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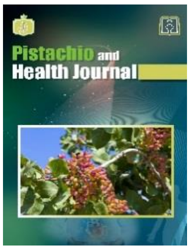

ORIGINAL ARTICLE

Optimization of Processing Variables for Pistachio Paste Production

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Background: Pistachios is one of the popular tree nuts in Iran and other countries. The effect of pistachio kernel roasting and milling parameters on the quality of pistachio paste was investigated in this study.

Material and Methods: Roasting variables were roasting temperature (90-190°C) and roasting time (5-65 min). Four grinding gap sizes (20, 40, 60, and 80 µm) were used to prepare pistachio pastes.

Results: Increasing roasting time and temperature had inverse associations with colour attributes of both kernels and pistachio powders, except for 'a' value of pistachio powder. The hardness (N) and colour parameters (yellowness index, L value and b value) of pistachio kernels and the 'a' value of pistachio powder can be used to control the roasting quality of pistachio kernels. The colloidal stability (CS) of pistachio pastes was found to be affected by particle size.

Conclusion: The recommended roasting condition ranges of the kernels for the pistachio paste production were 130-140°C (30-40 min). The most stable pistachio paste was obtained when the gap size of the mill was 20 µm.

Keywords: color; nut paste; pistachios**; r**esponse surface methodology

1. Introduction

Pistachios (*Pistacia vera* L.) is one of the most delicious and nutritious nuts. During the production process of pistachio paste, nut kernels are dehulled, roasted, and ground into paste [1]. Roasting of the nut is used to improve the texture, flavor, color and overall acceptability of the final product [2-5]. The roasting conditions of nuts are determined by the nut and roaster type. It was reported that the appropriate roasting conditions for macadamia [6], peanuts [7], and sesame seeds [8] were 135°C (20 min), 160°C (40-50 min), and 155-170°C (40-60 min), respectively. Although the roasting condition effects on the pistachio nut quality have been studied in previous studies, most of them focused on modeling and optimization of roasting for different varieties for direct consumption of pistachio nuts. However, this study aimed to find the optimum roasting parameters for producing pistachio paste. Pistachio paste can be used as an ingredient in desserts, ice cream, and sauces. Pistachio paste is usually shelf stable. However, oil separation during storage affects the colloidal stability, consumer acceptability, and marketability of the product [9]. The stability of food colloids, such as chocolate, peanut butter, and sesame paste are strongly affected by particle size distribution [10-14]. Although there are various published studies on the physical stability of pastes, none of them have investigated the impact of particle size distribution on the colloidal stability or the color of pistachio paste. Based on the above explanation, the objectives of this chapter were the following:

(1) To determine the optimum hot-air roasting conditions (temperature and time) that would produce suitably roasted pistachio nuts for production of paste, and
(2) To determine the effect of various particle sizes on the stability and the color of pistachio paste.

2. Materials and Methods

2.1. Materials

Pistachio nuts of the Ohadi cultivar were prepared from the Iran Pistachio Research Center. Unsplit nuts were separated from the split nuts before drying in a batch cylindrical dryer (Rezaei Model, Rafsanjan, Iran) to decrease the moisture content to around 5% (dry basis). The raw nuts were stored at -18±2°C before analysis.

2.2. Determining the optimum roasting conditions

The parameters used to determine the optimum roasting ranges were temperature and time. Fifty gr of kernels was placed in a single layer in Pyrex Petri dishes (9 cm in diameter) and were roasted in a convection Memmert oven (model UNB 500, Germany) between 90 to 190°C (5 to 65 min) (Table 1). Three replications were performed out for each run. After roasting, the kernels cooled at room temperature (20±2°C). About 25 gr of the kernels was ground for 1 min in a Waring laboratory blender (Model HGBTWT, Torrington, USA) at low speed to produce pistachio powder (ground kernel). Both whole and ground

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kernels were stored at -18±2°C prior to analysis for less than 3 days.

