Wageningen Academic Publishers

Intensification of pistachio by deep frying

R. Yeganeh[1] and G. Trystram[2]

[1]Department of Farm Machinery, Faculty of Agricultural Engineering, Ilam University, P.O. Box 69315-516, Ilam, Iran; [2]UMR GENIAL, AgroParisTech, 1 avenue des Olympiades, 91744 Massy cedex, France; r.yeganeh@ilam.ac.ir

Received: 24 February 2012 / Accepted: 16 March 2012

RESEARCH PAPER

Abstract

Hot air roasting is the classical way for processing pistachio. In this study, the classical operation was compared with a frying operation that was assumed to be as efficient as classical roasting and permit flavour intensification. The final moisture content at 180 °C was 5.6% at 5 min for fried samples and at 160 °C was 6% at 11 min for roasted samples. The breaking force of pistachio kernels was found to decrease from 2,008 N for raw pistachio to 780, 860, 975 and 1,030 N and then increased from there to 930, 1,460, 1,930 and 2,130 N at 140, 160, 170 and 180 °C, respectively, during frying. The results are similar for roasting. Oil content values ranged between 47 and 48% for the raw pistachio kernels and 53, 54, 55 and 56% after 5 min of frying at 140, 160, 170 and 180 °C, respectively. The results suggest that frying is an efficient intensive and innovative processing technique.

Keywords: frying, physical properties, pistachio nuts, roasting

1. Introduction

Pistachio is grown mainly in Iran, USA, and Turkey. The pistachio nut is the second highest non-petroleum export product, which has an important role in the development of the national economic value and agro-food industry of Iran. Based on FAO statistics (2005), Iran produced about 275,000 Mt of pistachio in 2003, which was approximately 54.7% of the world's pistachio production. Iran exported 184,946 Mt of its pistachio nut production in this year and the total export revenue from pistachio was about 679,940,000 US$ in 2003 (Razavi and Taghizadeh, 2007).

The pistachio (*Pistacia vera* L.) is a nut that has peculiar organoleptic characteristics. It is widely consumed as a raw or toasted ingredient in many desserts, ice cream, cakes, pastries and for the production of some sausages (Arena *et al.*, 2007). Pistachio has kernels rich in fixed oil (50-60%) and contains fatty acids beneficial for human health (Garcia, 1992; Maskan and Karataş, 1998; Mustafa *et al.*, 2002). Hsu *et al.* (1991) studied the physical and thermal properties of the Kerman variety of pistachio nut. These authors investigated some of the moisture-dependent gravimetrical properties (bulk density and specific gravity) of this variety. Texture is the other important control parameter for pistachio roasting. One of the objectives of pistachio roasting is to alter and significantly enhance the flavour, texture, colour and appearance of the product. Roasted pistachios are widely consumed as an appetizer and snack food and as raw materials in sweets, confectionery, chocolate and biscuits. During pistachio roasting, the time-temperature relationship strongly affects the resulting texture, as well as other quality factors. Force-deformation curves have been widely used to measure textural changes in food products (Demir and Cronin, 2005). In the literature, the fracture points on force deformation curves have been named as maximum force, peak force or first peak of break (Saklar *et al.*, 1999).

Owing to the seasonal nature of pistachio harvesting, a large quantity of it is stored during the months following the harvest. During the storage period, if the atmospheric moisture conditions in the storage room are not rigorously maintained, the hygroscopic characteristics of pistachios promote a considerable change in their moisture content. If the moisture content increases, the risk of the appearance of fungi is greater (Yazdani *et al.*, 2006). Pistachio is in the risky food group with respect to aflatoxin contamination that can be eliminated by the correct use of an efficient frying process. The most effective preventative control is to dry pistachio nuts to a water activity of 0.82 for short-term or 0.70 for long-term storage to prevent mould growth and aflatoxin contamination (FAO, 2001). Even if there is progress in terms of understanding different ways of preventing aflatoxin (Yeganeh, 2009), it is important to propose efficient processing methods which are easy to implement, rapid and able to stabilise the nuts quickly without loss of the main quality attributes. The intensification of the roasting operation is therefore an important task.

During frying processes, heat and moisture move within and around the food, and those transport phenomena result in physical and chemical changes to the product (Baik and Mittal, 2005). Factors that affect heat and mass transfer are the thermal and physicochemical properties of the food, oil and their interaction, the geometry of the food and the temperature of the oil (Krokida *et al.*, 2000). The effect of oil temperature on the fat uptake and properties of deep-fried products has been widely reported (Dobarganes *et al.*, 2000; Gamble *et al.*, 1987; Mellema, 2003; Moreira *et al.*, 1997; Saguy and Dana, 2003). A wide spectrum of factors has been reported to affect the oil absorption and structure of fried products. These include oil quality and composition, frying temperature and time, product composition, moisture content and the initial physicochemical characteristics of the materials (Moreira *et al.*, 1997).

Frying is certainly one of the main interesting operations for optimisation when moisture appears to be the key to the process. The mechanisms of water removal are totally different from those during hot air processing; generally it takes less time under frying conditions.

