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Effect of roasting conditions on hardness, moisture content and colour of pistachio kernels

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Abstract: Roasting of whole-kernels is an important step in the production of pistachio paste. The effect of hot air roasting temperatures (90-190°C) and times (5-65 min) on the hardness, moisture content and colour attributes ('L', 'a' and 'b' values and yellowness index) of both whole-kernel and ground-state were investigated using response surface methodology (RSM). Increases in roasting temperature and time caused a decrease in all the responses except for 'a' value of ground-state. The interaction and quadratic models sufficiently described the changes in the hardness and colour values, respectively. The result of RSM analysis showed that hardness and colour attributes ('L' and 'b' values, yellowness index) of kernels and 'a' value of ground-state could be used to monitor the roasting quality of whole-kernels. This study showed that the recommended range of roasting temperature and time of whole-kernel for the production of pistachio paste were 130-140°C and 30-40 min, respectively.

Keywords: Pistachio, kernel, roasting, optimization, hardness, colour, moisture content

Introduction

Pistachio nut (*Pistacia vera* L.) is one of the most delicious and nutritious nuts in the world. Roasted and salted or unsalted pistachio nuts are usually directly consumed as snack foods. The non-split pistachio form is used in the production of pistachio oil, pistachio butter, pistachio chocolate and pistachio halva. It is also added as ingredient in the sausage, confectionery and sauces industries (Ardakani, 2006). Roasting is one of the processing steps involved in the nut manufacturing industry to improve the flavour, colour, texture and overall acceptability of the product (Ozdemir and Devres 2000a; Pittia *et al.*, 2001; Sena *et al.*, 2001).

Development of roasted flavour and aroma depends upon the temperature and time of roasting beside the type of nuts and techniques applied. Birch *et al.* (2009) reported that the suitable roasting temperature and time for direct consumption of macadamia nuts were 135˚C and 20 minutes, respectively.

On the other hand, Kahyaoglu and Kaya (2006) reported that sesame seeds should be roasted at 155-170˚C for 40-60 minutes for the production of sesame paste. The textural characteristic of the whole-kernel is affected by the roasting condition to some extent. During roasting, the moisture content of most nuts was reduced (Emily *et al.*, 2009) and the texture became more crumbly and fragile (less hard) (Vincent 2004). In monitoring the textural changes during roasting, many researchers used the hardness property as an indicator of textural quality in sesame seeds (Kahyaoglu and Kaya, 2006); peanuts (Cea *et al.*, 2008) and pistachio nuts (Raei *et al.*, 2009; Nikzadeh and Sedaghat 2008).

The roasting condition of whole-kernels should be properly controlled because it does not only contribute to development of flavour and aroma but also to the colour of the final pistachio paste. Colour is an important quality indicator of the roasting process. During roasting, caramelization and browning reactions occur and result in formation of brown pigments (Cammarn *et al.*, 1990). The effect of roasting conditions on changes in colour were reported by several workers in their studies on peanuts (Cammerer and Kroh 2009), hazelnuts (Özdemir *et al.*, 2001; Özdemir and Devres,2000b), sesame seeds (Kahyaoglu and Kaya 2006) and macadamias (Wall and Gentry, 2007). Other studies concentrated on the effect of roasting conditions on the nutritional compositions (Kashani and Valadon 1983; Kashani and Valadon 1984) and storage stability of pistachios nuts (Raei *et al.*, 2009; Nikzadeh and Sedaghat, 2008).

RSM is a powerful technique for determining the best combination of factor levels for different responses. Its success depends on the nature of the process being characterized, the knowledge and skill of the researcher (Berger and Maurer, 2002). RSM

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has been applied in the optimization of several types of roasted products, and the technique is suitable for determining the optimum roasting conditions in hazelnut (Sena *et al*., 2001; Ozdemir and Devres, 2000); chashew nut (Hebbar and Ramesh, 2005); sesame seed (Kahyaoglu and Kaya, 2006); coffee (Mendes *et al*., 2001), peanut (Slade and Levince, 2006) and pistachio nut (Nikzadeh and Sedaghat, 2008; Kahyaoglu, 2008).

