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IMPACTS OF DRYING AIR TEMPERATURE, BED DEPTH AND AIR FLOW RATE ON WALNUT DRYING RATE IN AN INDIRECT SOLAR DRYER

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Abstract- Walnut is one of the world's top 20 agricultural products and is consumed mostly as dried [3]. This product must be dried with great care to maintain its quality. Walnut products are traditionally spread on open space for a long time to reduce the kernel moisture content to a safe level. Due to direct sun radiation and some environmental impacts such as long time exposure the quality of the products may be degraded. Application of renewable energy such as solar energy may be an appropriate substitution for traditional methods.
In this research a new pilot size walnut indirect solar batch type dryer was designed and fabricated. The effect of crucial factors affecting drying time namely: drying air temperature (T1:37° C; T2:39° C and T3:41°C), drying air flow rate (F1: 0.065 m^3/s, F2: 0.075 m^3/s, F3: 0.09 m^3/s) and bed depth (D1: 2 layers, D2: 4 layers and D3: 6 layers) were evaluated. The experimental results showed that, the effect of above factors on walnut moisture loss are significant. With increasing drying air temperature, drying air flow rate and number of layers, the amount of average moisture loss decreased from 37% (d.b) to 9% (d.b) at 3 hrs. Performance of dryer was determined at temperature 41°C, air flow 0.09m^3/s, 2 layers depth.
Key words- Walnut, Solar drying, Performance, air flow rate, drying air temperature, bulk depth

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Introduction

Walnut is one of the important nut fruits in the world with essential component of high nutrition values [1]. This fruit sets on the world's top 20 agricultural products and is consumed mostly as dried [3]. Walnut is mainly produced in China, USA, Turkey and Iran. Iran provides more than 10 % of world production of 300,000 ton per year [3].

Fresh walnut contains a moisture content of about 35-40 %(dry basis) which should be reduced to 4-8 % by drying in order to maintained the oil content. The traditional drying methods usually followed in Iran are sun drying in which the quality of the product is degraded [10]. Sun drying is time consuming and continues several days (about 7 days) and if the weather is not suitable the nut produced would be contaminated with fungi resulted in a grey rancid product. Furthermore, sun drying needs more space, labor intensive and dust attack can be damaged the quality of production as well as quantity. Moreover, microorganisms can increase the acid content, cause rancidity and reduce the amount of extractable nut resulting in poor-quality products [2]. On the other side it should be noted that in drying process walnut cannot tolerate drying air temperature more than maximum 43°C (110°F). For agricultural products, solar drying systems have been adopted successfully and several experimental and theoretical studies have been produced [4,5,9].The main objective of the present work was to study the drying characteristics of walnut produced in the solar dryer.

Material and Methods

The experiments were conducted in agricultural engineering department of Shiraz University, Shiraz, Iran during August to September 2010. Walnut was purchased from local market. In order to protect walnut fruit from direct solar radiation beam, indirect solar dryer was used in this research. The main parts of the experimental rig were: "Fig. (1)".

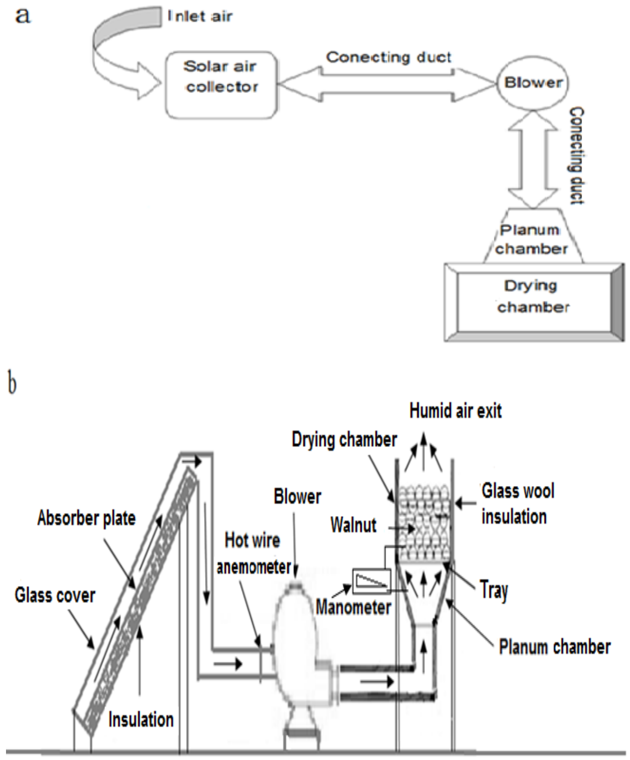

Fig. 1- Schematic layout of experimental rig (a), schematic view of the solar drier used for walnut drying (b).