Texture is one of the important control parameters for pistachio frying. Textural properties of fried products are usually determined after removal from the fryer, when unsteady conditions of moisture content and temperature exist inside the product (Aguilar *et al.*, 1997; Du Pont *et al.*, 1992; Rubnov and Saguy, 1997). During pistachio frying, the time-temperature relationship affects the resulting texture, as well as other quality factors. Force deformation curves have been widely used to measure textural changes in food products (Mustafa *et al.*, 1998). In the literature, the fracture points on force deformation curves have been named as maximum force, peak force or first peak of break (Saklar *et al.*, 1999).

The water activity of food describes the energy state of water in the food, and hence, its potential to act as a solvent and participate in chemical/biochemical reactions and growth of microorganisms (Aktas and Polat, 2007). It is an important property that is used to predict the stability and safety of food with respect to microbial growth, rates of deteriorative reactions and chemical/physical properties (Anthony and Fontana, 2000).

As far as we know, there is no literature reporting the frying of pistachio nuts, and in order to compare classical hot air roasting and the frying of pistachio nuts, an experimental study was proposed. The study focused on moisture removal, water activity and the texture resulting from roasting and frying.

2. Materials and methods

Pistachio

For the present study samples of 'Akbari' pistachio (*P. vera* L.) nut were used. Samples were supplied by the Pistachio Research Institute (2008 harvest season, Rafsanjan, Iran). They were manually cleaned to remove foreign matter and broken or immature nuts. The nuts were cracked and the kernel separated from the shell by hand. The nuts were kept at 4 °C in a refrigerator until analysed. All experiments were run as triplicates and Table 1 presents the physical characterisation of raw pistachio before processing.

Experimental set-up

Hot air roasting equipment

The pistachios were roasted in a pilot spouted bed roaster (Yeganeh, 2009). The roaster has a cell of roasting, which is made of Pyrex and is equipped with a metal grid in its lower part to hold the nuts. Hot air is introduced to the cell at a speed of 7.45 m/s, measured by an electronic anemometer (AM4205, Lutron company, Taipei, Taiwan). The temperature of the inlet air was measured by a thermocouple type K (1 mm diameter, Hoskins Manufacturing Company, Hoskins, NE, USA) placed at the entrance of the cell. Its control was carried out by a set point PI controller (temperature controller PID Rex-D-100®, RKC Instrument, Tokyo, Japan). Pistachio nuts were manually placed in the chamber before roasting. Roasting temperatures between 110 °C and 160 °C were investigated.

Table 1. Physical characteristics of raw pistachio kernels.

Characteristics	Values
Moisture content (% dry basis)	49.42-50.48
Moisture content (% wet basis)	32.55-33.95
Apparent density (g/cm^3)	0.912-0.924
Absolute density (g/cm^3)	1.087-1.095
Porosity	0.150-0.167
Water activity	0.97-0.98
Maximum force (N)	1,850-2,040

Frying

A commercial deep fat fryer (SEB, Écully, France) with temperature control of ±1 °C was used. The fryer was filled with 4 litres of sunflower oil. Samples were placed in a wire basket, to ensure good contact between the pistachio and the oil. To minimise variations in oil properties (especially viscosity) due to degradation, the oil was changed after 6 h frying. Frying temperature was set at 140, 160, 170 and 180 °C. The pistachios were fried for 2, 2.5, 3, 3.5, 4, 4.5 and 5 min. Time was recorded using a stopwatch with an accuracy of 0.1 s.

Measurements

Nut temperature

The temperature changes during frying and hot air roasting were monitored by inserting a thermocouple close to the centre of the nut. Figure 1 depicts, for frying, the data acquisition and processing method using a computer equipped with a temperature acquisition system (thermocouple conditioner, Pico Technology, St Neots, UK) and PicoLog recorder software (Pico Technology). Real-time data processing was carried out. The nuts were immersed in oil with several thermocouples (type K) that allowed the measurement of the internal temperatures of the nuts and the oil temperature with a precision of ±1 °C. The thermocouples were inserted through holes in the sample holder into the central part of the pistachio at 10 mm below the surface and at the product centre.

Moisture content

After sampling at a given time, pistachio kernels were mixed, ground and weighed separately using an electronic balance reading to an accuracy of 0.001 g (Sartorius AG, Göttingen, Germany). The initial moisture content of pistachio kernels was determined by oven drying at 105±1 °C for 24 h until the differences between two weighings was minimal (±0.05 g), followed by cooling in a desiccator before final weighing (AOAC, 1984). The quantity of evaporated water was calculated and moisture content was expressed as dry basis (d.b.). The moisture content (W) was calculated using:

$$W = \frac{M_1 - M_2}{M_2 - M_0} \times 100 \quad (1)$$

Where M_0 is the mass of the dish, M_1 is the mass of the dish and the pistachio before drying and M_2 is the mass of the dish and the pistachio after drying. The masses are expressed in grams.

Water activity

Water activity was determined using a water activity meter (FA-st lab, GBX, France Scientific Instrument, Romans-sur-Isère, France). The pistachio kernels were mixed, ground and emptied into special aluminium containers. After that, the samples were placed in the water activity meter.