Although the effect of roasting conditions on quality of pistachio nut has been studied by previous works, most works focused on modelling and optimization of the different varieties for direct consumption. In this paper, the effect of hot-air roasting temperature and time on the hardness, moisture content and colour of whole-kernel (Ohadi variety) for the production of pistachio paste was studied using response surface method.

Materials and Methods

Iranian Ohadi cultivar of pistachio nuts (*Pistacia vera* L.; Iran Pistachio Research Institute, season 2009) were used in this study. The pistachios were dehulled and dried in a batch cylindrical dryer (Model Rezaei Rafsanjan, Iran) to decrease the moisture content to around 3-4% (dry basis). After separating the non-split nuts from the split nuts, non-split nuts were broken into shells and kernels. Kernels were sorted out manually to get the uniform sizes for roasting. Fifty grams kernels were placed in a single layer on Pyrex Petri dishes (9 cm in diameter) and were roasted in convection oven (Memmert, UNB 500) at 90 to 190°C for 5 to 65 mins based on the experimental design shown in Table 1. Three replications were carried out for each run. After roasting, the whole-kernels were allowed to cool at room temperature (20 ± 2°C). The kernels were ground into ground-state for 1 min using a laboratory blender (Waring, USA) at low speed.

Hardness determination

The hardness of the whole-kernels was measured using a texture analyzer (TA.HD. Plus Texture Analyser, UK). A kernel was placed horizontally on the plate and double compression was applied using a cylindrical probe (75.0 mm in diameter) at a test speed of 1.0 mm/s and deformation of 1.5 mm. The test was performed in ten replications. The maximum peak of the first compression (N) in the force-time curves indicates the hardness value (Kayaoglu and Kaya 2006; Meullenet and Gross, 1999).

Moisture content determination

The moisture content of whole-kernels was determined according to the Analytical Association of Official Analytical Chemists (AOAC) Method 925.09 (1990). The measurements were carried out in triplicate.

Colour determination

The colour of roasted whole-kernel and ground-state were measured using an Ultrascan PRO spectrocolorimeter (A60-1012-402 Model Colorimeter, Hunter Lab, Reston, VA, USA). Parameters monitored were the L (whiteness or darkness), a (redness/greenness), b (blueness/yellowness) values and YI (yellowness index) (Kahyaoglu, 2008).

Response surface methodology

The RSM, was performed using two-factors (x_1 and x_2) with five levels (-1.414, -1, 0, -1 and 1.414) central composite design for the following responses which are hardness, moisture content, L-value, a-value, b-value, and YI of kernels and L-value, a-value, b-value and YI of the ground-state. The x_1 and x_2 reflect the air temperature and roasting time, respectively. Since the functional relationship between the responses and factors was unknown, the first order or second order polynomial expressions for a selected experimental region (90-190°C and 5-65 min) was used to estimate the actual response surfaces (Montgomery, 2009). A Minitab software version 15.1.1.0 was used for running the RSM and optimal design.

Results and Discussion

The changes in hardness, moisture content and colour attributes of roasted whole-kernels and the colour attributes of ground-state are presented in Table 2, whereas the analysis of variance (ANOVA) and lack-of-fit tests with R^2 (correlation coefficient) of the results are given in Table 3.

Hardness of whole-kernels

Hardness is an important parameter that needs to be controlled during roasting of whole-kernels. The decrease in hardness of whole-kernel during the roasting process is shown in Figure 1. The changes in textural parameters as a function of the temperature, time and their interactions were almost similar, i.e. showing a significant decrease ($p < 0.05$) as roasting temperature and time were increased indicating a reduction in the strength of the kernel. The decrease in hardness showed the same deformation trend and the force required to break the kernels was smaller

Table 1. Coded and actual variables for the response surface design for whole-kernel roasting process

Run number	Coded		Actual	
	Temperature (°C)	Time (min)	Temperature (°C)	Time (min)
1	0	−1.414	140	5
2	1	−1	190	5
3	0	0	140	35
4	0	0	140	35
5	0	0	140	35
6	−1	1	90	65
7	−1.414	0	70	35
8	1	1	190	65
9	0	0	140	35
10	0	1.414	140	77
11	0	0	140	35
12	1.414	0	211	35
13	−1	−1	90	5
14	0	−1.414	140	5
15	1	−1	190	5

