Effects of Roasting Conditions on Physicochemical Properties of the Watermelon Seed

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ABSTRACT: *Roasted watermelon seeds are consumed as snack foods. In this research, the Response Surface Methodology (RSM) was used in order to examine the effect of roasting on some physicochemical properties of watermelon seeds. The Central Composite Design (CCD) was applied to investigate the effects of two independent variables, i.e. temperature (180-260 ℃) and time (5-15 min), on moisture content, texture, color, total phenol, and antioxidant activity. According to the results, increasing the temperature and prolonging the duration of roasting caused reductions in the moisture content, ΔE and texture hardness. Meanwhile, the total phenol content and antioxidant activity increased. The linear, quadratic, and interactive effects between the independent variables (temperature and time) were significant on moisture content and texture hardness ($p<0.05$). All variables, except the quadratic effect of time and the quadratic effect of the two independent variables, caused significant changes to the antioxidant activity and total phenol content. However, the total difference in color was only significantly affected by the linear effect of the two variables. Finally, roasting conditions (i.e. roasting temperature and time) were optimized in a manner that the acquired model-generated results akin to the experimental data (desirability=0.74).*

KEYWORDS: *Roasting; Watermelon seed; Response surface methodology; Physicochemical properties.*

INTRODUCTION

The watermelon (*Citrullus lanatus*) can grow successfully in both temperate and tropical climates. It is one of the most important economic products in the world [1]. The watermelon probably originated from South Africa and was introduced from India to Iran. Among the countries that produce watermelon, Iran has an estimated annual production of 3.6 million tons which ranks third after China (74.8 million tons) and Turkey (3.9 million tons). Brazil ranks fourth with 2.2 million tons, while Egypt and the United States of America rank fifth and sixth, with annual productions of 2 million and 1.8 million tons respectively [2- 3]. The majority of watermelon fruits contain large quantities of seeds which are regarded as waste products. Only a small fraction of this agricultural byproduct is commercially processed and used, while a greater portion of it is discarded due to practical difficulties in the processing [2]. Several cultivars of watermelon are cultivated in different regions of Iran, but the seeds of only three cultivars are large enough to be edible. These three are, namely, Ghermez,

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Kolaleh and Sarakhsi, the seeds of which are commonly roasted and consumed traditionally as snacks [4]. About 75% of the weight of the watermelon seed is comprised of protein and fat, which classifies it as an oilseed. Nonetheless, watermelon seeds have not received considerable attention so far [3]. Reports suggest that several countries use the seeds only as an additive, but other regions such as the Middle East and Nigeria have established the practice of extracting cooking oil from watermelon seeds. It can be consumed as a thickener, fat binder, flavoring agent and a snack in various parts of the world [2, 4].

Roasting is an essential process which improves the taste, color, texture and appearance of the product. The shelf-life is also extended as a result of roasting [5-7]. Furthermore, roasting destroys undesirable microorganisms, toxins and food contaminants. It also acts against unwanted enzymes that cause nutritional loss and change the free amino acids, peptides, fatty acids, vitamins E, phytosterols and lignans [8]. The temperature and the duration of roasting are the most important factors that influence favorable traits. The properties of raw material (type, variety and moisture content), degree of roasting and the roasting method can all influence the optimum time and temperature of roasting [5]. Many researchers have studied the effect of roasting on food products and their extracted oil, including chemical compositions in coffee brew [6, 7], coffee-like maize beverage [8], carob powder [9], cocoa beans [10], coconuts [11], sesame seeds [12], soybean and its oil [13], sunflower seed and its oil [14, 15]. Roasting can also affect physical properties such as the color and texture in pistachio nuts [16-18], hazelnut [8], the jackfruit [19] and almond [20]. Shelf-life can be influenced by roasting in peanuts [21] and extraction efficiency can vary in cocoa butter [22] and the wood apple fruit [23]. *Berdiyev et al* [24] evaluated the drying of fresh slices from seven different cultivars of honeydew melons (*Cucumis melo L.*), originally from Turkmenistan. The research concluded that different samples of dried melons have different proximate compositions. Accordingly, it is important to optimize the drying process with respect to the nutritive value of each product and its physical or sensory properties.