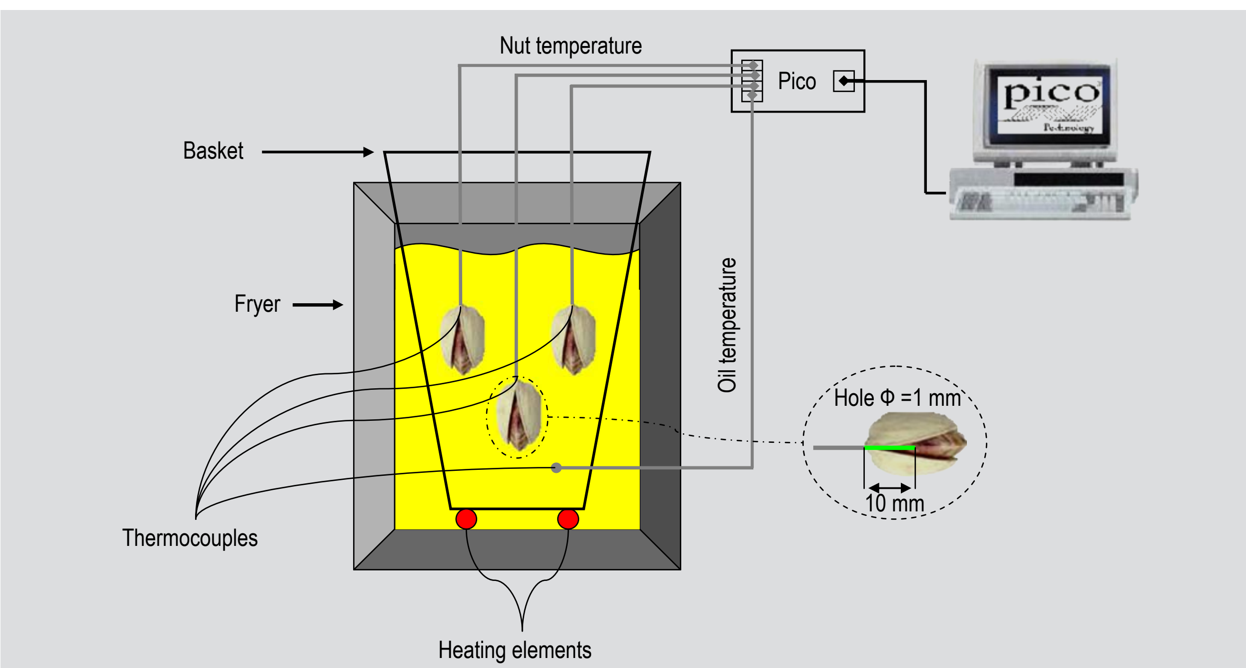

Figure 1. Scheme of experimental set-up used to determine the internal temperatures of pistachio nuts.

Apparent porosity

The porosity was calculated from density measurements. Apparent porosity (ε) is defined as the volume fraction of air in the sample. It can be calculated using:

$$\varepsilon = 1 - \frac{\rho_{ap}}{\rho_{ab}} \tag{2}$$

Where ρ_{ab} is the absolute density and ρ_{ap} is the apparent density.

Texture

The texture of the raw, roasted and fried pistachio kernels was measured using an Instron Universal Testing Machine, model 1122 (Instron, Canton, MA, USA) equipped with a 5,000 N load cell and crosshead speed of 20 mm/min. The internal dimensions of the test cell were 64 × 73 × 66 mm and the working temperature was 20±1 °C. Measurements were performed of at least 25-27 randomly chosen pistachio kernels, which were positioned individually between two parallel plates of the dynamometer on their longest side and with the flat side up (Pittia *et al.*, 2007).

Oil content

For samples obtained after frying, the surface oil was washed off using petroleum ether immediately after frying. The oil content of the fried samples was determined by extracting with n-hexane (Merck KGaA, Darmstadt, Germany) using a Soxhlet (Merck KGaA, Darmstadt, Germany) extraction method for 6 h (AOAC, 1984).

Method

A set of experiments was conducted for different air or oil temperature in the range of 110 to 160 °C and 140 to 180 °C, respectively, for air and frying roasting conditions. Temperature and weight were recorded online and samples were taken for analytical characterisation. Replications of experiments were from 2 to 5 times depending on the considered variable and experiment. In relation to the curves, the fitting of a simple model was proposed and interpolation was permitted to obtain a set of data. All of the results are presented as mean values (average of all the measurements considering replications). Experimental data were determined using Microsoft Excel 2007.

In order to compare the two operations, a criterion of moisture content of 6% was chosen from the literature and as a conservation criterion.

3. Results

In the case of hot air roasting, all the results are presented in Table 2. Some of these results are discussed for the comparison between hot air roasting and frying conditions.

Moisture content

A comparison of both operations for moisture content evolution is presented in Figure 2. The samples were subjected to roasting at specified temperatures. The relationship between the moisture content and frying time for pistachio kernels at all temperatures is offered as the function of time in Figure 2A, exhibiting a non-linear decrease in moisture content with frying time. The final moisture content at 180 °C was 5.6% at 5 min, which was lower than the samples fried at 140, 160 and 170 °C for the same time (18, 10.8 and 7.3%).

