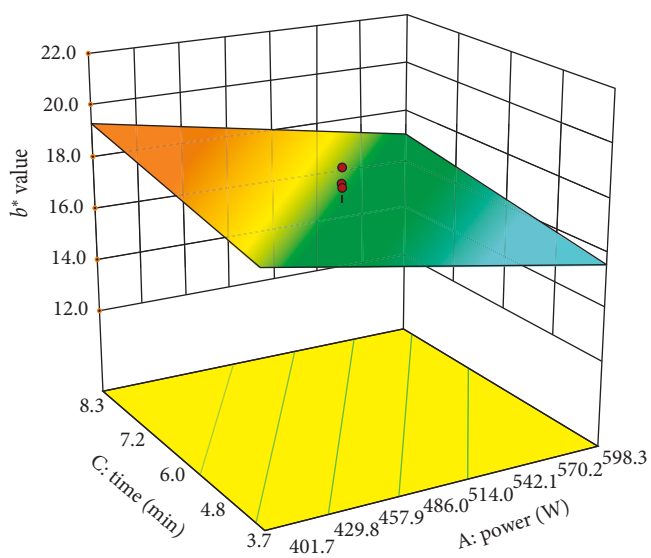

Figure 5: The effect of IR power and time of roasting on color parameter (b^* value) of sunflower seeds kernels.

and BI roasted peanut kernels by HA [29], but Sharma and Gujral [8] reported a decrease in ΔE during roasting of barley.

Also, it was reported that increases in roasting temperature (90–190°C) and time (5–65 min) caused a decrease in L^*, b^*, and yellow index except for a^* value of ground state-roasted pistachio kernels with HA. The quadratic model sufficiently described the changes in color [35]. These results are in agreement with those found by Soleimanieh et al. [24] for oven and microwave-roasted sunflower seed, Wani et al. [36] for pan and microwave roasting arrowhead tubers, Gujral et al. [37] for sand and microwave roasting of oats, Uysal et al. [19] for roasted hazelnut by using microwave-infrared combination.

The values of L^* and h° color parameters coffee roasted using HA were evaluated. With increasing temperature, L^* value and h° decreased. A second-order correlation was found between L^* and roasting time [38]. Change in color is due to formation of brown pigments with low and high molecular weight through nonenzymatic browning (NEB) reactions such as Millard reaction and caramelization and phospholipids degradation during roasting [26, 36, 39, 40].

3.3. Texture Analysis. Texture is one of the most important criteria in consumer acceptance of roasted sunflower kernels. In general, the roasting process is responsible for the crunchy texture of nuts resulting from structural and chemical changes such as the Millard reaction, decrease in moisture content, or lipid modifications reaction [41]. The results of hardness of kernels during roasting process were shown in Figure 11. Regression analysis indicated that two-factor interaction (2FI) model ($R^2 = 0.7256$) was the best to explain the effects of the three independent parameters on texture as following:

$$\begin{aligned}\text{Hardness of texture (N·S)} = {} & +21874.49716 - 28.70636A \\ & - 128.36302B - 974.46144C \\ & + 0.16857AB.\end{aligned} \tag{18}$$

The result showed that used power, temperature, and time had significant effect ($p < 0.05$) on texture, but power and time or temperature and time had no interaction effect on it ($p > 0.05$). The minimum and maximum values of hardness of texture were 256.9 NS in treatment 401 W, 158°C, 3.6 min, and 1962 NS in treatment 401 W, 121°C, 3.6 min. During the roasting, moisture content of kernels decreased and they became crispier and fragile that required force to break was less; therefore, hardness decreased.