Table 2. Measured data for all response parameters of roasted pistachio nut

Roasting Conditions		Whole-kernel						Ground-state			
		Colour Attributes				Moisture Content (%)	Hardness (N)	Colour Attributes			
Temperature (°C)	Time (min)	L	a	b	YI			L	a	b	YI
70	35	43.14	6.29	14.52	54.90	2.05	91.91	65.59	0.01	27.09	60.81
90	5	39.93	5.57	13.60	58.87	2.16	81.81	64.02	0.27	26.14	62.03
90	65	41.53	4.59	14.32	57.92	1.43	90.74	65.92	0.02	25.98	60.52
140	5	43.43	6.29	13.20	67.05	2.26	83.53	65.91	0.35	27.79	62.30
140	35	42.40	5.25	13.31	53.33	0.64	76.51	65.95	-0.49	28.39	62.03
140	35	38.42	6.81	12.63	58.90	0.44	54.50	64.43	0.94	28.14	66.32
140	35	43.32	5.64	14.36	58.12	0.63	60.35	66.78	-0.43	29.94	65.86
140	35	38.45	6.39	12.87	57.02	0.52	53.37	64.94	1.76	28.43	67.99
140	35	39.18	6.36	14.86	62.43	0.64	64.29	65.08	0.83	28.13	65.53
140	77	32.11	8.04	9.56	58.13	0.21	49.51	58.22	5.12	28.75	76.47
190	5	42.95	4.89	15.05	56.89	1.07	76.94	64.21	-0.89	27.81	63.99
190	65	24.24	1.50	1.10	9.73	0.03	26.31	25.41	4.52	4.05	32.46
211	35	24.81	2.65	2.06	18.13	0.11	27.44	25.89	6.75	7.63	58.52

Table 3. ANOVA and model fitting for response parameters of roasted whole-kernels

Test	DF	*P* values									
		L value whole Kernel	*a* value whole kernel	*b* value whole kernel	YI Value Whole Kernel	Moisture content whole kernel (%)	Hardness whole kernel (%)	L value Ground -state	a value Ground -state	b value Ground -state	YI Ground -state
Sequential model sum of squares:											
Linear	2	0.000	0.133	0.000	0.001	0.000	0.000	0.000	0.017*	0.005	0.521
Quadratic	2	0.046*	0.120*	0.018*	0.003*	0.001*	0.512	0.002*	0.294	0.010*	0.377
Interaction	1	0.004*	0.411*	0.003	0.005*	0.390	0.009*	0.002	0.116	0.015	0.157
Lack-of-fit tests											
Linear	6	0.058 (NS)	0.021	0.015	0.003	0.004	0.240	0.000	0.066 (NS)	0.000	0.002 (S)
Quadratic	3	0.401 (NS)	0.026 (S)	0.067 (NS)	0.063 (NS)	0.047 (S)	0.697	0.003 (S)	0.079	0.001 (S)	0.002 (S)
Interaction	5	0.158 (NS)	0.017	0.016	0.005	0.003	0.744 (NS)	0.000	0.085	0.000	0.002 (S)
***R*²**		0.92	0.63	0.93	0.93	0.97	0.91	0.95	0.75	0.89	0.47

* Shows suggested model.
S: Significant at $p < 0.05$; NS: not significant.
DF=Degree of freedom.

as roasting time and temperature were increased. The hardness values of whole-kernels during hot-air roasting varies from 26.31 N for whole-kernel that was roasted at 190°C for 65 min, to 91.91 N for kernel that was roasted at 70°C for 35 min (Table 2). This finding is concurrent with Nikzade and Sedaghat (2008) who observed a similar reverse relationship between roasting temperature and hardness of pistachio nuts. The decrease in hardness with the increase in roasting time has also been shown by Kahyaoglu and Kaya (2006) for sesame seeds. Significant linear temperature and time effects were found for hardness model at 5% level of significance. The interaction regression equation established in this study could be used for determining hardness of roasted whole-kernels (Table 3).

