Journal of Nuts 11(1) (2020) 23-36

Journal of Nuts
Journal homepage: ijnrs.damghaniau.ac.ir

Effect of Infrared Roasting Process on the Microorganism Contaminations of Long and Round Iranian Pistachio Kernels

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A R T I C L E I N F O

Keywords:

Aflatoxin;
Infrared;
Microbial contamination;
Pistachio kernel;
Roasting

A B S T R A C T

In this paper, the effect of infrared (IR) roasting conditions on Aflatoxins and total counts of two types of Iranian pistachio kernels, long and round, was studied. The optimized roasting conditions, 70 V for round pistachios and 90 V for long pistachios with 10 cm distance from IR source were used. Naturally Aflatoxin-contaminated kernels were supplied and roasted. Microbiological and Aflatoxins tests were done before and after roasting, and the results were analyzed by t-test at 5% confidence level. It was shown that 64.00% of total Aflatoxins and 63.99% of Aflatoxin B_1 were reduced in long roasted pistachio nut kernels after IR-roasting. However, the reduction levels were 71.40% and 64.94% for total Aflatoxins and Aflatoxin B_1 in round pistachio kernels, respectively. Total counts reduction was 99.99% in the round and 99.97% in the long pistachio kernels. In addition, mold and yeast numbers were reduced 99.99% in the round and 99.97% in the long pistachio kernels. Considering mild conditions (90°C and 11.5 min) in IR-roasting process, considerable amounts of reduction in bacteria, mold, and yeast, and the most important reduction of Aflatoxins. This research has shown that IR-roasting process can be considered as an effective method for pistachio nut roasting in Aflatoxin contamination reduction.

Introduction

Economically, pistachio is the most important horticultural product in Iran (Norozi *et al*., 2019). More than 70 pistachio cultivars are grown in Iran, the most numbers in the world (www.pri.ir, 2018). Iran is the second pistachio producer in the world, after United State of America, with 315151 metric tons of pistachio nuts in 2016 (FAO, 2017). Roasting of pistachio is a routine process for nut industries as pistachio. Roasting has good advantages for improving the pistachio taste, texture, and aroma and reducing the microbial contamination. So this process has shown good benefits for enzymes and microorganisms distractions (Ozdemir, 2001; Hojjati *et al*., 2013). Roasted pistachios are more acceptable than raw ones. After hot air roasting process, a number of bacteria such as *Salmonella* and *Enterococcus faseum* decrease at least three logarithmic cycles, and that number is 30% for *Aspergillus niger*, which is the most dominant mold flora in nuts (Smith *et al*., 2014).

Aspergillus species and their toxins (Aflatoxins) are a critical problem in the pistachio industry (Mojtahedi *et al*., 1978; Thomson *et al*., 1978; Emami *et al*., 1977; Mahbobinejhad *et al*., 2019). Aflatoxins are secondary metabolites of *Aspergillus flavous* and *parasiticus*

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Received: 23 May 2019; Received in revised form: 21 January 2020; Accepted: 27 April 2020
DOI: 10.22034/jon.2020.1869504.1057

molds. They are produced in orchards before pistachio nuts being harvested. Aflatoxin contaminates pistachio nut kernels especially in "early split" ones (Mojtahedi *et al*., 1979; Doster & Michailides, 1995; Emami *et al*., 1977; Thomson and Mehdy, 1978). Different processes such as sorting pistachio nuts and considering some of the physical treatments such as separation of stain shell, deformed shape, and small-sized pistachio nuts cause separation of 90% of early split pistachios, so Aflatoxin would be reduced (Doster and Michailides, 1995 and Sommer *et al*. 1986). By the way, doing these processes, and separating all contaminated pistachio nuts seems to be impossible (Doster & Michailides; Schatzki & Pan, 1997, De Mello *et al*., 2009).