The relationship between the moisture content for pistachio kernels, exhibits a non-linear decrease in moisture content with roasting time, for hot air roasting (Figure 2B). Initially, moisture decreased rapidly and then the decrease in moisture slowed down considerably as expected. The roasting time required to achieve the final moisture content varies with the roasting temperature. The experimental data regarding pistachio nut moisture variations during roasting from 110-160 °C showed that the time needed to reach around 15% moisture content was about 30 min for pistachio roasted at 110 °C and about 7 min for pistachio roasted at 160 °C. The times and temperatures required to bring the moisture content below 6% (d.b.) were 23, 18, 14 and 11 min for 130, 140, 150 and 160 °C, respectively. It was observed that the drying rate was greater at a higher temperature, as expected. But at a few points there were unexpected interactions of the curves and this was probably due to experimental variations. These variations do not appear to be sensitive enough to be significant.

Water activity

The sorption curves (Figures 3A and 3B) obtained during the two operations are quite similar. During frying, the duration was too short to cover the same range of water activity (because the operation was stopped when a moisture content of 0.6% was obtained).

Nut temperature

During pistachio roasting, in the two studied situations, temperature was recorded online. Figure 4 compares the evolution of the internal nut temperature during frying (Figure 4A) and hot air roasting (Figure 4B). Figure 4A shows an initial nut temperature increase at all oil temperatures during the first 60 sec of frying. It could be seen from the curves that in some cases the temperature

Table 2. Physical characteristics of roasted pistachio kernels depending on the temperature during hot air roasting.

Temperature (°C)	Time (min)	Moisture (% d.b.)	Apparent density (g/cm^3)	Absolute density (g/cm^3)	Porosity	Water activity	Maximum force (N)
110	5	34.53	0.913	1.136	0.197	0.94	1,495
	10	27.47	0.910	1.120	0.187	0.91	1,350
	15	24.56	0.883	1.114	0.207	0.86	1,465
	20	19.09	0.877	1.105	0.206	0.83	1,690
	25	15.33	0.836	1.098	0.239	0.75	1,760
	30	15.27	0.830	1.092	0.240	0.64	1,945
120	5	35.18	0.915	1.129	0.190	0.92	1,420
	10	26.96	0.904	1.121	0.193	0.88	1,250
	15	22.12	0.878	1.105	0.206	0.78	1,455
	20	13.31	0.867	1.100	0.212	0.63	1,785
	25	11.34	0.825	1.095	0.247	0.61	2,187.5
	30	10.66	0.810	1.095	0.260	0.60	2,382.5
130	5	29.99	0.872	1.118	0.222	0.88	1,085
	10	20.05	0.861	1.118	0.215	0.74	1,442.5
	15	13.43	0.842	1.097	0.225	0.54	1,910
	20	8.19	0.819	1.093	0.227	0.44	2,525
	25	5.13	0.795	1.082	0.273	0.38	2,777.5
	30	3.24	0.778	1.070	0.267	0.35	3,075
140	5	31.98	0.865	1.130	0.234	0.90	1,240
	10	17.28	0.804	1.116	0.273	0.78	1,650
	15	11.09	0.791	1.070	0.270	0.49	2,287.5
	20	4.50	0.783	1.058	0.260	0.37	3,010
	25	2.94	0.756	1.044	0.284	0.28	3,130
	30	1.35	0.752	1.034	0.270	0.19	3,190
150	5	28.86	0.827	1.131	0.269	0.89	1,105
	10	12.44	0.791	1.104	0.292	0.66	2,030
	15	5.15	0.760	1.060	0.286	0.35	2,785
	20	1.89	0.753	1.037	0.274	0.26	3,145
	25	1.32	0.727	1.032	0.296	0.20	3,132.5
	30	0.46	0.727	1.026	0.288	0.16	3,057.5
160	5	23.01	0.793	1.122	0.293	0.73	1,355
	10	8.65	0.761	1.094	0.314	0.41	2,355
	15	2.12	0.737	1.085	0.330	0.29	3,237.5
	20	0.82	0.725	1.050	0.309	0.18	3,267.5
	25	0.51	0.718	1.049	0.308	0.17	3,187.5
	30	0.33	0.711	1.039	0.317	0.14	3,312.5

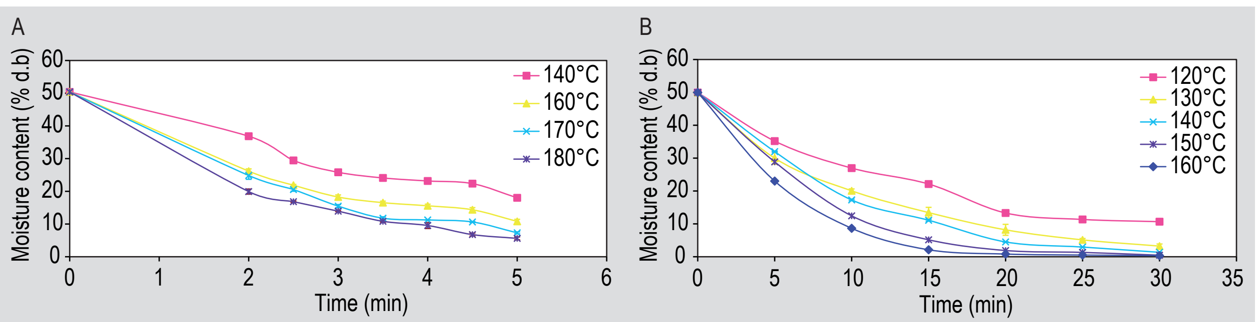

Figure 2. Comparison of experimental data for moisture content (% dry basis; d.b.) of pistachio at different temperatures as a function of time during (A) frying and (B) hot air roasting.