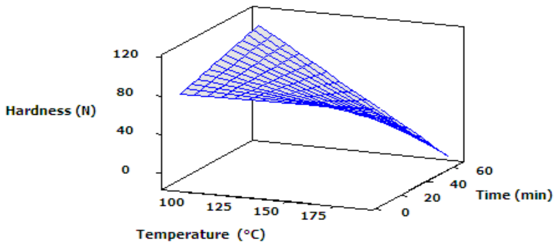

Figure 1. Response surface for hardness of roasted whole-kernels

Moisture content of whole-kernels

The changes in moisture content of whole-kernels during roasting is explained by a quadratic model (R^2 = 0.97) as shown in Table 3 and Figure 2. The results obtained proved that the roasting temperature and time were the main factors affecting the moisture content. Even though the quadratic term for temperature and time was significant ($p< 0.05$), the cross-product or the interaction was not. The lack of fit tests were found to be significant for linear, quadratic and interaction models, hence, the application of RSM for predicting a model to describe the changes in moisture content during roasting of whole-kernel was not successful. This finding was supported by Kahyaoglu and Kaya (2006) who discovered that moisture content is not the main parameter during roasting of sesame seeds.

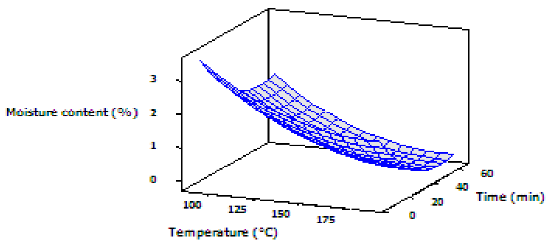

Figure 2. Response surface for moisture content of roasted whole-kernels

Colour attributes of whole-kernel and ground-state

During roasting of most nuts, brown pigments generally increase as browning and caramelisation reactions are in progress (Sena *et al*., 2001). Table 3 shows that the correlation coefficients of regression equations for the colour parameters of the whole-kernels and ground-state changed from 0.63 to 0.93 and from 0.47 to 0.95, respectively. According to lack of fit tests, it can be concluded that the proposed model estimates the response surfaces and can be used for prediction of L-value, b-value and YI of kernels and a-value of the ground kernel.

The linear and quadratic terms of the roasting temperature had a significant effect on all colour parameters of the roasted whole-kernels and ground-states except for the a-value and YI of ground-state. On the other hand, the interaction terms (roasting temperature and time) for the L, b-values and YI of kernel and L and b-values of the ground-state were also found to be significant ($p < 0.05$). On the overall, except for the a-value of the kernel, and the b-value and YI of the ground-states, all other values studied were significantly ($p < 0.05$) affected by roasting time. It was observed that roasting temperature is the main factor that influences the L, a, b-values, and YI of kernels and L, a, b-values of ground-states in the production of pistachio paste. In this study it was observed that both roasting temperature and time influence the changes in colour attributes of whole-kernels and ground-states but the effect of temperature is more important than time (Table 4). Similar findings were observed by Demir *et al*. (2002) and Özdemir and Devres (2000b) in their studies on hazelnuts.

The regression equations shown in Table 4 were used to run response plots for all the colour responses studied. The plots for colour parameters are presented in Figures 3-10. The L-values which reflects the whiteness of whole-kernels and ground-states ranges from 24. 24 to 43.43. The shape of L-values observed at the beginning of the roasting period was due to initial lightening effect as reported in hazelnuts by Özdemir and Devres (2000a, b). But in contrast to this finding, whole pistachio nut did not show any initial lightening (Kahyaoglu, 2008) similar to that found in whole-kernels and ground-states.

The shapes of the surface plots for L, b-values, and YI of kernel are similar to each other. All the values showed a decreasing trend at higher temperature and time. The shapes of the response surfaces were found to be different for a-value which showed falling-ridge behaviour with temperature and time. The change in behavior is probably due to exposure to the high roasting temperature and the longer time. It was found that the redness (a-value) of kernels decreased gradually with increase in temperature and time and the whole-kernels were darker when they were roasted at 211°C for 35 min and 190°C for 65 min (Figure 4). The response surface plots for whiteness (L-values) and yellowness (b-values) of ground-states were saddle in shape. The a-values and YI showed a sharp, increasing and sharp decreasing behavior, respectively. This indicates that the redness of ground-states increased whereas the yellowness decreased rapidly with the increase in roasting temperature and time. The initial colour of ground-state was green (a = -0.89 to 6.75 and it changed to red after roasting probability due to browning reactions between amino