Some researchers have studied heat treatment effects on mycotoxin degradation (Mendez-Albores, *et al*., 2008; Scudamore & Patel, 2008; Yazdanpanah *et al*., 2005; Rastegar *et al*., 2016). Heat combination with moisture and possible food additives may show a synergy effect (Mendez-Albores *et al*., 2013). Unusual processing is also studied by different researchers. For example, Usage of ozone in the washing stage of drying pistachio process, or UV radiation of dried pistachio nut kernels. Washing with ozonized water shows 12.5-47.9% reduction of Aflatoxin in shelled pistachio nuts, depending on the ozone concentration (Bashiri *et al*., 2013). Effect of UV radiation on different concentrations of Aflatoxin B1 in pistachio nut has been also studied (Mazaheri, 2012). Reduction of Aflatoxin was observed in pistachio depending on the radiation time used. The roasting process reduced this contamination in coffee beans to approximately 42.2-55.9%, depending on the type and temperature of roasting (Soliman, 2002). Roasting process decreased Aflatoxin contamination of cocoa beans up to 71% as well (Mendez–Albores, 2013). Different processing methods of almonds and their effects on Aflatoxin contamination have also been investigated (Zivoli *et al*., 2014). The results showed that blanching and peeling did not reduce total Aflatoxin, but roasting of peeled almonds decreased this contamination up to 50%, while up to 70% of Aflatoxin was lost during preparation and cooking of almond nougat in caramelized sugar. Other researchers believe that peanut roasting by oil and hot air methods can reduce Aflatoxin in the final product (Lee *et al*., 1969), and hot air roasting is an effective process that can significantly decrease Aflatoxin contamination (Afolabi *et al*., 2014).

Roasting is a routine process in pistachio and other nut industry. The majority of the world's pistachio is consumed as the roasted pistachio (Hojjati *et al*., 2013). Hot air pistachio roasting cannot decrease Aflatoxin contamination in pistachio nuts (Yazdanpanah *et al*., 2005). However putting pistachio nut kernels in salted water treated with lemon juice or citric acid and then roasting in $120^{O}C$ for 1 hour resulted in significant Aflatoxin degradation (Rastegar *et al*., 2016).

Infrared heating was first used in industry in 1930. Infrared waves can increase food matrix temperature rapidly while consuming less energy and reducing waste. Electromagnetic waves of IR are attracted by almost all of the mineral or organic material covalent bonds ((Nimol *et al*., 2005). Reflection, absorbance, and transmission are three major results of IR wave's incidence with food, depending on moisture content, thickness, and physicochemical properties (Nicolay *et al*., 2007; Atangulu & Pen, 2011).

Infrared process has used on food drying (Krishnamurthy *et al*., 2008). Drying process with IR produces higher quality products while consuming less energy intake in a shorter time compared to that of hot air drying (June *et al*., 2011). Roasting nuts with infrared not only decreases process time but also improves nut kernels' taste and texture (Uysel *et al*., 2009; Yong *et al*., 2013). Although using different new sources of energy such as infrared, ultrasound, and microwave have been studied for drying process by different researchers, pistachio roasting process based on new methods has not been studied completely.

Optimization of infrared roasting of commercial Iranian pistachio kernels was studied. Based on infrared lamp voltage and sample distance to lamps, process optimization was done and different Iranian pistachio kernels cultivars were different in IR- roasting optimum conditions (Morshedi *et al*., 2018). The optimum conditions of IR-lamp voltage and sample distance to IR- lamp determined for Iranian pistachio kernels were: 81 V& 0.05 m for ‘Fandoghi’, 66 V & 0.07 m for ‘Ahmad Aghaei’, 91 V & 0.05 m for ‘Kale Ghouchi’, and 94 V and 0.05 m for ‘Akbari’ respectively. In that study, the process effects on sensory qualities, oil quality factors, microbiological and toxicological features, oil and texture changes during storage time and process modeling were investigated. In this paper, the effect of the infrared roasting process of pistachio is noticed on Aflatoxins and microorganisms contaminations for the first time.

Materials and Methods

Materials

The most important commercial Iranian pistachio cultivars, 'Akbari', 'Ahmad Aghaei', 'Fandoghi', and 'Kale Ghouchi', were chosen. Naturally Aflatoxin-contaminated pistachio nut kernels were purchased from a pistachio trading company in Kerman province, Iran. For each bulk of pistachio, inferior pistachios were separated from the others by hand sorting. Inferior pistachios contains; very small, bad shaped, yellow colored, and pistachios that green hull is attached tightly to their bony skin in some which cannot be separated. In the last one pistachios, there is more than 99% of early split pistachios (Pearson & Schatzki, 1998). According to researches done by Pearson and Schatzki, more than 99% of Aflatoxin contaminations is related to these inferior pistachios. After separation of inferior pistachios from each cultivar, Aflatoxin test was carried out 5 times on raw pistachios to get sure about its contamination. Positive samples which had shown Aflatoxin contamination, were chosen as naturally contaminated samples and roasted considering infra-red roasting optimum points (Morshedi 2018; Razavi *et al*., 2018).