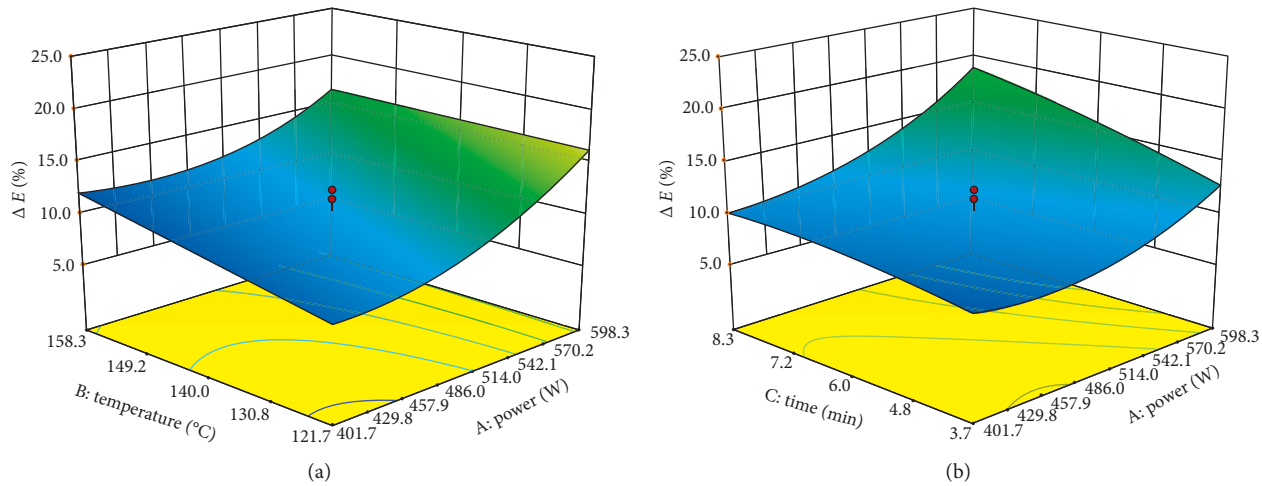

Figure 6: Response surfaces of ΔE value of sunflower seeds kernels during IR-hot air roasting in relation to IR power and temperature (a) and IR power and time (b).

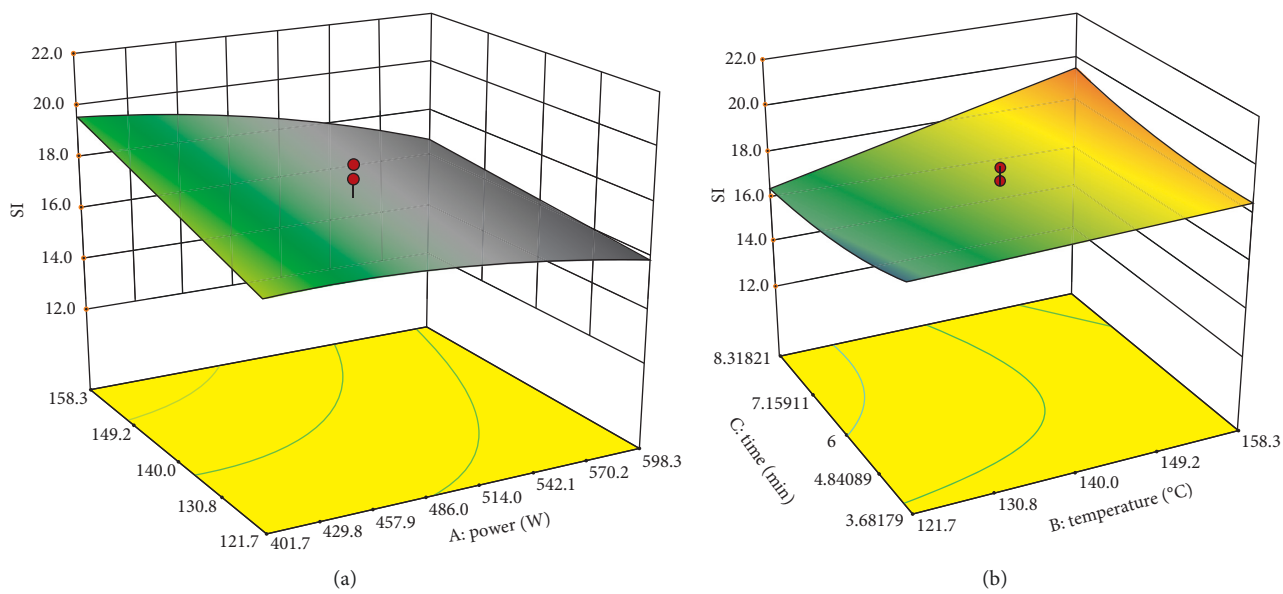

Figure 7: Response surfaces of color parameters (SI) of sunflower seeds kernels during IR-hot air roasting in relation to IR power and temperature (a) and temperature and time (b).

Similar results were reported for roasting roasted sunflower kernels by HA and microwave oven [24], peanut kernels by IR-HA roasting [17], roasted hazelnut by using microwave–IR [19], and roasted pistachio by HA oven [35, 42].