The response surface software is a useful tool for describing quality indicators during food processing. The main positive quality of this software is that it reduces the number of experimental runs to provide types of information that are sufficient and statistically correct [5]. In this regard, optimizing the roasting condition *via* the RSM has been performed on pistachio [16], hazelnut [8] and coffee-like maize beverage [5]. The available scientific literature shows that research on the roasting of watermelon seeds has been scanty. Multiple factors need to be taken into account in order to optimize the conditions in which watermelon seeds are roasted.

The purpose of this study was to investigate the effect of roasting temperature and duration on some physicochemical properties of watermelon seeds. It was also attempted to determine suitable models for describing the seeds' responses to the temperature and duration of roasting.

EXPERIMENTAL SECTION

Materials

Watermelon seeds (*Citrullus lanatus* var. Kolaleh) were obtained from a farm in Khesht and Kamaraj district, Kazerun, Fars province, Iran (29° 34′ 5.0"N latitude, 51° 20′ 21.0"E longitude, Alt. 480 m). The fruits were large (3-5 kg) and harvested at commercial maturity during June-July 2016. A voucher specimen (55084) is deposited in the herbarium of Shiraz University, Shiraz, Iran. After initial sorting, the seeds were sun-dried to reach constant weight. Then, the seeds were checked to be healthy and uniform in size for the roasting process. The weight of 100-seeds was approximately 19.63 g and the average size of melon seeds were nearly 13 mm length and 8 mm width.

The chemicals used in this study were of analytical grade and were purchased from Merck Chemical Company.

Roasting process

Watermelon seeds (about 50 g) were placed as a single layer in pyrex petri dishes and were then roasted in the oven (KM, ISUZU, Japan) under the conditions selected for each experiment. To ensure the stability of conditions, the oven was left to run for 1 h at premeditated temperatures before the seeds entered. The come-up time for the seeds in the oven was about 2-3 min. After oven roasting, melon seeds were transferred to desiccators for cooling down to 25 °C. This took about 8-13 min. Then, they were packed in polyethylene bags and were kept at 4 °C until further analysis.

Table 1: The coded and actual values of the independent factors during roasting of watermelon seeds.

Roasting conditions	Coded and actual levels		
	-1	0	1
A: Temperature (°C)	180	220	260
B: Time (min)	5	10	15

Experimental design and statistical analysis

The response surface method with central composite design was used as an experimental design in this study. The central composite design consisted of two variables of time and temperature (each in three levels) and a total of 13 experiments. Table 1 shows the design of the actual and coded values of the independent variables. The dependent variables in this design included moisture content, color change, texture hardness, phenolic content and antioxidant activity. The responses correlated with the independent variables by a second-degree polynomial via the equation below.

$$Y = \beta_\circ + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \beta_{11} X_1^2 + \beta_{11} X_2^2 \qquad (1)$$

In this equation, b_0 is constant, b_1 and b_2 are linear coefficients, b_{11} and b_{22} are quadratic coefficients, and b_{12} is the interaction coefficient.

Analysis of variance (ANOVA) used the F-test for individual terms. ANOVA tables and regression coefficients for each linear, quadratic, and interaction terms were determined. The significance level of all the parameters in the polynomial equations was statistically determined by calculating the F-value at probability levels (p) of 0.05, 0.01 and 0.1 separately. Regression coefficients were used for statistical calculations and for drawing contour curves. All statistical analyses were performed electronically by SPSS software [5].

Analysis of moisture content

The moisture content of samples was determined by drying the samples (about 5 g) in a drying oven at 105 °C until a constant weight was reached. The calculations were performed according to the initial weight of the roasted watermelon seeds before and after the drying in the oven [25].

Color measurements

The color of samples was evaluated in a special box under controlled conditions (in terms of light intensity and camera position) using a digital camera (Sony Cyber-Shot, 8.1 megapixels). The pictures taken were analyzed quantitatively using the Adobe Photoshop 8 software (Adobe Systems Incorporated, San Jose, CA) and the color parameters were determined in the “Lab” system. In this system, the a* component represents the redness/greenness (+ a for the red and –a for the green), the b* component represents the yellowness/blueness (+ b for the yellow and –b for the blue) and L* indicates the lightness of the sample (within a range 0-100). Finally, the color change (ΔE) was obtained from the following equation [26].

$$\Delta E = \sqrt{(L_i - L_o)^2 + (a_i - a_o)^2 + (b_i - b_o)^2} \qquad (2)$$

Where the subscript i and $_o$ represent the read out values of the considered and the control samples, respectively. Raw seeds were considered as control sample.