Aflatoxin standards (B1, B2, G1, and G2) were prepared from Sigma (MO, USA). Methanol, acetonitrile, water, sodium chloride, potassium bromide, nitric acid, potassium chloride, potassium phosphate, and sodium phosphate, were prepared from Merck Company (Merck, Darmstadt, Germany).

Sample preparation

Pistachio samples were cleaned manually and their shells were removed carefully by hand using plastic gloves and mask and considering hygiene practices. Clean pistachio kernels were refrigerated at 4°C until roasting. Before roasting, samples were put in environmental conditions in order to increase pistachio nut kernels temperature.

Roasting treatment

At first, 10% concentrated saline water was prepared. Then each kilogram of contaminated pistachio nut kernels was soaked in 5 liters saline water and stirred slowly (Goktas & Seyhan, 2003). After that, samples were rinsed and dried for 10 minutes with a clean towel to remove extra surface saline water (Mohammadi Moghaddam, 2014).

Before roasting, sample moisture content was determined by an oven (MEMMERT, UNB 400, Germany). Roasting was carried out using an IR-roaster (Iranian patent No. 87260). The kernels were roasted monolayer in the optimum conditions obtained for each cultivar (Morshedi *et al*., 2018). The samples were put on an electronic balance and their weight was monitored by a PC during the roasting process. Roasting was continued until 2% of the sample's moisture content achieved (Fig. 1).

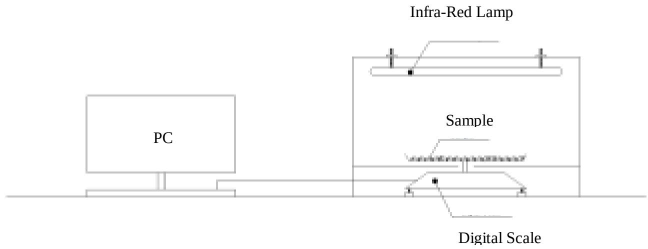

Fig. 1. IR-roasting system schematic.

Physical properties measurements

For classification of the selected cultivars, physical properties such as principal dimensions (length, width, and thickness), surface area, shape factor and sphericity were determined as follows.

Axial dimensions and surface area

The cultivars principle dimensions were estimated by the image processing method (Mohammadi Moghaddam, 2014). At first, to capture kernels images, 50 pistachio kernels in each cultivar were chosen and scanned (HP Scanner Scan jet, G3110, China) on dark background. The images were processed by Image J. software (Version 1.38, USA). Then, during scanning, to choose a scale, one strip meter was put besides kernels and each cm of this strip meter was chosen and considered as software data scale. After that, kernel images were isolated from the background and their noises were deleted. The length was defined as the largest dimension of the object's greatest area. The thickness was the smallest dimension of the object's area. Width diameter was the largest dimension of the smallest area or smallest dimension of the greatest area (Mohsenin, 1970). In addition, surface area of each pistachio kernel was estimated by image processing according to the method described by Mohammadi Moghaddam (2014). The principal dimensions and surface area were determined in 50 replications.

Shape Factor

Shape factor was calculated by the following relationship (Oscan & Kionso, 2005):

$$SF = 2L / (W + T) \qquad (1)$$

Where, L is length, W is width, and T is thickness. If SF equals 1, the shape is a sphere (round kernels), otherwise, it will be an oval shape (long kernels) (Ozkan& Koyuncu, 2005; Mohammadi Moghaddam, 2014).