Table 4. Regression equation coefficients, presented as coded terms[a], for response parameters of roasted whole-kernels

Coefficients	**Regression constant**					
	b_0	b_1	b_2	b_3	b_4	b_5
Whole -Kernel:						
L	39.6796	-5.02407 (S)	-4.13986 (S)	-5.07750 (S)	-2.74054 (S)	
a	6.17174	-1.11472 (S)	-0.236891 (NS)		-1.24553 (S)	
b	13.0374	-3.67389 (S)	-2.29722 (S)	-3.66750 (S)	-2.25576 (S)	
YI	58.9270	-12.7713 (S)	-7.59060 (S)	-11.5525 (S)	-11.8288 (S)	
MC	0.574000	-0.654197 (S)	-0.583642 (S)		0.256750 (S)	0.334250 (S)
Hardness	64.4008	-20.0593 (S)	-11.2264 (S)	-14.8900 (S)		
Ground -state:						
L ground kernel	64.3048	-12.0580 (S)	-5.97191 (S)	-10.1750 (S)	-9.3652 (S)	
a ground Kernel	1.44308	1.60897 (S)	1.48822 (S)			
b ground Kernel	28.1726	-5.97257 (S)	-2.82029 (NS)	-5.90000 (S)	-5.99674 (S)	
YI ground Kernel	61.9100	-3.66732 (NS)	-1.62507 (NS)			

[a] $Y = b_0 + b_{1x1} + b_{2x2} + b_{3x1x2} + b_{4x1}{}^2 + b_{5x2}{}^2$ where, x_1 = air temperature (°C) and x^2 = roasting time (min). (°C)
S: Significant at $p < 0.05$; NS: not significant.