Texture analysis

The force needed to break the roasted seeds (with hull) was evaluated using a texture analyzer (H50KS, Hounsfield, UK) equipped with a load cell of 25 kg. The sample (with a relatively similar size) was placed horizontally on a table and was compressed with a cylindrical probe with a diameter of 10 mm at a speed of 25 mm/s until the seed was broken. The force (N) was recorded as the fracturing occurred, and was reported as the fracture force. To cross out the effect of deviations among the results, about 10 replicates were used for each treatment. The temperature during the test was about 25 °C, and the test was performed immediately after opening the packaging.

Total Phenolic Compounds

Total phenolic compounds in roasted watermelon seeds were extracted according to the phenol’s extraction method by *Dewanto et al* [27], with slight modifications. About 2 g of the milled seeds were added to a 20 ml flask containing 80% methanol solution. The sample was shaken at 200 rpm for 30 minutes. Then, the resulting mixture was centrifuged at 10000 × g at 4 °C for 20 minutes and the supernatant was used in order to measure phenolic and antioxidant compounds.

The total phenol content was measured quantitatively by the Folin-Ciocalteu colorimetric method based on the reaction of reagents with the active hydroxyl groups of phenolic compounds. To dilute the extracts, 80% methanol and 7.5% sodium carbonate solutions were added, followed by the addition of the Folin-Ciocalteu reagent. After incubation for 15 min at 40-45 °C, the absorbance of the resulting solution was measured at 760 nm using a spectrophotometer (SPEKOL 1500, Germany). The total concentration of phenolic compounds was determined by comparison with the absorbance of gallic acid as standard [27].

Antioxidant activity

The radical scavenging activity of the samples was determined by the DPPH radical. In this method, 1,1-diphenyl-2-picrylhydrazyl (DPPH) stock solution was first prepared by dissolving 24 mg of DPPH powder in 100 mg of methanol. Then, 3 ml of watermelon seed extract was added to 1 ml DPPH and 3 ml methanol. After incubation of the solution in the dark for 30 minutes, the absorbance of the resulting solution was measured at 517 nm using a spectrophotometer (SPEKOL 1500, Germany). The radical scavenging activity was calculated using the following formula [27]:

$$\text{Percentage inhibition} = \left[1-(\text{absorbance of sample}/\text{absorbance of DPPH})\times 100\right] \quad (3)$$

Determination of fatty acids

Free fatty acids of raw and roasted watermelon seeds were detected at the optimum point by gas chromatography (YL6500, Korea) equipped with a flame ionization detector. The oil was extracted from the ground samples by the cold method with n-hexane. The free fatty acids of extracted oil were esterified by adding 40 ml methanol and less than 1mL of 1N potassium hydroxide in methanol. The resulting suspension was centrifuged and 1µl of the clear supernatant was directly injected into a column chromatography. The carrier gas was helium, with a flow rate of 0.5 ml/min at 50 °C, and the column height was 30m. The injector/ detector temperature was 220 °C [8].

RESULTS AND DISCUSSIONS

Statistical analysis

In the present study, the roasting process had several effects on some physicochemical properties of watermelon seeds, and these effects were investigated by a two-factorial layout (time and temperature), on a three-level CCD. The moisture content, fat and protein contents of the raw watermelon seeds in this study were 3%, 19.6% and 15.8%, respectively.

Table 2 shows the effect of independent variables on moisture content, total phenol, antioxidant activity, fracture force, and color changes of watermelon seeds during the roasting process. The experimental values were fitted using quadratic polynomial equations to obtain appropriate experimental models for predicting the responses. The models were then analyzed by statistical analysis to select the appropriate models.

The result of model fitting for the responses of roasted watermelon seed is indicated in Table 3. By applying the ANOVA, the significance of the linear, quadratic and reciprocal (or interactive) effects of coefficients for each response are investigated in the regression model. The correlation coefficient (R^2) should be high and the lack of fit should be non-significant for adequacy of the models.