Table 1. Variables for whole kernel roasting process

Run number	Roasting Temperature (°C)	Roasting Time (min)
1	140	5
2	190	5
3	140	35
4	140	35
5	140	35
6	90	65
7	70	35
8	190	65
9	140	35
10	140	77
11	140	35
12	211	35
13	90	5

2.3. Determining the hardness and fracturability

The hardness and fracturability of the kernels were evaluated using a texture analyzer (TA.HD. Plus Texture Analyser, UK). A kernel was set horizontally in the center of the analyzer plate and double compression was used by a cylindrical probe (75.0 mm in diameter instead of 5mm) at a test speed of 1.0 mm/s and a deformation of 1.5 mm. The test was carried out in ten replicates. Textural properties were obtained from the force–time curves. The two textural parameters fracturability (in Newton) (first peak of first compression) and hardness (in Newton) (maximum peak of first compression) were considered to evaluate textural properties [15, 16].

2.4. Determining the moisture content

The moisture content of the kernels was measured according to the AOAC Method 925.09 [17]. The measurements were carried out in triplicate.

2.5. Preparation of pistachio paste using colloid mill

The nut shells were manually removed to obtain the kernels. The kernels were roasted in the convection Memmert oven (model UNB 500, Germany) at 134±1°C for 30 min before grinding at 1000 rpm into a pistachio paste using a Supermass colloider mill (Masuko, Model MKZA6-5, Japan). The nut kernels were placed in a single layer in glass petri dishes (9 cm in diameter) in which each petri dish contained 50 gr of the kernel. Four milling gap sizes (20, 40, 60, and 80 μm) were applied in order to produce pastes of different particle sizes. One kilogram of pistachio kernel was grinded for each gap size. Three batches of paste were prepared for each gap size and stored at -18±2°C in polyethylene containers (each containing 100.0 g) for less than 3 days. Prior to analysis, the pastes were allowed to stand at 20±2°C for 1h.

2.6. Determining the pistachio paste particle size

The particle size of the pistachio pastes was measured using a particle size analyzer (Mastersizer 2000, UK) according to the Malvern method (2007) [18]. The samples (10.0 gr) were obtained from the container using a spatula suspended in water (1:10 w/v) and homogenized using an Ultra-Turrax T25 homogenizer (Jank and Kunkel, IKA-Labortechnik, Breisgau, Germany) at 2500 rpm for 3 min. The data were analysed using the Malvern software Version 5.60. Five replicate analyses were performed for each sample, and the mean was reported.

2.7. Determining the pistachio paste stability

Sixteen grams of pistachio paste of different particle sizes were placed in separate 15 ml rounded bottom centrifuge tubes (Pyrex, 1.5 cm in diameter, 11cm height) using a stainless steel spatula, heated at 80˚C water bath for 30 min, cooled in water at room temperature for 15 min, and then centrifuged at 4000 ×*g* at 20°C for 10 min. The height oil layer that separated from the pistachio pastes was measured using a dial micrometer. The colloidal stability (CS) was determined using equation 1, where H_0 is the height of the separated oil, and H_t is the total height of the pistachio paste in the test tube at the begining of the experiment [19, 20]:

$$CS = (H_t - H_o/H_t) \times 100 \qquad (1)$$

2.8. Determining the color of pistachio kernel and paste

The color of roasted whole kernel, ground kernel, and pistachio paste were evaluated using an Ultrascan PRO Spectrocolourimeter (Hunter Lab A60-1012-402 Model, Reston, VA, USA). Twenty grams of the sample was used for color measurement. The parameters measured were the L value (whiteness/darkness), 'a' value (greenness/ redness), b value (blueness/yellowness), and YI (yellowness index) for roasted whole kernel and ground kernel [21], and L, a, and b values for pistachio paste. The analysis was replicated three times.

2.9. Response Surface Methodology (RSM)

RSM was applied using two factors (x_1 and x_2) with five levels (70, 90, 140,190, and 211°C) central composite design for the responses hardness, moisture content, L value, 'a' value, b value, and YI of the kernels, and L value, 'a' value, b value, and YI of the pistachio powder. The x_1 and x_2 values reflected the air temperature and roasting time, respectively. The first or second order polynomial was used to evaluate the actual response surfaces [22]. Analysis of variance (ANOVA) was applied to evaluate the effect of particle size on the colloidal stability and the color of pistachio pastes. The correlation coefficients (R^2) were determined using the Rheowin Data Manager Version 3.30.0000. A Minitab software version 16.1.0.0 (Minitab Inc., USA) was used for running the response surface and ANOVA tests. Tukey's test was used for comparing the means of the pistachio paste samples ($P < 0.05$).