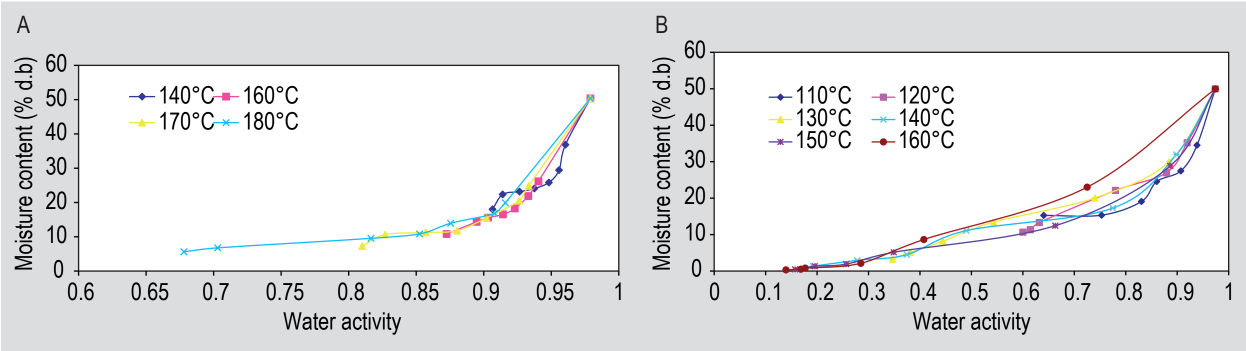

Figure 3. Water activity as a function of moisture content (% dry basis; d.b.) during (A) frying and (B) hot air roasting.

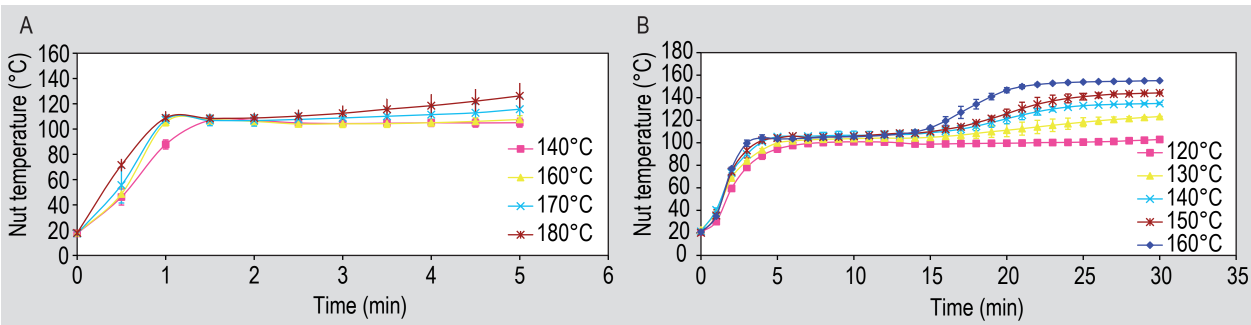

Figure 4. Experimental data for nut temperature of pistachio at different temperatures as a function of time during (A) frying and (B) hot air roasting.

reached more than 100 °C after 60 sec and decreased later. Then, the thermal equilibrium was reached and nut temperature stayed constant close to the saturation temperature (approximately 100 °C) where a balance between evaporation and heat transfer was reached.

In the case of hot air roasting, the experimental curves provided evidence of the classical effect of energy (heat) transfer on the change in nut temperature. The data show an initial nut temperature increase at all air temperatures during the first 6 min of roasting. Then thermal equilibrium was reached and the nut temperature stayed constant close to 100 °C where the balance between evaporation and heat transfers was reached. The duration of the plateau was approximately 10 min. When the constant evaporation period was finished, the internal nut temperature started to increase again, completing water evaporation, until eventually reaching values of 104, 123, 135, 144 and 156 °C after 31 min for roasting temperatures of 120, 130, 140, 150 and 160 °C, respectively.