3.4. Moisture Content. The changes in the moisture content of kernels during roasting were presented in Figure 12. A quadratic model ($R^2 = 0.7948$) was applied to describe the changes of moisture during roasting process as following (Equation (19)). Power significantly ($p < 0.001$) affected the moisture removal during roasting. Effect of other roasting parameters (temperature and time) on moisture content was not significant ($p > 0.05$). The moisture contents of samples were in the range of 0.1% in treatment 500 W, 109°C, 6 min, and 4.9% in treatment 334 W, 140°C, 6 min:

$$\text{moisture content}\,(\%) = +12.80062 - 0.070874A + 7.31726A^2. \quad (19)$$

Moisture content of IR-HA roasted peanut kernels decreased significantly by increasing IR power from 130 W to 200 W and led to decrease 22.4% in the moisture content [17]. Also, by increasing upper and lower lamp powers of the microwave-IR combination oven for roasting of hazelnut, moisture content decreased [19].

These results are in agreement with those found by Soleimanieh et al. [24] for roasted sunflower kernels and

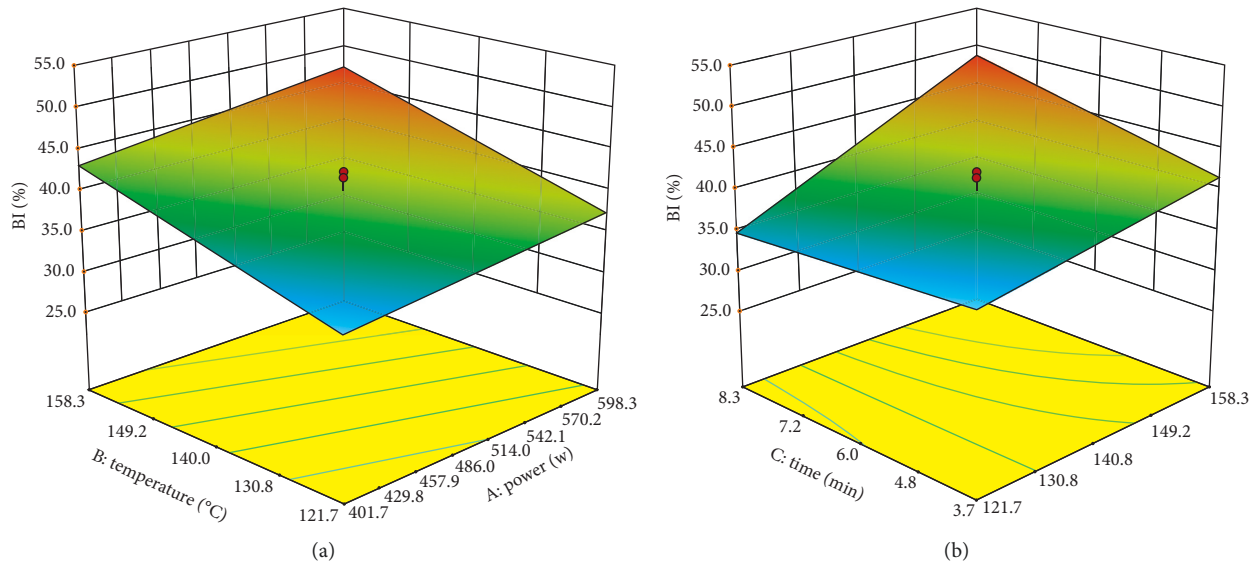

Figure 8: Response surfaces of color parameters (BI) of sunflower seeds kernels during IR-hot air roasting in relation to IR power and temperature (a) and air temperature and time (b).

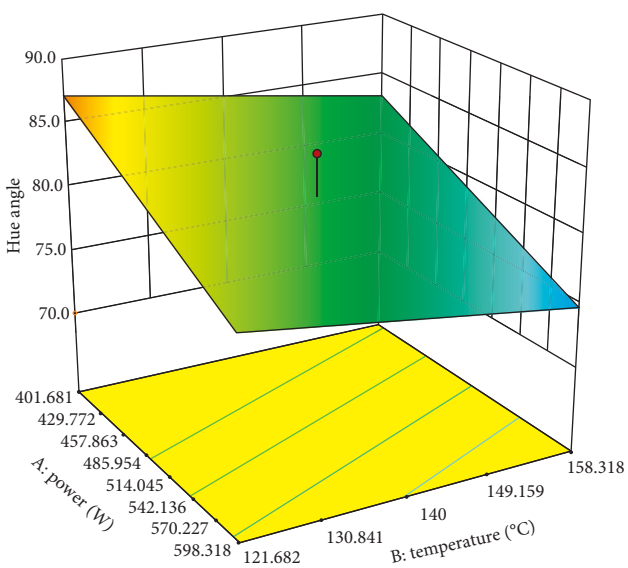

Figure 9: The effect of IR power and air temperature of roasting on *hue* angle of sunflower seed kernels.

