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Persian Pistachio Nut (*Pistacia vera* L.) Dehydration in Natural and Industrial Conditions

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***Abstract*—**In this study, the effect of various drying methods (sun drying, shade drying and industrial drying) on final moisture content, shell splitting degree, shrinkage and color change were studied. Sun drying resulted higher degree of pistachio nuts shell splitting on pistachio nuts relative other drying methods. The ANOVA results showed that the different drying methods did not significantly effects on color change of dried pistachio nut. The results illustrated that pistachio nut dried by industrial drying had the lowest moisture content. After the end of drying process, initially, the experimental drying data were fitted with five famous drying models namely Newton, Page, Silva et al., Peleg and Henderson and Pabis. The results indicated that Peleg and Page models gave better results compared with other models to monitor the moisture ratio's pistachio nut in industrial drying and open sun (or shade drying) methods, respectively.

***Keywords*—**Industrial drying, Modeling, Pistachio, quality properties, Traditional drying.

I. Introduction

PISTACHIO nut (*Pistacia vera* L.) is one of the main dried products, which are cultivated in some part of the world such as Iran, Turkey, and USA. Based on FAO statistics [1], Iran produced about 472,097 Mt of pistachio nut in 2012, which is approximately 46.96% of the world's pistachio production. Therefore, one of the most non-oil and valuable product of Iran exports is the pistachio nut that has great influence on its national economic. The main part of pistachio nut consumed as snack food but pistachio kernels utilized for cake, pastry industries, ice cream, and pistachio butter [2]. It is also used as a main ingredient of many traditional Persian foods such as Gaz, Baghlava and Ghotab.

The main important processing line operations of this valuable crop are including handling, transportation, green hull removal, washing, drying, grading, bulk storage and packaging. Among these operations, drying is the key part of any pistachio recording terminals, which affects the final quality and marketability of pistachio nut [3]. One of common methods of pistachio drying in Iran is traditional drying (open sun and shade drying). Since traditional drying of pistachio nut is very slow (usually takes 2-3 days period depending on the weather conditions) and it is not easy to control its final moisture content, a relatively low quality product is obtained after drying. In this method, pistachio nut is contaminated with dust, dirt, rainfall, animals, birds, rodents, insects, and microorganisms. In order to overcome previous problems, industrial drying can be used as a safer and more efficient method of preservation compared to traditional drying. It improves the final product quality and also reduces the product losses. There are several studies on pistachio nut drying in previous literatures. For example, [3] found that, the time required for drying of Kerman pistachio nuts in convective hot air dryer from initial moisture content of 47% (wet basis) to final moisture content of 4.5% (wet basis) as monolayer at 50°C and a velocity of 1 m/s took approximately 5 h. Kouchakzadeh [4] examined the effect of solar and acoustic energy on pistachio drying process. The results revealed that using of acoustic energy assisted solar energy lead to lower power consumption, greater economic saving and the drying period reduced to 4 hour. Thin-layer drying characteristics and modeling of pistachio nuts in an air recirculating dryer unit was investigated by [5]. They found that, drying process of pistachio nut took about 11 hours at 55°C, RH=5% and air velocity of 1.5 m/s (the initial moisture content was determined in the range of 36-37 %w.b). Midilli and Kucuk [6] studied mathematical modeling of thin layer drying of pistachio nut by using solar energy and deduced that the logarithmic model could sufficiently describe thin layer forced solar drying of shelled and unshelled pistachio, while the two term model could define thin layer natural solar drying of these products.

The object of this research was surveyed thin layer drying behavior of pistachio nut under different drying approaches (traditional & industrial drying) and comparison of pistachio nut quality properties in these methods.

II. Materials and Methods

A. Raw Materials Preparation

Fresh Kalle-Ghuchi variety of whole Pistachio (*Pistacia vera L.*) was purchased from a local grower in northeast of Iran, and its foreign matters, immature and broken nuts were manually eliminated. After removing green skin, they were immediately stored (at 3°C) in sealed plastic containers to prevent microbial contamination and maintain its moisture content constant before drying.