Texture

In Figure 5A changes in the breaking force of pistachio kernels under different frying conditions, as a function of moisture content, are reported. The curves present a similar form considering the different oil temperatures. After a decrease in the force, a minimum is reached and then the force increases significantly. The minimum of the force value corresponds to a 22% d.b. of moisture content

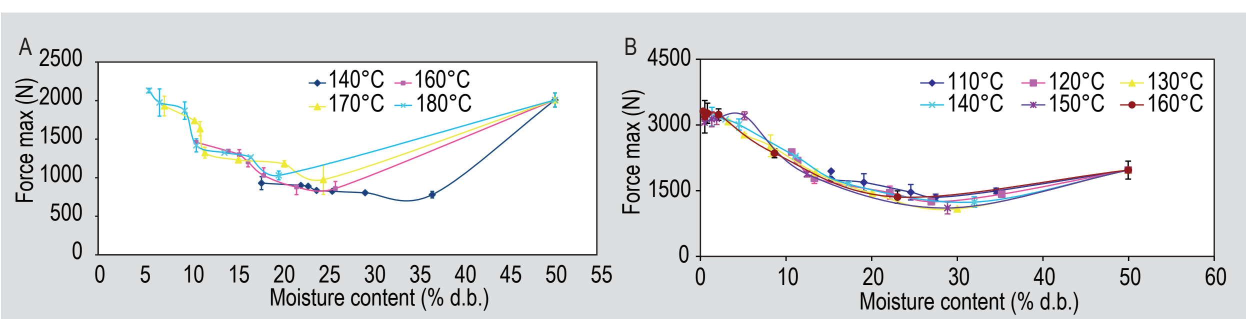

Figure 5. Experimental data presenting the force versus moisture content during (A) frying and (B) hot air roasting experiments.

that is reached after 2 to 3 min. The same behaviour is observed for hot air roasting conditions (Figure 5B). The value of the minimum is obtained around 26-30% d.b. of moisture content. It seems that the temperature influences the value of the minimum significantly. The breaking force of pistachio kernels was found to decrease from 2,008 N for raw pistachio to 780, 860, 975 and 1,030 N and then increased from there to 930, 1,460, 1,930 and 2,130 N at 140, 160, 170 and 180 °C, respectively, during frying, which is an important variation. Figure 6 illustrates the measurement of porosity of samples obtained after hot air roasting.

Oil content

The behaviour of the oil content during frying with time is displayed in Table 3. Oil content increased for all oil temperatures. Oil content values ranged between 47 and 48% for the raw pistachio kernels and were 53, 54, 55 and 56% after 5 min of frying at 140, 160, 170 and 180 °C, respectively.

4. Discussion

A first set of results was obtained with the experimental description of some important pistachio attributes obtained during hot air roasting. The results show how air temperature and time influence the main variables. It is quite easy from this set of data to establish by simple

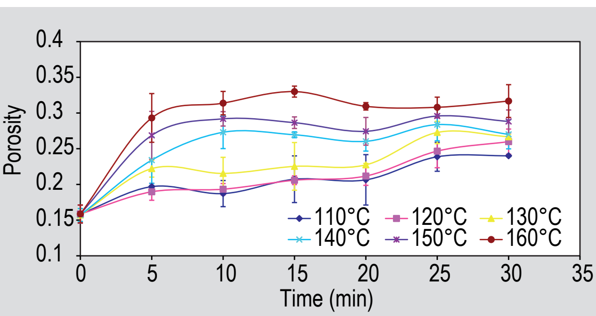

Figure 6. Experimental results obtained for porosity measurements during hot air roasting at different air temperatures.

Table 3. Oil content of pistachio at different temperatures during frying.

Temperatures (°C)	Oil content (% d.b.)
Raw pistachio	48.015
140	53.123
160	54.023
170	55.490
180	56.367

modelling a way to determine the best set of operating conditions.

Nevertheless, if optimisation is expected, the use of hot air roasting is limited. The possible use of frying as a way of processing raw pistachio is established as it is possible to dry the nut very quickly. It is possible to obtain an interesting set of properties related to texture and storage life (water activity). The data also show that the oil uptake is not important. The frying conditions permit a wide range of final moisture contents in a shorter time compared with classical roasting. It is an interesting result for a country like Iran, one of the largest producers and exporters of pistachio. The pistachio harvesting season is very short. Harvesting of pistachio has been carried out in different regions with high volumes, but the processing of drying and storage is slow. Optimisation is a challenge. The frying method is appropriate for obtaining a product with a suitable moisture content in a short time. All of the physical properties of pistachio nuts and its kernel are dependent on their moisture content. Therefore, having the proper moisture levels can facilitate the processing of pistachios.

During frying, the properties that are expected could be obtained. Values of water activity, sufficient for storage purposes (around 0.70), are easily obtained. The right order of texture indicators can also be obtained in a shorter time. On the other hand, with a decrease in moisture content, the problems would be financial due to the weight loss. Therefore it is necessary to have knowledge of the equilibrium of the moisture content of the pistachios for various water activities and temperatures that would permit the correct specification of the storage conditions. Considering the yield by weight, the oil impregnation could be of interest, but on the other hand, while the low water activity retards or eliminates the growth of microorganisms it results in higher lipid oxidation rates. It is important to find the optimal frying conditions to avoid damage to the pistachio's quality. To avoid the growth of fungi and to ensure safe storage, the moisture content should be around 5-7% (dry basis) and the water activity should be around 0.7 for long-term and 0.82 for short-term storage.