Nikzade et al. [42] and Shakerardekani et al. [35] for roasted pistachio.

3.5. pH. In this study, regression analysis indicated that 2FI model ($R^2 = 0.6141$) was the best to explain the effects of the three independent parameters on pH as following (Equation (20)). Temperature and time had significant effect ($p < 0.05$) on pH (Figure 13).

$$\text{pH} = +5.94 - 0.057B + 0.054C. \quad (20)$$

The pH of sunflower kernels before roasting was 5.52. In general, the pH increased with an increase in temperature and time of roasting. Bagheri et al. [29] conversely reported that a decrease in pH of peanut kernels during roasting due to Millard reaction products and conversion of sugars to acidic compounds during roasting. The effect of pH has been evaluated in model studies finding a close relationship with the formation of volatile compounds; low pH (≤5) favors the formation of pyrazines and higher pH favors the methyl pyrazines and Strecker aldehydes [43].

3.6. Total Phenolic Content (TPC). Roasting treatment influences TPC as well as antioxidant activities for nuts including cashew, hazelnut, and peanut [44]. ANOVA showed that the model developed for the TPC was quadratic ($R^2 = 0.7893$) as in Equation (21) and Figure 14. The minimum and maximum values of TPC were 12.87 and 64.89 mg gallic acid equivalent (GAE)/g in treatment 401 W, 158°C, 3.6 min and 665 W, 140°C, 6 min, respectively. Interestingly, TPC increased compared with fresh samples (Table 2) by roasting. Therefore, IR-HA roasting can produce high-quality roasted sunflower kernels.

$$\text{TPC}\,(\text{mg}\cdot\text{GAE/g}) = +572.697 - 0.674A + 23.170C + 6.620A^2. \quad (21)$$

There are few works in the literature reporting data on the TPC of IR-roasted sunflower kernels. The TPC in roasted hazelnuts using IR and HA at two different time/temperature conditions ranged from 0.48 to 0.69 mg·GAE/g. The TPC increased during roasting compared with fresh samples (0.42 ± 0.01). The TPC in roasted samples by using HA was greater than the TPC roasted samples by using IR, probably because IR caused a higher heating in the hazelnut than HA and higher degradation of phenolic compounds [7].

Lin et al. [44] reported that the levels of total phenols substantially decreased in the initial roasting phase (5 min)

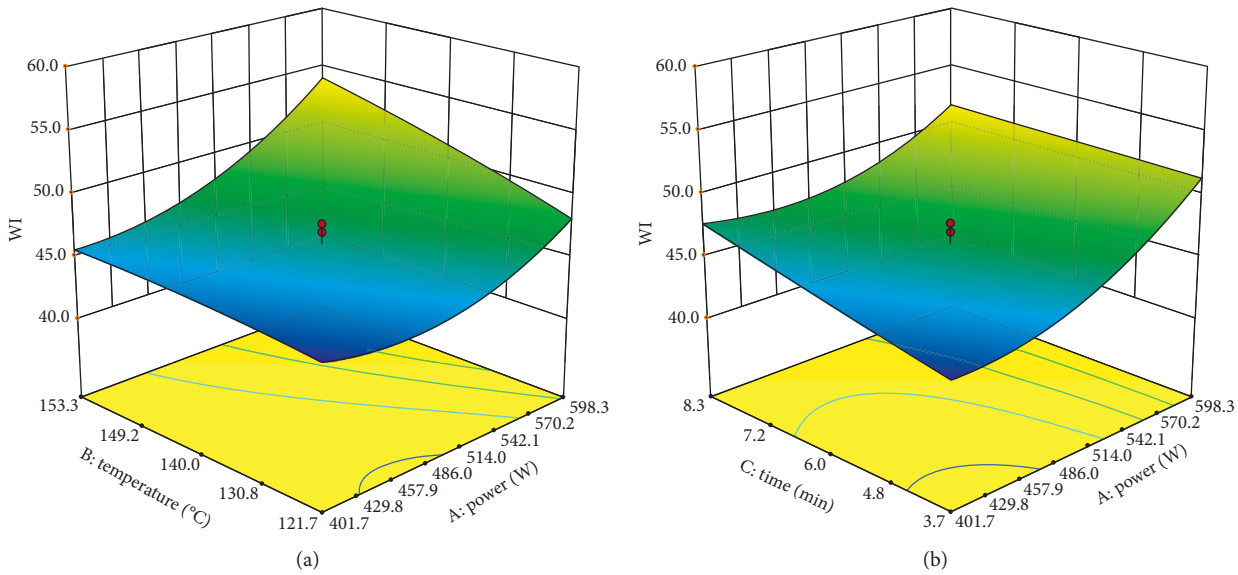

Figure 10: The effect of IR power and air temperature (a) and IR power and time (b) of roasting on WI of sunflower seed kernels.