B. Experimental Procedures

The drying methods which used in this research are as:

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- **Industrial drying**: Two kg of peeled pistachio was used for this method. Fresh pistachio was extended on dryer trays. A constant drying temperature according to previous study (at 50ºC) was selected. The drying process was continued until pistachio weight becomes constant.
- **Open sun drying**: Four kg of peeled pistachio (without green skin) were dried with this method. A cotton cloth was covered with a single layer of fresh pistachio and exposed to direct sunlight. The drying process was continued until the product weight did not decrease and remained constant. According to the local weather station report, the average values of wind velocity, air temperature and solar radiation during drying time were 5.89 ($m.s^{-1}$), 28.2 ºC and 752.2 ($W.m^{-2}$), respectively. The pistachios was packed in sealed plastic packs and stored in dark and dry environment during night hours.
- **Shade drying**: similar to before drying method, a single layer of fresh pistachio was extended on a cotton cloth and exposed to ambient air until its weight did not decreased and became constant. The drying process was done continuously for 5 days. The average values of wind velocity and air temperature during drying time were 3.19 ($m.s^{-1}$) and 30.94 ºC, respectively.

C. Experiments

The final moisture content of dried pistachio nut was measured according to AOAC standard method No.931.04 [7]. Shell splitting was obtained by direct measurement of distance between pistachio nut shells by a Vertex digital caliper (Model M502, China) with an accuracy of ±0.01mm [8]. Equation (1) was used to determine the color change (ΔE) in the various drying modes. Color change was measured by Image J software version 1.48.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

where, ΔL is the lightness difference, Δa is the red/green difference and Δb is the yellow/blue difference [9], [10]. Shrinkage of the dried pistachios was computed by (2):

$$\%\ Shrinkage = \frac{V_i - V_f}{V_i} \times 100 \quad (2)$$

where, V_i is initial sample volume before drying (m^3) and V_f is sample volume after drying (m^3).

D. Data Fitting

To recognize the best fitting kinetics model for drying curve of pistachio nut at different drying methods, five selected mathematical models including Newton, Page, Silva et al., Peleg and Henderson and Pabis were used. The equations of these models are shown in (3)-(7).

Newton:

$$MR = exp(-kt) \quad (3)$$

Page:

$$MR = exp(-kt^n) \quad (4)$$

Silva et al.:

$$MR = exp(-at - bt^{0.5}) \quad (5)$$

Peleg:

$$MR = 1 - (t/(a + kt)) \quad (6)$$

Henderson and Pabis:

$$MR = a\ exp(-kt) \quad (7)$$

The coefficient of determination R^2 was one of the main criteria for selecting the best equation. In addition to R^2, the goodness of fit was determined by various statistical parameters such as reduced chi square (χ^2), mean relative deviation modulus *P(%)* and root mean square error *RMSE*. For quality fit, R^2 value should be higher and χ^2, *P(%)* and *RMSE* values should be lower [11]. The above parameters can be calculated as:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} (MR_{p,i} - MR_{e,i})^2}{\sum_{i=1}^{N} (\overline{MR}_{p,i} - MR_{p,i})^2} \right] \quad (8)$$

$$\mathrm{RMSE} = \left(\frac{1}{N} \sum_{i=1}^{N} (\mathrm{MR}_{p,i} - \mathrm{MR}_{e,i})^2\right)^{0.5} \quad (9)$$

$$\chi^2 = \frac{\sum_{i=1}^{N} (\mathrm{MR}_{e,i} - \mathrm{MR}_{p,i})^2}{N - z} \quad (10)$$

$$P(\%) = \frac{100}{N} \sum_{i=1}^{n} \left| \mathrm{MR}_{p,i} - \mathrm{MR}_{e,i} \right| \quad (11)$$

which $MR_{e,i}$ is i^{th} experimental moisture ratio, $MR_{p,i}$ is i^{th} predicted moisture ratio, $\overline{MR}_{p,i}$ is average predicted moisture ratio, N is the number of observations and z is the number of model's constants. Also, mathematical modeling was carried out by Sigma Plot software version 12.

E. Statistical Analysis

The Statistix program version 8 was used to make ANOVA (analysis of variances) for the recorded data (obtained from the five replicates of each modes) and compare the mean values by using least significant difference (*LSD*) test at a confidence level of 95%.