Sphericity

Principal dimensions were used to calculate sphericity (Φ) by the following equation (Mohsenin, 1970):

$$\Phi = (L.W.T)^{0.33} / L \qquad (2)$$

Microbiological assays

Microbiological experiments for each cultivar were carried in two parts on both raw and roasted pistachio kernels and in 5 repetitions. Aerobic Plate Count (APC) is intended to indicate the number of microorganisms in products. The APC method has been developed by AOAC (Association of Official Chemists) and APHA (American Public Health Association). Peptone water was used as dilution liquid. At first, pistachio kernels were ground thoroughly and then 10g of each sample was added to 100ml of sterile peptone water. Providing different dilutions of 10^{-2}, 10^{-3}, and 10^{-4}, each dilution was prepared by adding 10ml of the previous dilution to

90ml of diluent. Plate count agar was used as a culture. After culture, plates incubated in 35°C for 48h. Normal plates (contained 25-250 colonies) were counted and considering dilution (s), the total number of colonies was calculated.

Mold and yeasts counts were done according to FDA method (2001). 25-50g from each sample was considered. The sample was diluted by peptone water and different dilutions were prepared. The pour-plate method was used for culture preparation by Yeast Extract Agar. Petri dishes incubated in dark incubators at 25°C for 5 days. Standard plates (contained 10-150 colonies) were counted and counts of molds and yeasts were calculated by considering dilution ratios.

***Aflatoxin* test**

To carry out Aflatoxin measurement, samples from different pistachio kernels were prepared. Pistachio kernels of each cultivar were mixed thoroughly, then divided into 10 parts with the same weight. Each part was divided into 5 parts again and finally, 5 parts were chosen randomly. These 5 parts were mixed and ground completely. Each cultivar samples was added to water (5:7.5), then a slurry produced by a mixer for 15min. 125g of the slurry was taken as a test sample. Aflatoxin standards solution (B1, B2, G1, and G2) were prepared and determination of their concentration was done by UV-Visible Spectrophotometer (Varian, Cary100, USA), considering AOAC Official method No. 971.22 (AOAC, 2006, Chap. 49.2.03). Then mixed standards were prepared to HPLC analysis. Working standards were prepared by diluting mixed standards with water and methanol. Liquid chromatography analysis was performed using a reverse-phase HPLC (Dionex, Sunnyvale, California LP, USA), equipped by vacuum degasser (ultimate 3000, Dionex, Sunnyvale, California, LP. USA), temperature controller oven (Ultimate-3000, Dionex, Sunnyvale, California LP, USA), Fluorescence detector (RF 2000; Dionex, Sunnyvale, California, LP. USA), and workstation (GX-271 Aspec Gilson, USA). The LC column was C18-15 cm 4.6 mm ID, 5 µm particles (Waters, Milford/MA) and Aflatest immunoaffinity columns (IAC) were prepared from Vicam (MA, USA). Reversed-Phase LC, using post column bromination with Kobracell (Coring system, Gernsheim, Germany) was performed. The isocratic mobile phase was a solution of deionized water: acetonitrile: methanol, 60:20:30 (V: V: V). 1 ml/minutes flow rate with fluorescence detection at 365 nm excitation wavelength and 435 emission wavelength were used. The column temperature was 36°C. Retention times for AFB1, AFB2, AFG1, and AFG2 was respectively 7.894 – 11.080, 6.634- 9.021, 5.875- 7.675 and 4.940- 6.340 min. Each analysis was done in 5 replications.

Statistical analysis

To do statistical analysis, t-test analysis was carried out. Raw and roasted pistachio kernels in each cultivar were compared for every property in 5% probability level. Data regression was done with Mini-Tab software (Version 16, USA).

Results

Principle dimensions

Principle dimensions of raw and roasted pistachio kernels are mentioned in Tables 1-3. IR- roasting had no significant effect on length, width, and thickness of pistachio kernels ($p > 0.05$). The greatest length, in both raw and roasted samples, was observed in the order of 'Akbari','Kale Ghouchi', 'Ahmad Aghaei', and 'Fandoghi', respectively (Table 1). 'Fandoghi', 'Kale Ghouchi', 'Ahmad Aghaei', and 'Akbari' were shown the most length reduction during IR roasting, respectively. The greatest width was seen in 'Kale Ghouchi', 'Akbari', 'Fandoghi' and 'Ahmad Aghaei', respectively. Although IR-roasting caused decreasing in width, it was not significant (p>0.05) (Table 2). Kernels of 'Akbari', 'Kale Ghouchi', 'Fandoghi', and 'Ahmad Aghaei' had the most reduction in width, respectively. In addition, IR-roasting didn't changed thickness of kernels significantly (p>0.05) (Table 3), however the changes was highest in 'Kale Ghouchi', and lowest in 'Ahmad Aghaei'.