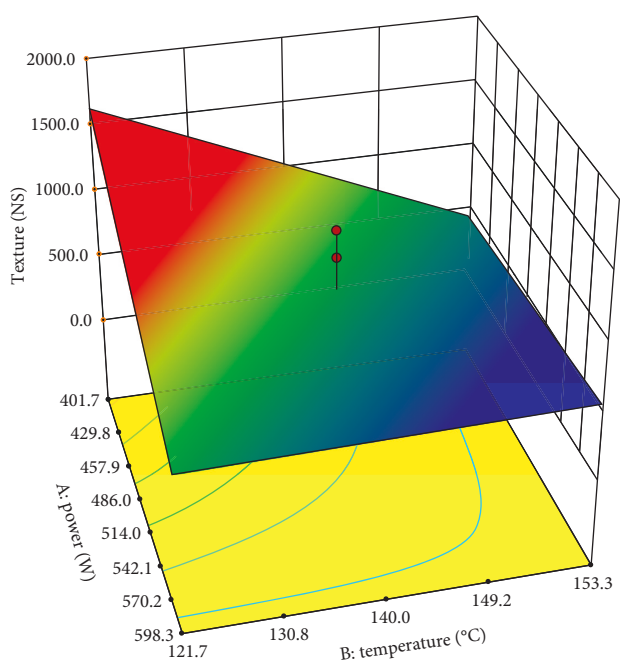

Figure 11: Response surface of texture in sunflower seeds kernels during IR-hot air roasting process.

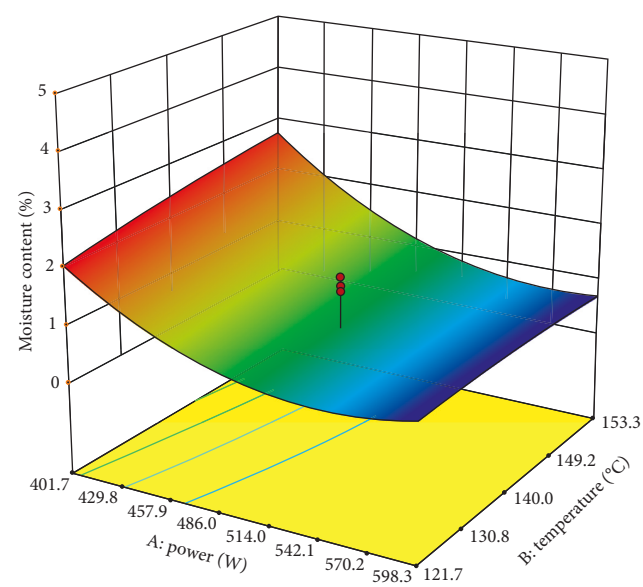

Figure 12: The effect of air temperature and IR power of roasting on moisture content of sunflower seeds kernels.

and then increased gradually with roasting duration in roasted almond kernel into air convection oven.

Other authors have observed the same behavior in other products [17, 25, 45]. The reason for increasing the TPC upon roasting could be because of increasing in heat induced and extractable phenolic compounds after roasting to the formation of Millard products, complex physical and chemical reactions on phenolic, including leaching of water soluble phenolic, freeing phenolic from bond forms, degradation of polyphenols, and breakdown, and transformation of phenolic, such as formation of complex products from phenolic and proteins, and formation of Millard reaction products having antioxidative activity such as pyrroles and furans that react with Folin–Ciocalteu reagent [46, 47]. Lin et al. [44] indicated that Millard reaction products produced during thermal treatments may increase the antioxidant effects of processed foods.

3.7. Peroxide Value of Oil Extracted from Processed Sunflower Kernels. The peroxide value is a primary lipid oxidation index. Treatment 401 W, 121°C, 3.68 min showed the lowest peroxide value, 3 meq·O_2/kg of sunflower oil. The greatest PV was 106 meq·O_2/kg of sunflower oil in treatment 500 W, 170°C, 6 min, which indicates that the sunflower kernels