Indirect Solar Dryer

The solar drier consisted of a solar air collector with $2m^2$ (2m×1m) surface area connected to an air circulating duct. In order to provide the hot drying air a single glazed solar air heater (absorber plate; 1×2m, Al plate, coated with matt black color) was employed. A centrifugal fan (1400 RPM, 50 HZ) was inserted in the rig for circulating the drying air. The dryer body was made of 5mm thickness wood with dimensions of width, depth and height of 0.3m×0.5m×0.4m, respectively.

In order to monitor the drying air temperature throughout the drying system, four calibrated thermocouples (Pt 100) with ±0.25°C accuracy were inserted at different locations of drying system. A power metering device (±0.1% accuracy) was used in the system to measure the consumption of blower electrical energy. A monometer was coupled across the drying bin to record the static pressure drop. The velocity of drying air was recorded well apart the solar air collector exit using hot wire anemometer having ±0.1 m/s accuracy. Solar radiation was measured applying a solar intensity meter (Casella) having an accuracy of about $\pm 1mv/m^2$.

Experimental Procedure

The dryer bin was loaded by fresh walnut fruit (2, 4 and 6 layers, natural filling). Three levels of drying air flow velocities (8m/s, 9.5m/s and 11m/s) and three dying air temperatures (37°C, 39°C and 41°C) were adopted for the experiments. The drying air temperature can be adjusted by covering partly the collector surface area according to ambient condition. The moisture content of walnut was determined using Eq. (1) [6]. Variations of moisture content of the samples were determined 0.5, 1.5 and 3h after commencing the experiments. The experiments were only conducted during day times (9 A.M- 4P.M) in three replications. In this research the effect of each factor (bed depth, drying air temperature and flow rate) on drying time was investigated using SPSS.

Data Analysis

In order to measure the initial moisture of the product, ten randomly selected kernels were peeled and kept in a convective electrical oven (Heraeus T5050) at 105±1°C for 24h. The initial (W_i) and final (W_f) weight of the samples was record using an electronic balance (Sartorius, 2354, ±0.01gr). The sample moisture contents (M_{wb}) were calculated using Eq. (1):

$$Mwb = \frac{(Wi - Wf)}{Wi} \times 100 \qquad (1)$$

The main goal of this work was defined to be the moisture ratio investigation of the walnut fruit in a batch type solar dryer. In each experiment (2,4 and 6 layers), fifty kernels were numbered and picked up randomly for measuring the moisture ratio investigation of the drying product at different operating conditions (3 levels of drying air temperature and flow rate).

Results and Discussions

Effect of Drying Air Temperature on Moisture Ratio

Table 1 shows the average moisture ratio changes of the walnuts during a period of drying experiments (3 hrs). These results were presented graphically in "Fig. (2)". the drying process was performed totally on falling rate period which is usually stated for agricultural materials [2,12]. The experimental data were applied to find the constants in drying exponential equations, table 2. The results illustrated a good agreement with what other researcher reported in the literature such as: peanuts [7] and hazelnuts [8].