Table 1. Effect of IR-roasting process at optimum conditions on the length of four Iranian pistachio kernels.

Cultivar	Treatment	Mean (mm)	Std. Dev.	t-value	H_0 hypothesis (μ_1=μ_2)
‘Ahmad Aghaei’	Raw	16.89	0.01	0.32	Accept
	Roasted	16.85	0.08		
‘Fandoghi’	Raw	16.69	0.01	0.12	Accept
	Roasted	16.60	0.14		
‘Akbari’	Raw	19.41	0.04	0.02	Accept
	Roasted	19.37	0.01		
‘Kale Ghouchi’	Raw	19.23	0.07	0.42	Accept
	Roasted	19.16	0.11		

The data are average of 50 replications

Table 2. Effect of IR-roasting process at optimum conditions on the width of four Iranian pistachio kernels.

Cultivar	Treatment	Mean (mm)	Std. Dev.	t-value	H_0 hypothesis (μ_1=μ_2)
‘Ahmad Aghaei’	Raw	11.79	0.07	0.22	Accept
	Roasted	11.65	0.05		
‘Fandoghi’	Raw	12.69	0.01	0.13	Accept
	Roasted	12.46	0.04		
‘Akbari’	Raw	12.62	0.02	0.31	Accept
	Roasted	12.27	0.01		
‘Kale Ghouchi’	Raw	12.89	0.06	0.51	Accept
	Roasted	12.66	0.10		

The data are average of 50 replications.

Table 3. Effect of IR-roasting process at optimum conditions on the thickness of four Iranian pistachio kernels.

Cultivar	Treatment	Mean (mm)	Std. Dev.	t-value	H_0 hypothesis (μ_1=μ_2)
‘Ahmad Aghaei’	Raw	0.99	0.01	0.25	Accept
	Roasted	0.98	0.03		
‘Fandoghi’	Raw	1.19	0.01	0.19	Accept
	Roasted	0.99	0.10		
‘Akbari’	Raw	1.42	0.013	0.37	Accept
	Roasted	1.21	0.031		
‘Kale Ghouchi’	Raw	1.81	0.007	0.41	Accept
	Roasted	1.54	0.11		

The data are average of 50 replications.

Surface area

IR-roasting of four Iranian pistachio kernels had no significant effect on their surface area (p>0.05) (Table 4). Surface area calculation before and after IR-roasting showed the biggest surface area belonged to ‘Kale Ghouchi’, ‘Akbari’, ‘Fandoghi’ and 'Ahmad Aghaei' cultivars, respectively. Considering kernels' length and width, it seems logical completely. The most surface area changes due to IR-roasting were observed in the kernels of ‘Kale Ghouchi’, ‘Akbari’, ‘Fandoghi’ and 'Ahmad Aghaei', respectively. The surface are changes were as same as principle dimension changes.

Table 4. Effect of IR-roasting process at optimum conditions on the surface area of four Iranian pistachio kernels.

Cultivar	Treatment	Mean (mm^2)	Std. Dev.	t-value	H_0 hypothesis ($\mu_1=\mu_2$)
‘Ahmad Aghaei’	Raw	354.05	0.61	0.14	Accept
	Roasted	352.01	0.53		
‘Fandoghi’	Raw	359.15	0.11	0.45	Accept
	Roasted	353.06	0.23		
‘Akbari’	Raw	408.01	0.50	0.17	Accept
	Roasted	406.65	0.39		
‘Kale Ghouchi’	Raw	436.26	0.51	0.43	Accept
	Roasted	433.70	0.18		

The data are average of 50 replications.