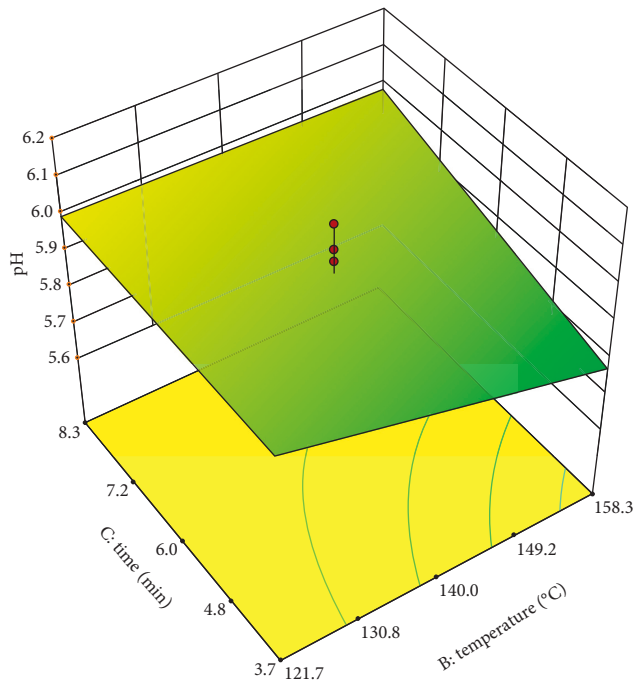

Figure 13: The effect of air temperature and time of roasting on pH of sunflower seeds kernels.

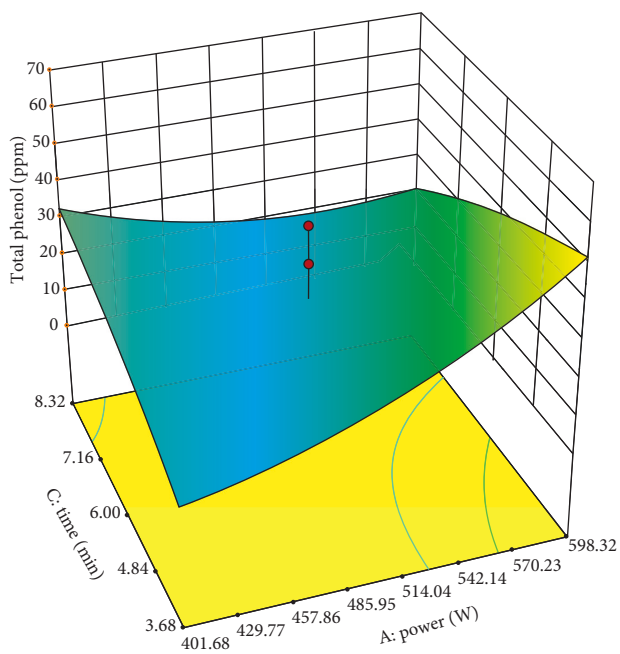

Figure 14: The effect of IR power and time of roasting on total phenol content of sunflower seeds kernels.

show primary oxidative rancidity. ANOVA showed that the model developed for the PV was linear ($R^2 = 0.6220$) as in Equation (22) and Figure 15. It can be concluded that roasting temperature had a more pronounced effect on sunflower kernels oxidation than power. Peroxide values up to 10 meq O_2/kg oil in sunflower kernels can be considered safe according to ISIRI14615 [48]. These results were in agreement with Nikzade et al. [42], Yang et al. [13], Soleimanieh et al. [24], and Belviso et al. [7].

$$\text{PV}\left(\text{meq } O_2/\text{kg of sunflower oil}\right) = -219.136 + 0.257A + 0.765B. \tag{22}$$

3.8. Sensory Analysis. The desired aroma and flavor of sunflower kernels are developed during roasting. The

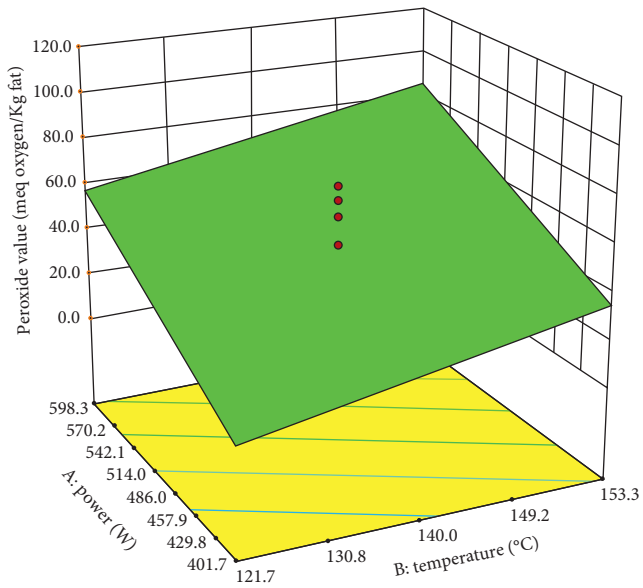

Figure 15: The effect of IR power and temperature of roasting on peroxide value of sunflower seeds kernels.