III. Results And Discussion

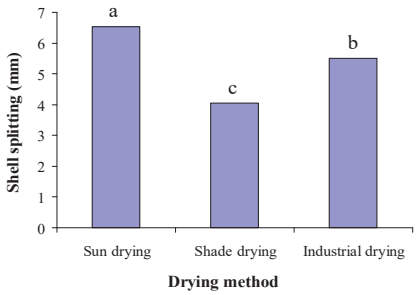
A. Variation of Quality Criteria during Drying

The ANOVA results showed that the different drying methods had meaningful and significant effects ($p<0.05$) on shell splitting of pistachio nut (Fig. 1 (a)). The pistachio nut dried in sun drying method shows the highest amount of this factor and those dried in shade drying method obtained the lowest shell splitting values. Similar results were obtained by [8] and [12]. According to results of these researchers, moisture content is one of the main factors affecting on shell splitting of pistachio nut. Based on our obtained results, pistachio nuts dried in sun and industrial drying methods due to the lowest moisture content (Fig. 1 (d)) obtained the highest shell splitting (with no significant difference or $p>0.05$).

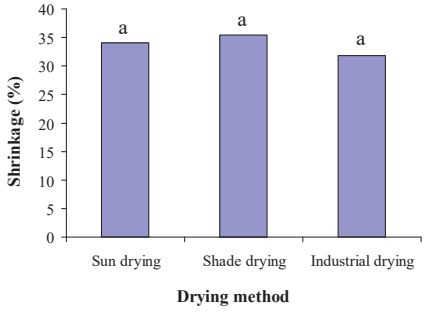
The ANOVA results showed that the different drying methods did not have any significant effects ($p<0.05$) on shrinkage of pistachio nut (Fig. 1 (b)). However, shrinkage value of nuts dried in shade drying method was significantly higher than the other ones. The result showed that the lowest amount of shrinkage was remarked for dried pistachio nuts in industrial drying method. A higher shrinkage was observed in shade drying most probably due to a longer drying time.

The ANOVA results showed that the various drying methods did not have significantly effects ($p<0.05$) on color change (ΔE) of dried pistachio nut. However, the nuts dried in shade drying mode achieved the highest value of color change undergoing drying (Fig. 1 (c)).

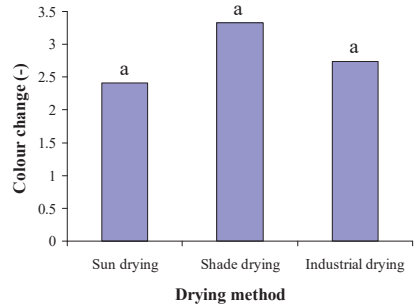
The ANOVA results (Fig. 1 (d)) showed that drying modes had pronounced effects on moisture content of dried pistachio nut ($p<0.05$). The results illustrated that, pistachio nut dried in industrial dryer gained the lowest moisture content values among dried samples by the other methods; whereas those dried in shade drying method got the highest moisture content value. The results of this study had high correlation with the results of [13] who affirms that the dried pistachio nuts moisture content was less than 6% (w.b.). Furthermore, [14] studied the influence of the various drying methods on pistachio nuts quality. They claim that moisture content of nuts was less than 4% (w.b.) in various drying methods.



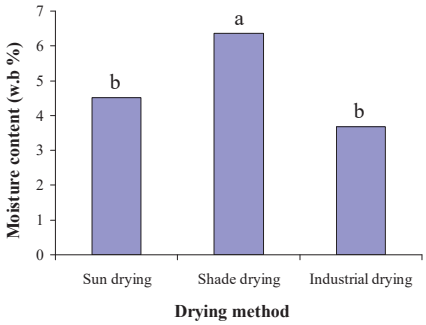
(a)



(b)



(c)



(d)

Fig. 1 Effects of various drying methods on quality attributes of dried pistachio nut (a) Splitting (b) Shrinkage (c) Color (d) Moisture content

B. Data Fitting of Drying Curves

The five thin-layer drying models were evaluated in terms of the statistical parameters R^2, χ^2, *P(%)* and *RMSE*. The results of statistical analysis are shown in Table I for difficult dehydration methods. As can be seen, in all methods, the R^2 values were greater than 0.9841. The fitting results illustrated that, Peleg and Page models were introduced as a goodness model for describing drying curve of pistachio nut drying process in industrial drying and open sun (or shade drying) methods, respectively. Several models have been proposed for different pistachio varieties for example modified page model for Abasali cultivar [11], page and two term models for drying of Ohadi cultivar [5], [15], page model for Kerman cultivar in convection hot air drying [16], page model for Khany and Abasali cultivars in microwave-convective drying [17].