Shape factor

Shape factors of the selected pistachio kernels are shown in Table 5. The results showed that IR-roasting at the optimum conditions had no significant effect on pistachio shape factors ($p>0.05$). The maximum and minimum values of shape factor belonged to 'Ahmad Aghaei' and 'Kale Ghouchi', respectively. The shape factors in all studied cultivars were oval, which were similar to those reported by Kashani Nejad *et al*., (2006); Razavi *et al*., (2007 I) and Mohammadi Moghaddam, 2014). The shape factors showed these 4 cultivars can be divided into two shapes pistachio kernels: long and round. Long pistachios are ‘Ahmad Aghaei’ and ‘Akbari’ and round ones are ‘Kale Ghouchi’ and ‘Fandoghi’.

Table 5. Effect of IR-roasting process at optimum conditions on the shape factor of four Iranian pistachio kernels.

Cultivar	Treatment	Shape factor	Std. Dev.	t-value	H_0 hypothesis ($\mu_1=\mu_2$)
‘Ahmad Aghaei’	Raw	1.46	0.10	0.4	Accept
	Roasted	1.44	0.30		
‘Fandoghi’	Raw	1.23	0.10	0.15	Accept
	Roasted	1.25	0.20		
‘Akbari’	Raw	1.41	0.10	0.18	Accept
	Roasted	1.35	0.20		
‘Kale Ghouchi’	Raw	1.34	0.11	0.3	Accept
	Roasted	1.33	0.30		

The data are average of 50 replications

Sphericity

The sphericity of selected cultivars is mentioned in Table 6. IR-roasting didn't change the sphericity factor of pistachio kernels significantly ($p>0.05$). According to the Table 5, sphericity values in 'Fandoghi' and 'Kale Ghouchi' kernels were more than 80%, while in 'Akbari' and 'Ahmad Aghaei' kernels were less than 70%.

Table 6. Effect of IR-roasting process at optimum conditions on the sphericity of four Iranian pistachio kernels.

Cultivar	Treatment	Sphericity %	Std. Dev.	t-value	H_0 hypothesis ($\mu_1=\mu_2$)
‘Ahmad Aghaei’	Raw	65.6	0.1	0.2	Accept
	Roasted	65.8	0.2		
‘Fandoghi’	Raw	80.6	0.1	0.3	Accept
	Roasted	80.8	0.1		
‘Akbari’	Raw	67.8	0.1	0.15	Accept
	Roasted	67.9	0.1		
‘Kale Ghouchi’	Raw	79.2	0.1	0.22	Accept
	Roasted	79.5	0.1		

The data are average of 50 replications.

Microbial contamination

The microbiological test results of long and round pistachio kernels, after and before roasting, are shown in Tables 7 and 8, respectively. It can be seen that IR roasting process can decrease microorganisms including bacteria and molds-yeasts significantly ($p \leq 0.05$) in all cultivars. The total counts of bacteria were reduced by 99.99% in ‘Ahmad Aghaei’, and 99.83% in ‘Fandoghi’, 83.61% in ‘Kale Ghouchi’, and 99.20% in ‘Akbari’. Bacteria total count reduction in long pistachio kernels was more than the round ones. The reason is not understood because there is no related research, but perhaps it depends on the pistachio kernels surface area. Long pistachio kernels have more expanded surface in comparison with round kernels (Table 4).

The counts of molds and yeasts were decreased by 99.97% in ‘Ahmad Aghaei’, 99.99% in ‘Fandoghi’, 98.81% in ‘Kale Ghouchi’, and 97.62% in ‘Akbari’ after IR-roasting process. In addition, round pistachio kernels were shown more decreasing in molds and yeasts total count than the long ones.

As there is no similar research, its reason is not clear but perhaps it can be related to the surface area difference between long and round pistachio kernels (Table 4). Molds are aerobic microorganisms and probably their total counts on the surface is more than bacteria which are both aerobic and anaerobic.

Table 7. Effect of IR-roasting process at optimum conditions on the numbers of bacteria, molds and yeasts in long pistachio kernels.

Contamination	Treatment	Mean	Std. dev.	t- Value	H_0 Hypothesis $\mu_1 = \mu_2$
Bacteria	Raw	95800	0.360	11.32	Reject
	Roasted	7.60	0.448		
Molds & yeasts	Raw	65000	0.307	18.40	Reject
	Roasted	18.01	0.374		

The data are average of 5 replications.