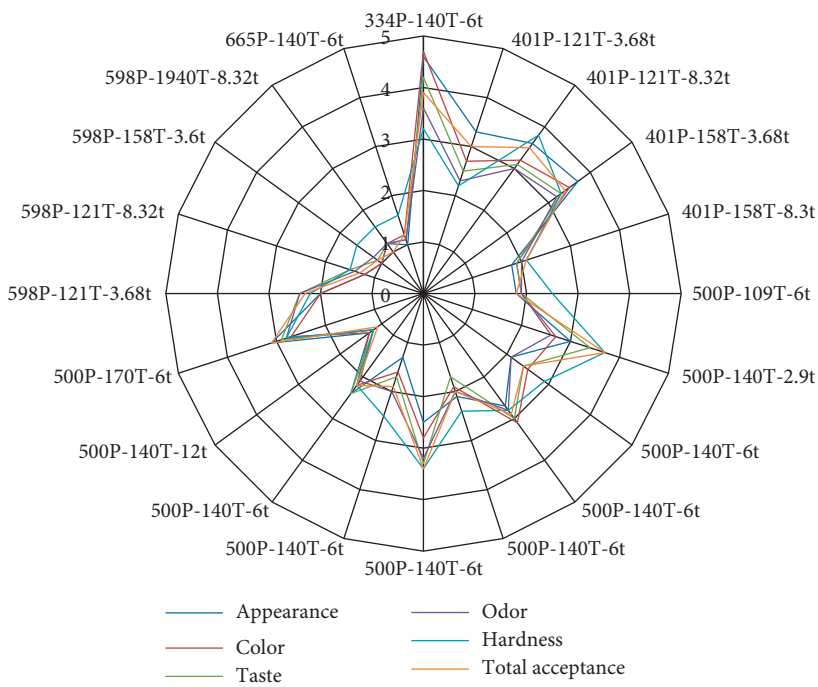

Figure 16: Effects of different roasting conditions on the sensory analysis of roasted sunflower kernels.

roasted kernel composition will vary with the processing conditions, which is reflected on the external color of the kernels (varying from light to dark brown), and development of typical taste and flavor [49]. Sensory attributes for roasted kernel were evaluated using 5-hedonic scale and are presented in Figure 16. The sensory evaluation of roasted kernel with IR-HA method indicates that IR technology did not affect any undesired taste and flavor, texture, or appearance to the kernels that could be detected by panelists.

4. Determination of the Optimum Roasting Condition

Optimal roasting conditions were investigated based on the lowest energy consumption which is important in determining the optimal conditions. The best suggested condition by the software was 425.7 W of power and heating at 124.3°C for 3.7 min (Figures 17(a)–17(c)) which results in moisture content = 1.97%, hardness = 1437.3 NS,