3. Results

The effects of roasting parameters on the physicochemical properties of roasted pistachios are presented in Table 2, and the results of ANOVA and lack-of-fit tests along with their related R^2 (correlation coefficient) values are presented in Table 3.

3.1. Hardness and fracturability of whole kernels

Changes in the hardness of roasted whole kernel are presented in Table 2. The trend of changes in hardness as a function of temperature, time, and their interactions with the different roasting regimes were almost similar, so that a significant ($P < 0.05$) decrease in hardness was observed as roasting parameters increased, indicating a decrease in the kernel strength. The decrease in hardness indicated the same deformation trend, and the required force for breaking the kernels was smaller as roasting parameters increased. The hardness values of whole kernels during roasting varied from 26.3 N for whole kernels roasted at 190°C for 65 min to 91.9 N for kernels roasted at 70°C (35 min) (Table 2). The regression equation for interaction established in the present study could be used for measuring the hardness of roasted kernels (Table 3).

3.2. Moisture content of whole kernels

Changes in the moisture content of kernels during roasting was described by a quadratic model ($R^2 = 0.97$), as shown in Table 3. While the quadratic term for temperature and time was significant ($p < 0.05$), the cross-product or the interaction was not significant. The lack-of-fit tests were significant for the linear, quadratic, and interaction models. Hence, it was difficult to use moisture content as a predictive model.

3.3. Color attributes of whole kernel and ground kernel

According to the lack of fit test, it can be derived that the proposed model can be used for estimation of the response surfaces and to predict L value, b value, and YI of kernels and 'a' value of the pistachio powders. As shown in Table 4, the linear and quadratic terms roasting temperature had a significant effect on all color attributes of the roasted kernels and ground kernels, except for the 'a' value and YI of the pistachio powders. On the other hand, the cross terms (roasting temperature and time) for the L and b values and YI of the kernels and L and b values of the pistachio powders were found to be significant ($P < 0.05$). Overall, except for the 'a' value of the kernels and the b value and YI of the pistachio powders, all other values were significantly ($p < 0.05$) affected by roasting time. Table 4 shows that both temperature and time of roasting influenced the color properties of whole kernels and ground kernels. However, roasting temperature was more effective.

3.4. Effect of particle size on colloidal stability of pistachio paste

The particle sizes of the pistachio paste samples after passing through the colloid mill are listed in Table 6. As shown, a decrease in the milling gap size resulted in a reduction in pistachio paste particle size. Also, as expected, the narrowest gap size produced a paste with the smallest particle size. Visual observation showed that the paste was smoother than the rest when the gap size was the lowest. The particle sizes varied in the ranges of 0.9-46.7, 1.0-76.3, 1.2-85.9, and 1.9-97.3 µm for mill gap size of 20, 40, 60, and 80 µm, respectively. A significant difference ($p < 0.05$) was observed in the particle size of paste as the mill gap size increased. As the milling gap size increased from 20 to 80 µm, more roasted kernels could enter the spaces between the mill discs to produce a fine paste at a faster rate with a bigger particle size. The changes observed in the stability of pistachio paste are shown in Table 6. A significant difference ($p < 0.05$) was observed between the stability of pistachio paste produced using a mill gap size of 20 µm and those produced using the other gap sizes. It was clear that the pistachio paste was more stable when the particle size was 15.10 µm and less stable when it was in the range of 19.0-31.4 µm since the paste formed a larger dispersion of solid phase in oil phase when the number of smaller particles increased and, hence, became more stable.

3.5. Effect of particle size on the colour of pistachio paste

According to color measurements, no significant difference ($p<0.05$) was observed in the 'L', 'a', and 'b' values of pistachio pastes produced using all of the mill gap sizes studied.