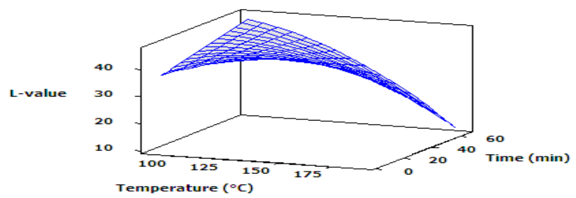

Figure 3. Response surface for l value of roasted whole-kernels

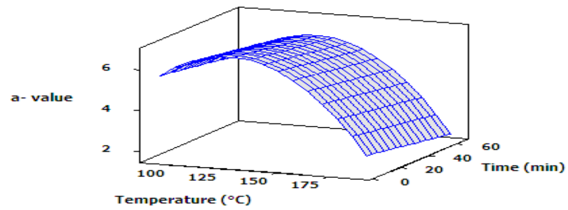

Figure 4. Response surface for a value of roasted whole-kernels

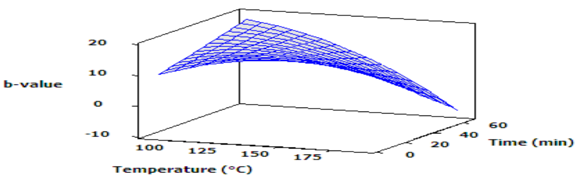

Figure 5. Response surface for b value of roasted whole-kernels

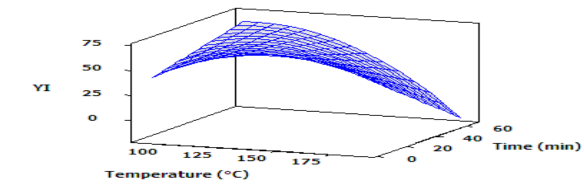

Figure 6. Response surface for yellowness index of roasted whole-kernels

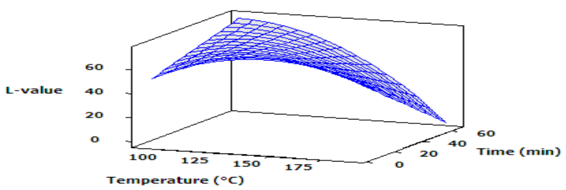

Figure 7. Response surface for l value of roasted pistachio ground-state

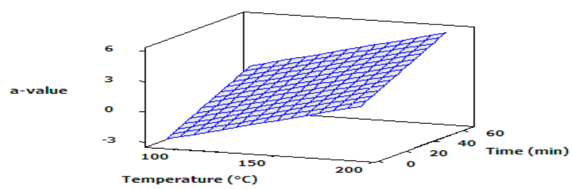

Figure 8. Response surface for a value of roasted pistachio ground-state

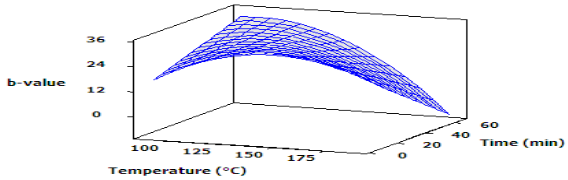

Figure 9. Response surface for *b* value of roasted pistachio ground-state

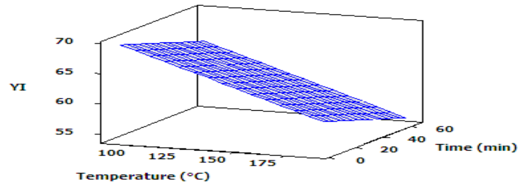

Figure 10. Response surface for yellowness index of roasted pistachio ground-state

the pistachio. The result of RSM analysis showed that in term of colour parameters the L, b-values, and YI of kernels and a-values of ground-state should be monitored during roasting of whole-kernels.

Optimization of roasting conditions for whole-kernels

The desirability functions of RSM were used to determine the optimum roasting conditions of whole-kernels for the production of pistachio paste.

acid and reducing sugar in
The L- value, b-value, YI and hardness of whole-kernels and the a-value of ground-state were selected as the control parameters. The optimum quality characteristics of roasted whole-kernel for production of pistachio paste are determined by considering the roasting time and temperature only. Other factors that might influence the result such as variety of pistachio, type of roaster and capacity of the roaster is beyond the scope of this study. The optimum colour and textural parameters of roasted whole-kernel for paste production (i.e. using commercial pistachio paste samples as reference) were as follows: L-value = 32-35; b-value = 10-16; YI = 56-67; hardness = 57-90N; and a-value of ground-state = 1-3. The desirability function response surface and validity is given in Figure 11 and Table 5. The point with the highest possible desirability functions that could be taken as the optimum conditions for roasting of whole-kernels for the production of pistachio paste was found to be 134°C and 35 min (optimal desirability=0.92610). However, for the application of pistachio paste in other food products, the recommended range of roasting temperature and time were 130-140°C and 30-40 min, respectively.

Table 5. Validation for roasting[a] optimal point

Attribute	Experimental	Predicted
L-value	39.9±0.7	40.5
b-value	14±0.3	13.6
YI	61.5±0.5	60.8
a-value	1.3±0.1	1.2
Hardness	69.7±1.5	67.7

[a] Mean ± standard deviation.

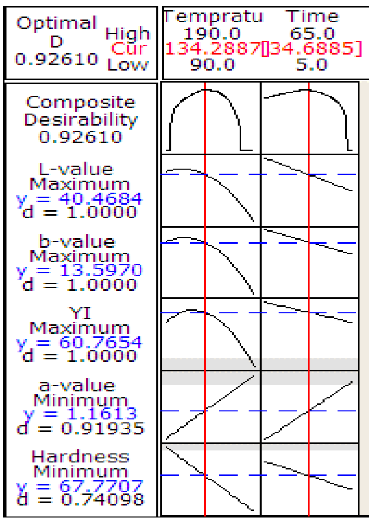

Figure 11. Optimization plot for whole-kernels roasted in a hot-air roaster

Conclusions

This study showed that response surface methodology could be used to predict satisfactory models for describing the changes in colour and hardness of whole-kernels during hot-air roasting. The changes in colour attributes and hardness parameters of whole-kernels were successfully described by the quadratic and interaction models, respectively. The hardness, L-value, b-value and YI of the whole-kernels and also a-value of the ground-state, could be used as indicators in controlling the roasting quality of whole-kernel. Successful optimization of the pistachio roasting processes can be obtained by using the desirability functions of RSM. Based on these findings, it can be concluded that for pistachio paste production, the recommended range of roasting temperature and time for whole-kernel was at 130-140°C for 30-40 min.

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