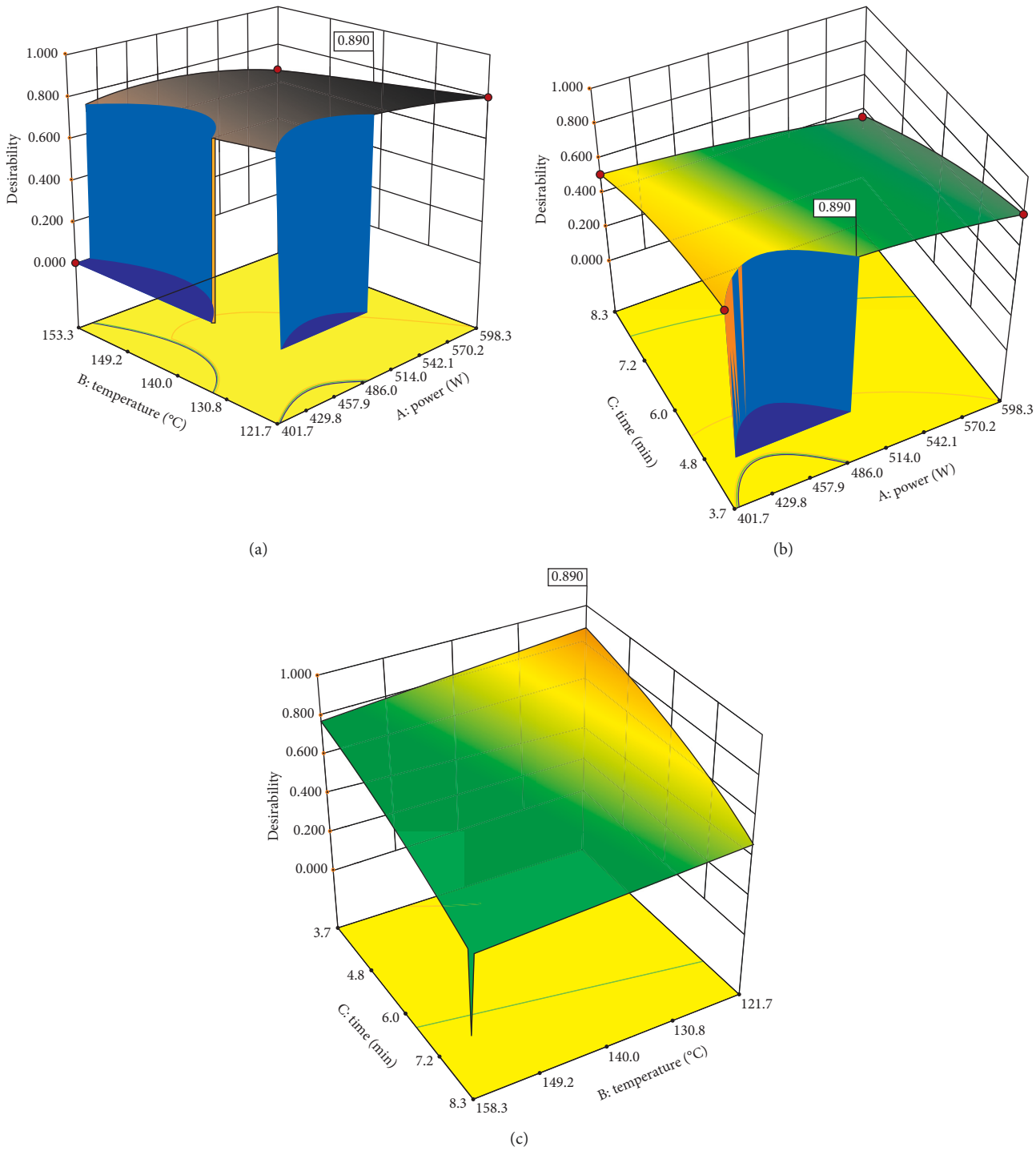

Figure 17: The optimum values of the operating conditions of roasting of sunflower seed kernels in the IR-hot air roaster.

energy consumption = 0.084 kW·h, specific energy consumption = 0.421 kW·h/kg, $L^* = 61.340$, $a^* = 0.249$, $b^* = 17.830$, $\Delta E = 6.538$, SI = 18.023, BI = 34.196, $h^\circ = 89.418^\circ$, WI = 42.420, pH = 6.012, total phenol = 19.7 ppm, and PV = 3.837 (desirability = 0.879). To validate the optimization results, additional experiments with three replications were carried out at the optimum situation. It was observed that the moisture content (1.835 ± 0.038%), hardness (1426.1 ± 7.288), energy consumption = 0.091 ± 0.008 kW·h, $L^* = 58.930 \pm 0.45$, $a^* = 0.248 \pm 0.013$, $b^* = 16.756 \pm 1.450$, $\Delta E = 8.419 \pm 0.13$, SI = 16.757 ± 1.183, $h^\circ = 89.150^\circ \pm 0.0001$, WI = 44.374 ± 0.107, pH = 6.010 ± 0.03, total phenol = 24.482 ppm, and PV = 3.680 ± 0.008 were very close to the predicted values ($p < 0.05$) which indicated the high accuracy of the presented models.

5. Conclusion

Roasting is one of the methods of improving color, flavor, and taste in seeds, and the conditions of roasting play an important role in the appearance of tissue and sensory response procedure in optimizing the IR-HA roasting process. In conclusion, this study showed that energy consumption increased with increasing power and time. TPC in most treatments increased compared with fresh samples during roasting. These may provide inexpensive sources of natural antioxidants for use as functional food ingredients and nutraceuticals. A quadratic model was proposed for color change (L^*, ΔE, SI, WI, moisture content, total phenol contents) and linear relation for (a^*, b^*, h°) and 2FI for BI, texture, pH, and PV. For sunflower kernels, roasting at 425.7 W IR power and 124.3°C for 3.7 min was found to be proper roasting conditions.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors are grateful the Iranian National Standards Organization (INSO)-Golestan Standard Office for technical support and providing the facilities that made this project possible.

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