4. Discussions

4.1. Kernel hardness and fracturability of whole kernels

A similar inverse relationship between roasting temperature and hardness of pistachio nuts and sesame seeds had been previously reported [8, 23, 24]. At the same deformation, the required force needed to break the sesame seeds decreased with an increase in roasting time [15], showing a decrease in the strength of the seeds. Similar to hardness, the result of fracturability studies (which is an indicator of brittleness) showed a decrease during roasting process. However, the fracturability could not be detected by the texture analyzer.

4.2. Kernel moisture content of whole kernels

The moisture content of pistachios has been reported to be 5% [25], but the moisture content of unroasted pistachio kernels in this study was 2.67%. Therefore, the difference between the moisture content of raw pistachio kernels and the final moisture content of roasted pistachio kernels was small [8].

Table 2. Effect of roasting conditions on the quality properties of roasted pistachio nut

Roasting conditions		Whole Kernel							Ground Kernel (powder)			
		Hardness (N)	Fracturability (N)	Moisture content (%)	Color Attribute				Color Attribute			
Temperature (°C)	Time (min)				L	a	b	YI	L	A	b	YI
70	35	91.9±2.6	nd	2.1±0.2	43.1±1.5	6.3±0.4	14.5±0.7	54.9±1.1	65.6±1.7	0.0±0.0	27.1±0.5	60.8±1.0
90	5	81.8±2.3	80.1±2.4	2.2±0.2	39.9±1.8	5.6±0.4	13.6±0.7	58.9±1.2	64.0±1.5	0.3±0.0	26.1±0.4	62.0±1.1
90	65	90.7±2.3	65.4±1.6	1.4±0.1	41.5±1.5	4.6±0.5	14.3±0.8	57.9±0.9	66.0±1.4	0.0±0.0	26.0±0.5	60.5±1.2
140	5	83.5±2.0	79.2±1.3	2.3±0.2	43.4±3.0	6.3±0.5	13.2±0.7	67.1±1.2	65.9±1.6	0.4±0.0	27.8±0.6	62.3±1.3
140	35	76.5±1.7	nd	0.6±0.1	42.4±2.1	5.3±0.4	13.3±0.6	53.3±1.0	66.0±1.6	-0.5±0.0	28.4±0.6	62.0±1.4
140	35	54.5±1.6	nd	0.4±0.0	38.4±2.2	6.8±0.5	12.6±0.5	58.9±1.2	64.4±1.2	0.9±0.1	28.1±0.5	66.3±1.5
140	35	60.4±1.7	nd	0.6±0.1	43.3±3.2	5.6±0.4	14.4±0.6	58.1±1.3	66.8±1.5	-0.4±0.0	29.9±0.7	65.9±1.3
140	35	53.4±1.5	nd	0.5±0.1	38.5±4.4	6.4±0.6	12.9±0.4	57.0±1.3	64.9±1.6	1.8±0.2	28.4±0.6	68.0±1.2
140	35	64.3±1.5	nd	0.6±0.1	39.2±3.5	6.4±0.7	14.9±0.5	62.4±1.5	65.1±1.4	0.8±0.1	28.1±0.5	65.5±1.5
140	77	49.5±1.4	nd	0.2±0.0	32.1±2.0	8.0±0.3	9.6±0.4	58.1±1.3	58.2±1.2	5.1±0.4	28.8±0.4	76.5±1.5
190	5	77.0±1.3	62.3±2.4	1.1±0.2	43.0±3.1	4.9±0.1	15.1±0.5	56.9±1.3	64.2±1.3	-0.9±0.1	27.8±0.4	64.0±1.6
190	65	26.3±0.8	15.6±1.1	0.0±0.0	24.2±1.9	1.5±0.2	1.1±0.1	9.7±0.9	25.4±0.8	4.5±0.1	4.1±0.1	32.5±0.9
211	35	27.4±0.7	10.6±0.7	0.1±0.0	24.8±1.8	2.6±0.1	2.1±0.1	18.1±0.3	25.9±0.7	6.8±0.1	7.6±0.1	58.5±1.1