Results showed that the roasting temperature and time had diverse effects on moisture content, antioxidant activity, total phenol and fracture force, all of which were regarded as quadratic effects. Meanwhile, the effects were linear regarding total color change. The relevant equations for each response were obtained and are presented in Table 4. Only the significant effects ($P \leq 0.05$) were included in the final reduced models. The signs and magnitude of the regression coefficients showed the influence of responses on the independent variables [28]. A negative sign indicates the decrease in response as the value of an independent variable increases (and vice versa). A model with a correlation coefficient (R-square) of more than 0.80 is considered to have a good fit [29]. High values of R2 were recorded for moisture content (0.99), antioxidant activity (0.94), total phenol (0.92), fracture force (0.99) and total color change (0.91) which indicates that the models were able to predict the responses closely.

According to Myers and Montgomery [30], a model with a significant lack-of-fit should not be used for prediction as it is not a good indicator of the response. The F ratio and P values stated the significance of each influence in the final predicted model (Tab. 3). A significant reciprocal effect was observed for all responses to variables with the exception of total color change. As shown in Tab. 3, moisture content was significantly influenced ($P \leq 0.01$) by the linear, quadratic and interactive effect of temperature and time. Antioxidant activity was significantly ($P \leq 0.01$) influenced by the quadratic effect

Table 2: Matrix of the experimental design for the central composite design considered in the roasting of watermelon seed.

Run order	Temperature (°C)	Time (min)	Moisture Content (%)	Antioxidant activity (%)	Total Phenol (%)	Force (N)	ΔE
1	180	15	0.89	27.82	2.07	5.20	8.08
2	220	15	0.47	27.59	3.19	3.59	7.51
3	220	10	0.62	28.39	2.28	4.24	8.13
4	180	5	2.26	25.37	1.75	8.68	8.77
5	260	15	0.39	26.00	4.00	2.63	7.08
6	180	10	1.51	26.95	1.94	5.90	8.50
7	220	10	0.69	27.90	2.17	4.47	8.20
8	220	10	0.73	27.94	2.37	4.04	8.13
9	260	10	0.53	27.09	3.25	3.29	7.35
10	220	10	0.66	28.25	2.26	4.17	7.91
11	220	10	0.75	28.38	2.08	3.93	7.73
12	260	5	0.90	28.07	2.25	5.09	7.53
13	220	5	1.41	28.05	2.02	6.65	8.35

Table 3: Analysis of variance for the effect of the roasting conditions on the physicochemical properties of watermelon seeds.

	Moisture content		Delta E		Fracture force		Phenol content		Antioxidant activity	
Source	Sum of Squares	p-value	Sum of Squares	p-value	Sum of Squares	p-value	Sum of Squares	p-value	Sum of Squares	p-value
Model	3.26	< 0.0001	2.57	< 0.0001	30.28	< 0.0001	4.61	< 0.0001	9.82	< 0.0001
A	1.34	< 0.0001[a]	1.91	< 0.0001[a]	12.83	< 0.0001[a]	2.34	< 0.0001[a]	0.18	0.1752[c]
B	1.33	< 0.0001[a]	0.66	0.0004[a]	13.52	< 0.0001[a]	1.75	0.0002[a]	1.504E-003	0.8937[c]
AB	0.18	0.0003[a]	--	--	0.26	0.0341[b]	0.52	0.0080[a]	5.11	< 0.0001[a]
A^2	0.18	0.0003[a]	--	--	0.34	0.0192[b]	--	--	4.54	< 0.0001[a]
B^2	0.082	0.0031[a]	--	--	2.15	0.0001[a]	--	--	--	--
Residual	0.029		0.24		0.26		0.41		0.63	
Lack of Fit	0.018	0.2258	0.093	0.8407	0.091	0.5905	0.36	0.0569	0.41	0.2897
Pure Error	0.011		0.15		0.17		0.049		0.23	
Cor Total	3.29		2.81		30.54		5.01		10.45	

[a, b, c] *Significant at p < 0.01, 0.01<= p <0.05 and p >=0.1 (not significant) , respectively*

of roasting temperature, followed by the interactive effect of roasting temperature and time. Total phenol was significantly influenced (P≤0.01) by the interactive effect of the two variables, followed by the linear effects of temperature and time. For fracture force, all coefficients of the model were significant. Specifically, the linear effect of roasting temperature and time and quadratic effect of time were all significant at P≤0.01, and the interactive effect of the two variables and quadratic effect of temperature were significant at P≤0.05. Total color difference, however, was only significantly affected by the linear effect of the two variables, i.e. temperature and time. The lack of fit for all responses at the 95% statistical level of confidence was not significant.