Table 8. Effect of IR-roasting process at optimum conditions on the numbers of bacteria, molds and yeasts in round pistachio kernels.

Contamination	Treatment	Mean	Std. dev.	t-value	H_0 Hypothesis $\mu_1 = \mu_2$
Bacteria	Raw	25000	23.16	78.91	Reject
	Roasted	42	5.83		
Mold & yeast	Raw	2260	91.74	13.99	Reject
	Roasted	28	4.35		

The data are average of 5 replications.

***Aflatoxins* contaminations**

The results of the Aflatoxin tests (total and B1) conducted before and after IR-roasting process are shown in Tables 9 & 10. It is clear that the effects of IR-roasting process on the Aflatoxins contamination reduction were significant ($p \leq 0.05$). Aflatoxin B1 reduction was observed as 64%, 71%, 64% and 90% in 'Ahmad Aghaei', 'Fandoghi', 'Kale Ghouchi', and 'Akbari' kernels, respectively. In addition, total Aflatoxins reduction was 64% in 'Ahmad Aghaei', 65% in 'Fandoghi', 63% in 'Kale Ghouchi' and 90% in 'Akbari'.

Table 9. Effect of IR-roasting process at optimum conditions on the Aflatoxins in round pistachio kernels.

Aflatoxin	Treatment	Mean (ppb)	SE	t-value	H_0 (μ_1=μ_2)
B1	Raw	115.9	5.46	5.28	Rejected
	Roasted	82.36	3.28		
Total	Raw	128.8	0.395	6.63	Rejected
	Roasted	82.36	0.792		

The data are average of 5 replications

Table 10. Effect of IR-roasting process at optimum conditions on the Aflatoxins in long pistachio kernels.

Aflatoxin	Treatment	Mean (ppb)	SE	t-value	H_0 (μ_1=μ_2)
B1	Raw	31.37	0.386	21.32	Rejected
	Roasted	12.23	0.811		
Total	Raw	31.41	0.395	21.41	Rejected
	Roasted	12.46	0.792		

The data are average of 5 replications

Discussion

During studying principal dimension of four pistachio cultivars was observed that 'Ahmad Aghaei' cultivar had the lowest changes in the principal dimensions during IR-roasting process. It is worth mentioning that 'Ahmad Aghaei' kernel has the highest oil, and the lowest protein contents compared to other cultivars (Morshedi, 2018). In addition, the most changes in the principle dimensions belonged to ‘Akbari’ cultivar, which had the highest protein content in the kernel (Razavi *et al*., 2018).

Some researchers have measured principle dimensions of different pistachio cultivars (Pearson *et al*., 1984; Kashaninejad *et al*., 2006; Razavi *et al*., 2007 I, II, III; Polat *et al.*, 2007; Nazari Galedar *et al*., 2008; Porshokouhi *et al*., 2014). Razavi *et al*., (2007) were studied different cultivars such as 'Ohadi', 'Akbari' and 'Kale Ghouchi'; but there is not any published paper about the principle dimensions of 'Ahmad Aghaei' cultivar. Mohammadi Moghaddam (2014) showed that moisture content changes in roasting process of pistachio kernels by hot air is limited (2%) and the roasting process effect on axial dimensions changes was not significant. The results of this research are consistent with the previous studies.

Mohammadi Moghaddam (2014) reported the surface area of 'Fandoghi' cultivar kernels was in range 389.90–426.87 mm^2. On the basis of the results reported by Razavi *et al*. (2007), surface area of the kernels of 'Akbari', 'Ohadi', and 'Kale Ghouchi' were in the range of 350-400, 300-370, and 400-520 mm^2, respectively. Porshokouhi *et al*., (2014) reported the value of 360 mm^2 for the surface area of 'Ahmad Aghaei' kernel. Small observed differences were probably because of the primary different sizes of pistachio kernels.

Shape factor was not changed after IR-roasting process as other researchers mentioned (Kashani Nejad *et al*., (2006); Razavi *et al*., (2007 I) and Mohammadi Moghaddam, 2014).

Sphericity data suggest dividing the kernels of the selected cultivars into long and round shapes. IR-roasting caused increasing in sphericity factor in round kernels more than long kernels. It means that IR-roasting had the most effect on length dimension, so decreasing length means increasing sphericity factor.