Not all the mechanisms are clearly established and the work was mainly performed in order to explore the use of an alternative to roasting. Frying works, and the use of boiling temperature as the driving force is an interesting approach. Frying is one of the ways to preserve pistachio nuts; superheated steam and other technologies are available too and could be further explored in order to achieve faster and more efficient processing of pistachio.

It is interesting to note that the roasting process influences the textural properties of the pistachio nuts, rather than just influencing the moisture content. The maximum breaking force of pistachio kernels was found to decrease in the first 5 min of process and then increased as roasting time increased.

The comparison of the two curves is quite simple. Energy transfer is significantly different in the two operations. It is faster in the case of frying due to a better convective heat transfer process (Vitrac *et al.*, 2000) As a consequence the saturation temperature is reached faster. At higher frying temperatures, the duration of the plateau is shorter and the increase in temperature occurs after a short time. It is well related to the observations in Figure 2 showing moisture content changes. Both results for mass and energy transfer nicely illustrate the interest in frying as an intensification process for roasting of pistachio.

The creation of porosity is a result of the competition between the gas expansion due to temperature increases in the nut and the mechanical resistance of the nut itself. Bubbles of gas grow and porosity is created. During the few first minutes, the porosity increases. At the same time the force decreases, reaching a minimum value (Figure 5B). It is easier to break the nut, because most probably the walls of the bubbles inside the nut are smaller and therefore easier to break. After 2 min the porosity reaches a plateau that may be due to an equilibrium between the ability of mechanical resistance and the forces of thermal expansion probably reduced due to leakage of gases. At the observation level we are working at, it was not possible to observe gas leakage. The resulting increase in the breaking force as presented in Figure 5B and Figure 5A for frying is not clear, and some biochemical transformation of the nut due to thermal treatment is probably responsible for that. It seems that the behaviour under frying is similar to that under hot air roasting. Figure 5B shows a similar condition in process roasting of pistachio kernels.

The discussion concerning the way the oil is impregnated into the product is complicated; the proposed mechanisms are not easy to explain and there is no consensus (Achir, 2007; Ziaiifar, 2008). One of the proposed interpretations highlights the replacement of water by oil (Bouchon and Pyle, 2005). The idea is related to the creation of pores and their volume is directly related to the water removal mechanisms. The best way to illustrate whether this is the explanation or if it is only partially responsible for the oil impregnation is to plot oil impregnation versus moisture content (Figure 7). If the assumption is valid, the relation must be a linear one. Figure 7 shows clearly that a non-linear relation exists with high oil bath temperatures, there is also high moisture loss and that most probably, the porosity created during roasting is responsible for the oil uptake. The intensity of mass transfer resulting from intensive heat transfer is the most probable explanation. Nevertheless, in relation to oil uptake, it is clear that during the frying of pistachio some increase in oil content is visible.

Frying and hot air roasting deliver a similar set of results. A deeper understanding may be possible using other experimental techniques, such as real-time tomography or NMR analysis.

5. Conclusion

This study reported some changes in physical properties, including temperature, moisture content, porosity, water activity and texture, of pistachio nuts (Ahmad Aghaei variety) during processing. Comparison between hot air and frying roasting was considered. Frying appears to be a way for intensification of the operation, preserving the same set of roasted nut attributes. Oil uptake occurs, but is acceptable.

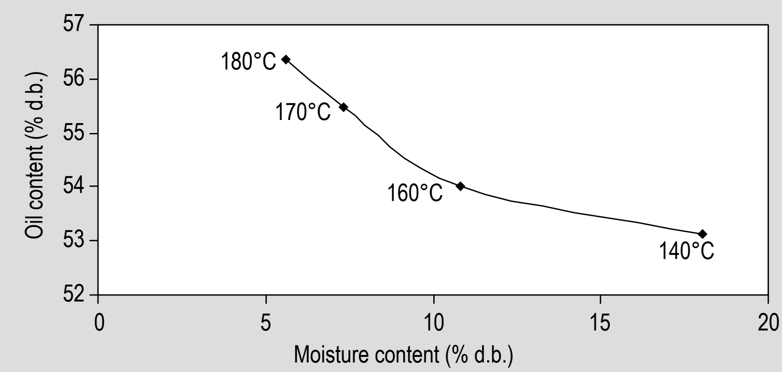

Figure 7. Oil content as a function of moisture content during frying of pistachio nuts.

References

Achir, N., 2007. Caractérisation des transformations d'un aliment au cours de l'opération de friture profonde en vue de l'optimisation de sa conduite. PhD thesis, AgroParisTech, Massy, France.

Aguilar, C.N., Anzaldúa-Morales, A., Talamás, R. and Gastélum, G., 1997. Low-temperature blanch improves textural quality of French-fries. Journal of Food Science 62: 568-571.

Aktas, T. and Polat, R., 2007. Changes in the drying characteristics and water activity values of selected pistachio cultivars during hot air drying. Journal of Food Process Engineering 30: 607-624.

Anthony, J. and Fontana, J., 2000. Water activity's role in food safety and quality. Second NSF International Conference on Food Safety, October 11-13, 2000, Savannah, GA, USA.