In order to investigate the interactive relationship between dependent and independent variables, a 3D surface plot was obtained from the predicted model for application.

Table 4: Regression equations for roasted watermelon seeds.

Response	Equation	R^2	R^2_{adj}
Moisture content (%)	$+0.71-0.47^* A-0.47^* B+0.22^* AB+0.25^* A^2+0.17^*B^2$	0.991	0.985
Total phenol (%)	$+2.43+0.62^* A+0.54^* B+0.36^* AB$	0.919	0.892
Antioxidant activity (%)	$+28.07+0.17^* A-0.016^* B-1.13^* AB-1.19^* A^2$	0.939	0.909
Force (N)	$+4.19-1.46^* A-1.50^* B+0.25^* AB+0.35^* A^2+0.88^* B^2$	0.991	0.985
Delta E	$+7.94-0.56^* A-0.33^* B$	0.913	0.896

Effects of roasting temperature and time

The roasting process caused several changes to the watermelon seeds depending on the type of thermal treatment, time and temperature. Fig. 1 shows the response surfaces for moisture content, total color difference, fracture force, phenol content and antioxidant activity of watermelon seeds after roasting at different temperatures and durations.

Moisture content

The moisture content tended to decrease with increasing roasting temperatures and time. This result may be associated with the temperature gradient that was created between the seed and the environment that increased with increasing temperature, thereby resulting in the reduction of moisture content in the product. On the other hand, prolonging the heating time provides the opportunity for heat to penetrate into the seed and therefore reduce the moisture content. The lowest moisture content (0.39%) was obtained with a roasting temperature of 260 °C and a roasting time of 15 min (Fig. 1). Previous reports claimed that roasting temperature and time influenced the moisture loss of pistachio kernels [16] and pumpkin seed pulp [31].

Color

During the roasting process of most nuts, brown pigments appear more prominently when the Maillard and caramelization reactions intensify [32]. Investigations of the color parameters during the roasting of watermelon seeds suggest that the largest variations occur in L* value. Therefore, the color change (delta E) of the whole sample is largely dependent on L* value. According to Fig. 1, there is a significant relationship ($p<0.01$) between the time and temperature of the roasting with the color change (delta E). As the values of these two variables increased, the watermelon seeds became darker, due to the decrease in the level of L* values, which led to the increase in color change (delta E). The main reason of this event is the production of brown compounds resulting from the Maillard and caramelization reactions. The relationship between temperature and time in the Maillard reaction is very important. Higher temperatures and longer durations of time lead to an increase in the reaction between amino acids and reducing sugars [33]. Accordingly, the effect of roasting temperature for longer durations was more significant than shorter durations. This was in accordance with previous results which indicated that by prolonging the roasting duration and by increasing the temperature, the brown color of peanuts intensified and the L* value decreased [34].

Texture

One of the most important parameters that must be controlled during the roasting of nuts is the texture. As the roasting process was prolonged, less force was needed for the fracture of watermelon seeds, resulting in the production of crispy nuts. The fracture force was lower in all roasted watermelon seeds (2.63-8.68 N), compared to raw nuts (11.85 N), indicating that hot-air roasted watermelon seeds were more crunchy. It can be observed in Fig. 1 that the increase in temperature and time caused the decrease in the maximum force required for the fracture of watermelon seeds due to the decrease in moisture and hence the increase in the porosity of the sample. This finding is in accordance with *Nikzade* and *Sedaghat* [18] who observed a similar reverse relationship between roasting temperature and hardness of pistachio nuts. The decrease in hardness parallel to the increase in roasting time has also been observed by *Kahyaoglu* [35] in sesame seeds and *Shakerardekani et al.* [16] in pistachio nuts. On the contrary, *Uysal et a.l* [36] reported that increasing the roasting time of the hazelnut caused the fracture force to increase. This may be explained