Note: ±Standard deviation; nd: not detectable

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

Model	*df*	p-values									
		Whole kernel						Ground (powder) kernel			
		Moisture content (%)	Hardness (N)	L	a	b	YI	L	A	b	YI
		Sequential model sum of squares:									
Linear	2	0.000	0.000	0.000	0.133	0.000	0.001	0.000	0.017*	0.005	0.521
Quadratic	2	0.001*	0.512	0.046*	0.120	0.018*	0.003*	0.002*	0.294	0.010*	0.377
Cross	1	0.390	0.009*	0.004*	0.411	0.003	0.005*	0.002	0.116	0.015	0.157
		Lack of fit test:									
Linear	6	0.004	0.240	0.058(ns)	0.021	0.015	0.003	0.000	0.066(ns)	0.000	0.002
Quadratic	3	0.047	0.697	0.401(ns)	0.026	0.067(ns)	0.063(ns)	0.003	0.079	0.001	0.002
Cross	5	0.003	0.744(ns)	0.158(ns)	0.017	0.016	0.005	0.000	0.085	0.000	0.002
R^2		0.97	0.91	0.92	0.63	0.93	0.93	0.95	0.75	0.89	0.47

* Shows suggested model; ns = not significant at $P < 0.05$; *df* = Degree of freedom

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	39.68	-5.02(s)	-4.14 (s)	-5.10 (s)	-2.74(s)	
a	6.17	-1.12(s)	-0.24 (ns)		-1.24(s)	
b	13.04	-3.67(s)	-2.30(s)	-3.67(s)	-2.25(s)	
YI	58.93	-12.77(s)	-7.59(s)	-11.55(s)	-11.83(s)	
Moisture content	0.57	-0.65(s)	-0.58(s)		0.26(s)	0.33 (s)
Hardness	64.40	-20.06 (s)	-11.23(s)	-14.89(s)		
Ground kernel:						
L	64.30	-12.06(s)	-5.97(s)	-10.18(s)	-9.37 (s)	
a	1.44	1.61(s)	1.49(s)			
b	28.17	-5.97(s)	-2.82(ns)	-5.90 (s)	-6.00 (s)	
YI	61.91	-3.67(ns)	-1.63 (ns)			

[a] $Y = b_0+b_1x_1+b_2x_2+b_3x_1x_2+b_4x_1^2+b_5x_2^2$ where, x_1 = air temperature (°C) and x_2 = roasting time (min). s: Significant at $P< 0.05$; ns: not significant.

4.3. Color attributes of whole kernel and ground kernel

It has been demonstrated that, during nut roasting, caramelization and browning reactions increase, which leads to the development of higher brown pigments [5]. Similar findings on roasting conditions of hazelnuts have been reported [2, 3]. All of the color parameters studied here showed an inverse association with temperature and time.

Changes in color properties of whole kernels were due to the exposure to a high roasting temperature for a longer period of time. In general, the redness ('a' value) of whole kernels decreased gradually with an increase in roasting temperature and time. The greenish color of ground kernels ('a' value = -0.9) changed to reddish ('a' value = 6.6) after exposure to 70-211°C for 5-77 min as a result of browning reactions between amino acids and reduced sugar in the pistachio nuts. The obtained result showed that the color parameters L and b values, and YI of kernels and 'a' value of pistachio powder should be evaluate during roasting of whole kernels. At high temperatures and long roasting periods of time such as 211°C (35 min) and 190°C (65 min), the kernels were over-roasted and, therefore, undesirable. On the other hand, at lower temperatures and shorter periods of roasting time such as 70°C (35 min) and 90°C (5 min), the roasted flavor was relatively weak. The roasting condition affect the fluidity and consistency of the paste made from the roasted kernels as well [26].