Arena, E., Campisi, S., Fallico, B. and Maccarone, E., 2007. Distribution of fatty acids and phytosterols as a criterion to discriminate geographic origin of pistachio seeds. Food Chemistry 104: 403-408.

Association of Official Analytical Chemists (AOAC), 1984. Official methods of analysis of AOAC International (14th Ed.). AOAC, Washington, DC, USA.

Baik, O.-D. and Mittal, G.S., 2005. Heat and moisture transfer and shrinkage simulation of deep-fat tofu frying. Food Research International 38: 183-191.

Bouchon, P. and Pyle, D.L., 2005. Modelling oil absorption during post-frying cooling: I: model development. Food and Bioproducts Processing 83: 253-260

Demir, A.D. and Cronin, K., 2005. Modelling the kinetics of textural changes in hazelnuts during roasting. Simulation Modelling Practice and Theory 13: 97-107.

Dobarganes, C., Márquez-Ruiz, G. and Velasco, J., 2000. Interactions between fat and food during deep-frying. European Journal of Lipid Science and Technology 102: 521-528.

Du Pont, M.S., Kirby, A.R. and Smith, A.C., 1992. Instrumental and sensory tests of texture of cooked frozen French fries. International Journal of Food Science and Technology 27: 285-295.

Food and Agriculture Organization (FAO), 2001. Manual on the application of the HACCP system in mycotoxin prevention and control. FAO Food and Nutrition paper 73. Available at: ftp://ftp.fao.org/docrep/fao/005/y1390e/y1390e00.pdf.

Food and Agriculture Organization (FAO), 2005. FAOSTAT. Available at: http://faostat.fao.org/site/339/default.aspx.

Gamble, M.H., Rice, P. and Selman, J.D., 1987. Relationship between oil uptake and moisture loss during frying of potato slices from c. v. Record U.K. tubers. International Journal of Food Science and Technology 22: 233-241.

Garcia, J.M., Agar, I.T. and Streif, J., 1992. Fat content and fatty acid composition in individual seeds of pistachio varieties grown in Turkey. Gartenbauwissenschaft 57: 130-133.

Hsu, M.H., Mannapperuma, J.D. and Singh, R.P., 1991. Physical and thermal properties of pistachios. Journal of Agricultural Engineering Research 49: 311-321.

Krokida, M.K., Oreopoulou, V. and Maroulis, Z.B., 2000. Water loss and oil uptake as a function of frying time. Journal of Food Engineering 44: 39-46.

Maskan, M. and Karataş, Ş., 1998. Fatty acid oxidation of pistachio nuts stored under various atmospheric conditions and different temperatures. Journal of the Science of Food and Agriculture 77: 334-340.

Mellema, M., 2003. Mechanism and reduction of fat uptake in deep-fat fried foods. Trends in Food Science and Technology 14: 364-373.

Moreira, R.G., Sun, X. and Chen, Y., 1997. Factors affecting oil uptake in tortilla chips in deep-fat frying. Journal of Food Engineering 31: 485-498.

Mustafa, A., Ilkay, O. and Bilge, E., 2002. Comparison of the seed oils of *Pistacia vera* L. of different origins with respect to fatty acids. International Journal of Food Science and Technology 37: 333-335.

Mustafa, Y., Türkan Gürcan, S. and Özdemir, M., 1998. Oil composition of pistachio nuts (*Pistacia vera* L.) from Turkey. Lipid/Fett 100: 84-86.

Pittia, P., Nicoli, M.C. and Sacchetti, G., 2007. Effect of moisture and water activity on textural properties of raw and roasted coffee beans. Journal of Texture Studies 38: 116-134.

Razavi, S.M.A. and Taghizadeh, M., 2007. The specific heat of pistachio nuts as affected by moisture content, temperature, and variety. Journal of Food Engineering 79: 158-167.

Rubnov, M. and Saguy, I.S., 1997. Fractal analysis and crust water diffusivity of a restructured potato product during deep-fat frying. Journal of Food Science 62: 135-137.

Saguy, I.S. and Dana, D., 2003. Integrated approach to deep fat frying: engineering, nutrition, health and consumer aspects. Journal of Food Engineering 56: 143-152.

Saklar, S., Ungan, S. and Katnas, S., 1999. Instrumental crispness and crunchiness of roasted hazelnuts and correlations with sensory assessment. Journal of Food Science 64: 1015-1019.

Vitrac, O., Trystram, G. and Raoult-Wack, A.-L., 2000. Deep-fat frying of food: heat and mass transfer, transformations and reactions inside the frying material. European Journal of Lipid Science and Technology 102: 529-538.

Yazdani, M., Sazandehchi, P., Azizi, M. and Ghobadi, P., 2006. Moisture sorption isotherms and isosteric heat for pistachio. European Food Research and Technology 223: 577-584.

Yeganeh, R., 2009. Contribution à l'amélioration de la torréfaction de la pistache. PhD thesis, AgroParisTech, Massy, France.

Ziaiifar, A.M., 2008. Oil absorption during deep-fat frying: mechanisms and important factors. PhD thesis, AgroParisTech, Massy, France.