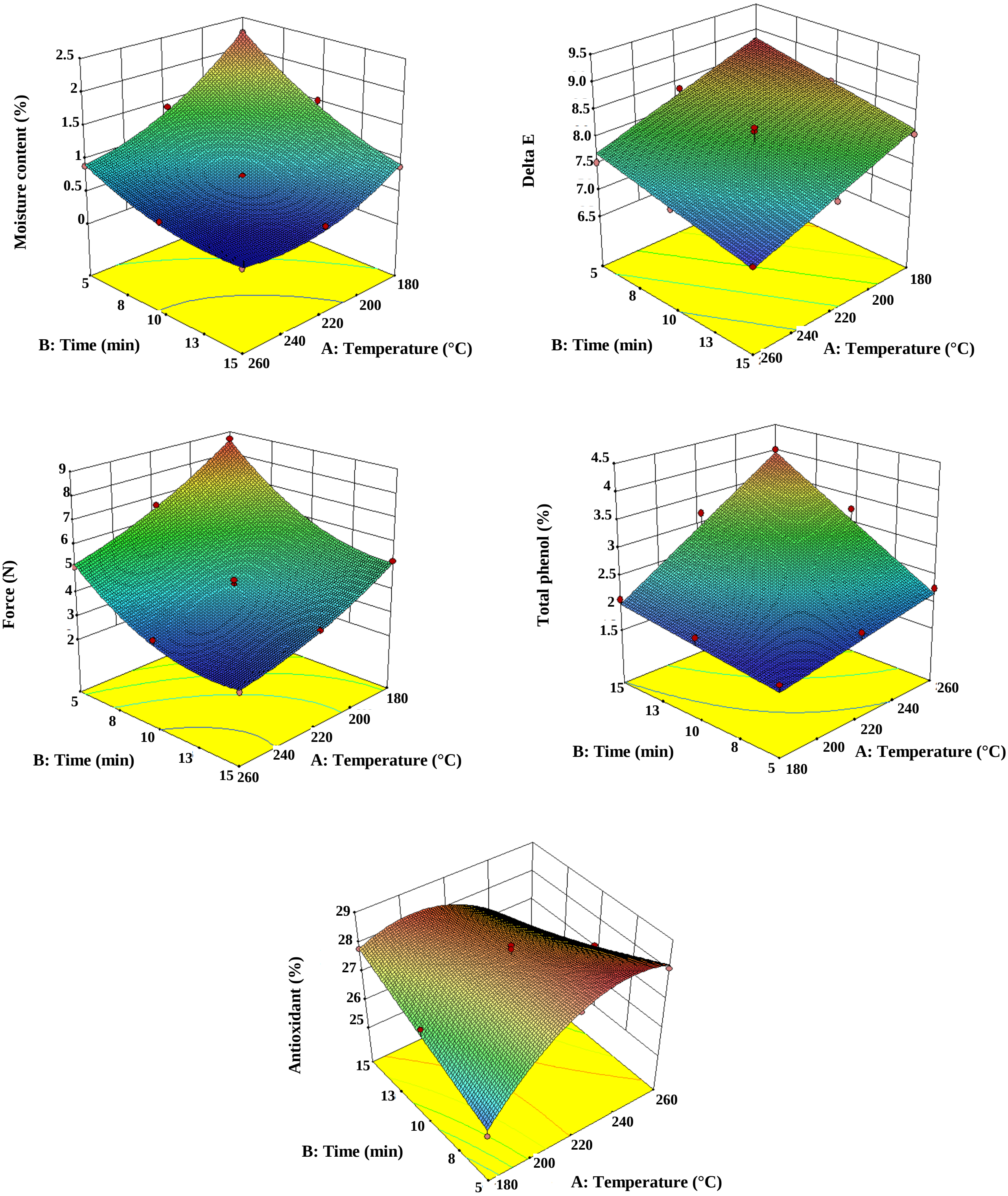

Fig. 1: Response surfaces for moisture content (a), total color change (b), fracture force (c), total phenol content (d), and antioxidant activity (e) as a function of roasting temperature and time.

by the difference between the mechanisms of microwave energy combined with infrared heating and conventional heating in this study. *Demir* and *Cronin* [8] also reported that both roasting temperature and time had significant effects on the textural changes in hazelnuts, and the variability in the texture decreased during the roasting process. In accordance with these results, *Lewicki* and *Jakubczyk* [37] reported that during the drying of apples at three temperatures of 40, 60 and 80 °C, the moisture content decreased which caused the force required for the compression of dried apples to increase.