Sphericity factor was recorded by different researchers for some pistachio cultivars: Porshokouhi *et al*. (2014) reported the sphericity of 'Ahmad Aghaei' kernel was 76%. In addition, Razavi *et al*. (2007 I) calculated 68%, 79% and 80% for the kernels of 'Akbari', 'Kale Ghouchi', and 'Ohadi', respectively. According to Kashaninejad *et al*. (2006), the sphericity of 'Fandoghi' kernel was 80.71%.

On the basis of the kernels shape factors, It can be concluded that 64% total as well as B_1 Aflatoxin reductions occurred in long pistachio kernels, while the reductions in the round ones were 71% and 65%, respectively. Rastegar *et al*. (2016) reported that the Aflatoxins contamination can be reduced by treatment of pistachio nuts with lemon juice and acid citric soluble before hot plate roasting. Yazdanpanah *et al*. (2005) studied the effect of pistachio nut hot air roasting on Aflatoxins contamination. They found that except for the samples roasted at 180^{o}C, other temperatures had no significant effect on the reduction of Aflatoxins contamination, however the nuts roasted at 180^{o}C were not consumable.

Aflatoxins melting points is in the range of 250-270°C (Poland *et al*., 1982). Complete decomposing of Aflatoxin B_1 requires at least 237°C (Rustom, 1997), but it can be started in lower temperatures. Heat processing efficiency in Aflatoxin decomposition depends on time and temperature levels (Bullerman & Bianchini, 2007; Arzandeh & Jinap, 2011). Based on the literature, if a good combination of time and temperature is applied, Aflatoxins decomposition will occur. The fact of the conventional roasting process is that heat transfers through hot air or plate, from the out layer into the inner layer of pistachio nut kernels. But in this research, IR-process was chosen as a heat source, and IR waves penetrate directly into inner layers and heat transfers from depth to the surface of kernels. Inner layers warm sooner and better against the IR- process, so heating the kernels happens in lower temperature and time, which can destroy severely the microorganisms and toxins and keep more bioactive compounds (antioxidants) in pistachio nut kernels. In our study, more than 60% of Aflatoxin B1 was destroyed at 95°C & 8 minutes for the long kernels and 90°C & 9 minutes for the round ones by applying the IR-roasting process.

Rastegar *et al*., (2016) applied different treatments in pistachio roasting process to decrease Aflatoxin B1 and found that the best treatment was “lemon juice (15ml), citric acid (2.25g) and water (30ml) at 120°C for 60 minutes, with or without salt”. Pistachio nut roasters in Iran do not use more than 10% sour additives in brine to treat pistachio nut kernels before roasting (www.iranpistachio.org).

Conclusions

The most important commercial Iranian pistachios are ‘Ahmad Aghaei’, ‘Fandoghi’, ‘Akbari’ and ‘Kale Ghouchi’. They can be divided into two shapes including long (‘Akbari’ and ‘Ahmad Aghaei’) and round (‘Fandoghi’ and ‘Kale Ghouchi’). Roasting is an important process in the nut industry which brings about better taste, aroma, and texture in the product. In routine roasting methods such as hot air and hot plate roasting, the process temperature has to be increased to roast inner layers of nut kernels, and the used temperature will destroy valuable compounds such as antioxidants, carbohydrates, proteins, vitamins etc. IR-roasting method is different from the commercial roasting processes. In this method of roasting, because of IR penetration to the inner layers of nut texture, heat transfer occurs from inside to the outside of nut kernels, thus avoiding the necessity to increase roasting process temperature, which can be decreased to below 100^{O}C. Penetration of IR waves in the texture of pistachio kernels can reduce inner contamination and toxins more than the conventional methods. IR roasting not only does fulfill consumer's expansions from roasted pistachio but can also decrease microbial and toxic contamination considerably, besides lower destruction effect on beneficial basic compounds. It seems that treatment with citric acid and lemon juice (up to 10%), prior to IR roasting of pistachio nut kernels probably reduces more percentage of Aflatoxins in the final product. IR roasting can be considered as a good choice of roasting to control toxic contaminations and its daily intake by consumption.

Acknowledgements

Conflict of interests.

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