TABLE I
STATISTICAL RESULTS OF THIN LAYER DRYING OF PISTACHIO NUT IN DIFFERENT CONDITIONS

Model	Model coefficients*	R^2	P(%)	RMSE	χ^2
Industrial drying					
Newton	k=0.2576	0.9918	2.196	0.02594	0.000724
Page	k=0.2769, n=0.9546	0.9925	2.000	0.02490	0.000723
Silva et al.	a=0.2292, b=0.0602	0.9931	1.868	0.02389	0.000666
Peleg	**k=0.7495, a=3.2751**	**0.9976**	**1.133**	**0.01407**	**0.000231**
Henderson and Pabis	k=0.2519, a=0.9776	0.9925	2.174	0.02484	0.000720
Open sun drying					
Newton	k=0.1618	0.9841	3.462	0.03869	0.001575
Page	**k=0.1016, n=1.230**	**0.9962**	**1.493**	**0.01893**	**0.000398**
Silva et al.	a=0.2113, b=-0.1289	0.9933	2.158	0.02506	0.000697
Peleg	k=0.6197, a=6.436	0.9957	1.703	0.02009	0.000448
Henderson and Pabis	k=0.1703, a=1.055	0.9876	3.086	0.03418	0.001298
Newton	k=0.0702	0.9853	3.018	0.03522	0.001266
Page	**k=0.0402, n=1.194**	**0.9947**	**1.805**	**0.02113**	**0.000465**
Silva et al.	a=0.0856, b=-0.0616	0.9908	2.424	0.02780	0.000806
Peleg	k=0.6557, a=14.140	0.9946	1.701	0.02126	0.000471
Henderson and Pabis	k=0.0731, a=1.0436	0.9872	2.911	0.03284	0.001124

*$k=h^{-1}$

Fig. 1 gives effects of various drying methods on quality attributes of dried pistachio nut. Also it shows the comparison between predicted and experimental data of thin layer drying of pistachio nut in different drying methods for the best fitted models. As can be seen, models represented moisture ratio values had low error (high correlation), which demonstrated the fitness of these models for describing the drying characteristics of pistachio nut. Similar results have been reported by other researchers [11], [18].

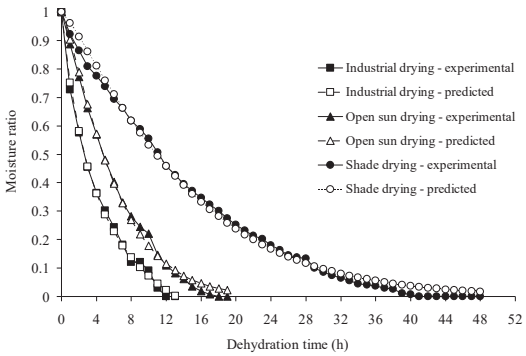


Fig. 2 Moisture ratio (MR) variation against dehydration time at different drying methods

IV. CONCLUSIONS

The pistachios moisture at harvesting time is about 40 to 50% moisture content (dry basis (d.b.)) according to date and climatic location. However, for storage and consumption pistachios need to be dried to moisture content around 5% to 7%. In this research the effects of the various drying methods such as sun drying, shade drying and industrial drying on quality properties of pistachio nut were studied. The effects of the various drying methods on pistachio nuts quality illustrated that different drying methods did not have any positive effect ($p<0.05$) on shrinkage and color change. As well, the lowest final moisture content and shrinkage were observed in industrial drying method. The pistachio nut dried in sun drying shows the highest amount of shell splitting and those dried in shade drying obtained the lowest shell splitting values. The results of data fitting indicated that Peleg and Page models gave better results compared with other models to monitor the moisture ratio of pistachio nut in industrial drying and open sun (or shade drying) methods, respectively.

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