Total phenol

Phenolic compounds which are widely distributed in plant products have multiple functional and biological properties affecting the product quality and human health. The amount and type of phenolic compounds in different products are heavily influenced by the type of each product, the roasting method and the position of phenolic compounds in the cell [38]. The total phenolic compounds in the raw watermelon seed was 1.68 (mgGAE/g dw) which was less than the values of all roasted watermelon seeds. This confirmed that the total phenolic compounds were positively affected by the roasting process in the oven. As presented in Fig. 1, prolonging the roasting duration at a constant temperature (and vice versa) caused the values of phenolic compounds to increase, which becomes more intense by longer durations and temperatures due to the increased rate of browning reactions and the amounts of energy required for breaking the bonds. These results are in agreement with those reported previously by *Kim et al.* [13] and *Youn* and *Chung* [5] who demonstrated that roasting small black soy beans at 150 and 250 °C for 26, 30 and 34 min, and roasting maize at 160-240 °C for 10-50 min led to the increase in phenolic compounds. Accordingly, *Jannat et al.* [12] eported that the γ-tocopherol and the total polyphenol in sesame seeds significantly increased when the seeds were exposed to increasingly higher roasting temperatures (until 200 °C) for longer periods. Nonetheless, they decreased when the seeds were roasted at 220 °C. The highest levels of phenolic compounds in watermelon seeds were obtained with a roasting temperature of 260 °C and a roasting time of 15 min (Fig. 1) which, compared to raw samples, increased by about 4%. The increased production of phenolic compounds during roasting in this study may be attributed to the breakage of the bond between phenolic compounds with adjacent molecules such as proteins. This would then facilitate the release of those molecules from the cell wall. Moreover, as the products of the Maillard reaction are created, the release of phenolic compounds during the roasting process can be effectively furthered. Nonetheless, the production of these phenolic compounds at high temperatures may cause undesirable tastes.

Antioxidant activity

To determine the antioxidant activity of watermelon seeds that were roasted under different conditions, the DPPH radical scavenging activity was investigated. The antioxidant activity of raw watermelon seeds was initially 24.8%, which increased to 28.43% after the seeds were roasting at 243 °C for 5 min. Generally, the level of the antioxidant activity is largely dependent on the level of phenolic and flavonoid compounds present in the sample and other phenolic compounds resulting from the non-enzymatic browning reaction during the roasting process [39]. According to *Darsini et al.* [40] and *Ilaiyaraja et al.* [23], the TPC and antioxidant activity of two tropical fruits both showed similar changes when they were exposed to different roasting durations and temperatures. In this study, however, the antioxidant activity and the level of phenolic compounds were considered as functions of the roasting conditions but did not show identical graphs. According to Fig. 1, by increasing the roasting temperature while setting shorter durations for the process, or by having longer durations of roasting at lower temperatures, the antioxidant activity increased because of higher levels of phenolic compounds in the sample. However, with the simultaneous increase in roasting temperature and time, the antioxidant activity decreased significantly. These results are consistent with previous findings reported by del *Castillo et al*. [7] and *Chung et al.* [6] who studied the effects of roasting conditions on the antioxidant activity of coffee brews. In fact, roasting watermelon seeds at very high temperatures for a long time, as observed here, would lead to the thermal degradation of phenolic compounds and their conversion to other phenolic structures that do not have radical scavenging activity. The creation of new phenolic compounds resulting from the Maillard reaction without radical scavenging activity can also entail effective implications in this regard. Accordingly, *Djikeng et al* [10] showed that the decrease in antioxidant

Table 5: Predicted and experimental responses obtained after roasting of watermelon seeds at optimized conditions.

Response	Predicted values	Experimental values	Error (%)
Moisture content (%)	0.44	0.51	- 15.91
Total phenol (%)	2.89	2.64	8.65
Antioxidant activity (%)	27.93	27.75	0.64
Force (N)	3.68	4.03	- 9.51
Delta E	7.67	7.93	- 3.39

activity of cocoa beans during roasting can be related to the destruction of their polyphenols. These results suggest that applying the correct conditions for the roasting of watermelon seeds could increase their antioxidant activity.