4.4. Optimizing roasting conditions for kernels

Based on the obtained results, the 'L' value, 'b' value, YI and hardness of kernels, and the ‘a’ value of pistachio powders were selected as control parameters. The optimal color and hardness parameters of roasted whole kernels for paste production using commercial pistachio paste samples as reference were as follows: L value = 35-41; b value = 10-16; YI = 56-67; hardness = 57-90 N; and 'a' value of the ground kernels= 1-3. The predicted values of the response surface and validity are given in Table 5. The point with the highest possible desirability functions were taken as the optimal conditions for roasting of kernels prior to production of pistachio paste, and this was found to be at 134°C for 35 min (at optimal desirability = 0.92610). However, if the pistachio paste is to be used for other food product applications, the recommended ranges of roasting conditions for the whole pistachio kernels will be 130-140°C (30-40 min) (at optimal desirability of > 0.85).

Although the effects of roasting parameters on the quality of the pistachio nuts have been studied by Kahyaoglu in 2008, he focused on modeling and optimizing roasting of the Kirmizi Turkish variety of the pistachio nuts for direct consumption of whole roasted nuts. The aim of this study was to find the optimum roasting parameters for the production of pistachio paste from the Ohadi variety of pistachio nuts, which is more popular in the world. In addition, this study recommends the best roasting conditions for the production of pistachio paste, while Kahyaoglu did not suggest the optimal roasting conditions.

Table 5. Validation of optimal point for roasting variables of whole pistachio kernels

Attribute	Predicted value
L value	40.50
b value	13.60
'a' value*	1.20
YI	60.80
Hardness	67.70

[a] Mean ± standard deviation; YI: yellowness index;
* 'a' value for ground kernel

Table 6. Physicochemical properties and colloidal stability of pistachio paste at different mill gap size

	Gap Size of Colloid Mill (µm)			
	20	40	60	80
Properties: Particle size (µm)	15.10 ± 0.20d*	19.00 ± 0.50c	22.70 ± 0.50b	31.40 ± 1.50a
Colloidal stability	99.3 ± 0.1a	99.0 ± 0.1b	98.9 ± 0.1b	98.8 ± 0.1b
Color parameters:				
L value	37.67 ± 0.20a	37.10 ± 0.30a	37.74 ± 0.40a	37.88 ± 0.4a
'a' value	1.34 ± 0.03a	1.38 ± 0.04a	1.43 ± 0.09a	1.49 ± 0.06a
b value	15.88 ± 0.20a	15.98 ± 0.20a	15.95 ± 0.30a	15.56 ± 0.6a

Note: *Different letters show significance difference (P<0.05); ± Standard error

4.5. Effect of particle size on physical stability of pistachio paste

In 1994, Barnes reported that decreasing particle size improves the dispersion of solid phase in oil phase and subsequently increases the cohesiveness of the final pistachio paste product and finally resulted in a more stable colloid. On the other hand, no significant difference (p >0.05) in colloidal stability was observed when the grinding gap size was above 20 µm (40, 60 and 80 µm), due to the narrow range of size among the paste particles. In 1987, Matsunobu *et al.* claimed that the instability of almond paste was observed only when the particle size was larger than 105 µm. The findings obtained in this study clearly indicated that the pistachio paste particle size influenced the colloid stability.

4.6 Particle size effect on the pistachio paste color

In 2008, The Ciftci Group reported no significant particle size effect on the color of sesame paste. However, the presence of pigments such as green pigments and chlorophyll can influence the color of pistachio paste. The paste color can also be influenced by the roasting process [15]. However, in this study, the roasting conditions of all samples were the same, and no significant difference (p < 0.05) in the color of samples was observed.

5. Conclusions

Response surface methodology can use to establish the optimum roasting parameters for both whole and ground kernels. Changes in color and hardness characteristics of pistachio kernels were successfully accomplished by the quadratic and interaction models, respectively. The hardness, L, b, and YI values of the whole kernels and also 'a' value of the pistachio powder could be used as index in controlling the roasting process of pistachio kernels. Successful optimization of the pistachio roasting parameters can be established by using the RSM desirability functions. Based on these results, it can be deduced that, for pistachio paste production, the recommended ranges of roasting parameters for pistachio kernel are at 130-140°C (30-40 min). The grinding gap size influenced the pistachio paste colloidal stability. The colloidal stability of pistachio paste was increased by particle size reductions as verified by the rheological data. The recommended mill gap size for the pistachio paste production was 20 µm.

Conflicts of interest

The authors declare no conflicts of interest.

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