Optimization

To determine the optimum conditions for the roasting of watermelon seeds, the desirability functions of RSM was used. For this purpose, the input variables were determined in the range and the responses were considered in their most favorable state. The desired properties of roasted watermelon seeds and the optimum outcomes were to have the minimum amount of moisture content and fracture force against the maximum level of antioxidant activity and total phenol content. Minimizing the fracture force was a criterion of the brittleness of the seeds. Since there is no standard value for the color of roasted watermelon seeds in the available literature, the color factor was determined through questionnaires and surveys in which lighter colors were selected as more favorable.

The point with the highest possible functions of desirability was found to be 216 °C and 15 min (optimal desirability=0.739) which could be taken as the optimum conditions for roasting watermelon seeds. In order to verify the accuracy of the optimality presented by the model, the experiments were performed in three replicates and the results were compared with the predicted values (Table 5). Regarding the prediction error calculated for all the responses, the proposed model was valid to show the effect of the two variables (time and temperature of roasting) on the physicochemical characteristics of watermelon seeds.

Fatty acid

The fatty acid composition of roasted watermelon seeds at optimum conditions were compared to raw samples (Table 6). According to this table, watermelon seeds are an important source of essential fatty acids: linoleic acid (57%) and oleic acid (22.3%). The seeds can therefore be considered as a nutritious edible product. The fatty acid composition of raw pistachios was in agreement with a previous study by *Acar et al* [1]. According to their studies, more than 75% of the oil in watermelon seeds is composed of unsaturated fatty acids. The content of unsaturated and saturated fatty acids in the roasted watermelon seed was 79.7% and 19.6%, compared with the control sample (79.9% and 19.5%). This indicates that the roasting treatment did not significantly affect the fatty acid composition of watermelon seeds. Moreover, the ratio of unsaturated fatty acids (UFA) to saturated fatty acids (SFA) for roasted (4.07%) and raw samples (4.1%) were not significantly different. These results were not in agreement with those reported by *Hojjati et al* [17] who reported the undesirable effect of roasting pistachios by hot-air treatments. According to their research, roasting by hot-air treatments caused a significant decrease ($p<0.05$) in the content of unsaturated fatty acids (74.7%), compared to raw pistachios (85.8%). The reported ratio of UFA to SFA was 2.95 in hot-air roasted samples compared to 5.85 in the raw pistachios.

CONCLUSIONS

In this research, the response surface methodology was used in order to describe the changes of color, texture, moisture, phenol content and antioxidant activity of watermelon seeds during the process of roasting. ANOVA analysis was performed to evaluate the accuracy of the models obtained herein. The results indicated that all of the above responses (except for the total color difference) could be described adequately by using the quadratic polynomial models, as shown from the high correlation coefficients. However, the total color change correlated linearly with the temperature and duration of roasting. The optimum roasting conditions were 216 °C through 15 mins of exposure, and the desirability (D) value was 0.74.

Table 6: Fatty acid profile of roasted watermelon seed at optimized condition compared with raw sample*[†]*.

Fatty acids	Raw Content (%)	Roasted Content (%)
Palmitic acid	12 a	12.3 a
Stearic acid	7.5 a	7.3 a
Oleic acid	22.3 a	23 a
Linoleic acid	57 a	56.2 a
Linolenic acid	0.6 a	0.5 a
Sigma unsaturated F.A (UFA)	79.9 a	79.7 a
Sigma saturated F.A (SFA)	19.5 a	19.6 a
UFA/SFA	4.1 a	4.07 a

[†]*Results presented in the table are the means±SD of 3 replications. Different capital letters within rows indicate significant differences between formulations at a significance level of 0.05*

Moreover, as the roasting treatment did not significantly affect the fatty acid composition of watermelon seeds, the hot-air treatment in the oven can be used as a convenient method of roasting watermelon seeds. The consumption of this product requires further research and advertisement so as to establish the knowledge of its benefits among various cultures and populations that are not already familiar with the unique taste of watermelon seeds and the changes that occur as a result of its roasting.

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