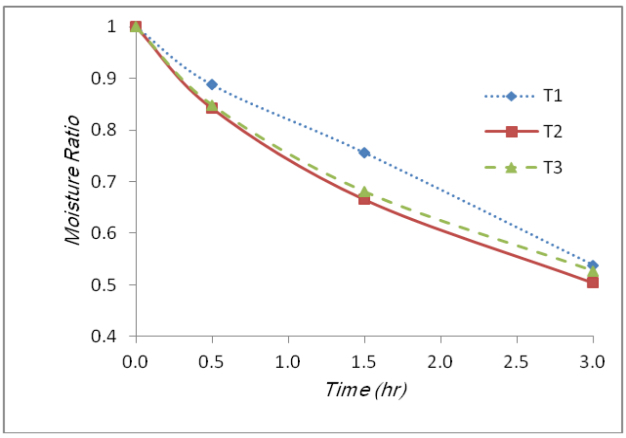

Fig. 2- Graphical representation of moisture ratio vs drying time at different drying air temperatures

Table 1- The average moisture ratio against drying time at different air temperatures

Time (hr.)	T_1	T_2	T_3
0.5	0.887	0.848	0.841
1.5	0.755	0.68	0.665
3	0.537	0.526	0.503

Table 2- Moisture ratio prediction equations at different drying air temperatures

Drying air temperature	Predicted equation
T1	$M.R= 0.9989e^{-0.203t}$
T2	$M.R = 0.9636e^{-0.209t}$
T3	$M.R= 0.9635e^{-0.223t}$

Effect of Depth on Moisture Ratio

The effect of bed depth on moisture ratio during the drying experiments was presented on table 3. As the drying process precedes the difference between the moisture ratios of the 2-kernel depth and the other depths showed a major variations. This effect may be attributed to the rate of moisture removal from the thinner layer of the walnut compared with thicker ones. The variations of moisture ratio for different drying depth were shown in "Fig. (3)". Based on experimental values, the moisture ratio prediction equations at different drying bed depth were displayed in table 4. The reports of other researchers such as Moss, 1989 on peanut and Ozdemir, 2004 on hazelnut confirm the result of present research.

Table 3- The average moisture ratio against drying time in different bed depths

Time (hr.)	D1	D2	D3
0.5	0.859	0.863	0.9
1.5	0.7	0.69	0.788
3	0.522	0.537	0.649

Table 4- Variation functions of moisture ratio of walnut against drying time at different bed depths

Bed depth	Predicted equation
D1	$M.R = 0.9818e^{-0.14t}$
D2	$M.R = 0.9704e^{-0.203t}$
D3	$M.R = 0.9704e^{-0.203t}$

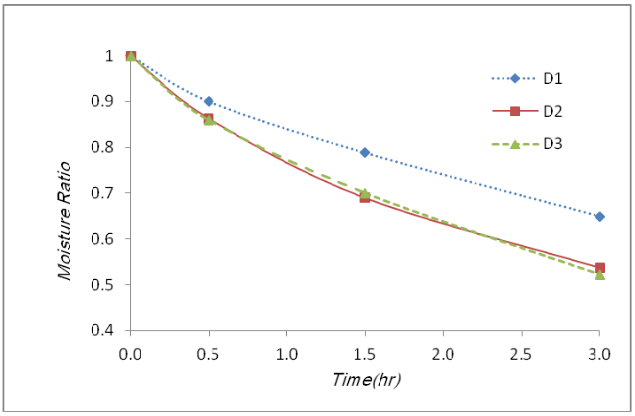

Fig. 3- Graphical representation of moisture ratio vs drying time at different bed depths

Effect of Air Flow Rate on Moisture Ratio

Although variations in air flow rates on drying rate is reported to be non-significant for many small drying kernels [11], the statistical analysis shows a significant effect of air flow rate variations on drying rate of walnut kernel, table 7. This result was illustrated schematically in "Fig. (4)". Since the sphericity of walnut kernel is high and the bulk bed porosity is low, therefore the drying air has got enough time to capture the moisture from the product. The prediction equation for moisture ratio vs time at different air flow rate depicted in table 6.

Table 5- The average moisture ratio against drying time in different air flow

Air flow rate Time (hr.)	F_1	F_2	F_3
0.5	0.88	0.84	0.812
1.5	0.76	0.656	0.609
3	0.57	0.531	0.511

Table 6- Variation functions of moisture ratio of walnut against drying time at different air flow rate

Air flow rate	Predicted equation
F1	$M.R = 0.9867e^{-0.182t}$
F2	$M.R = 0.9517e^{-0.206t}$
F3	$M.R= 0.9307e^{-0.218t}$

Table 7- The interaction effect of three factors on variation of moisture content

source	Sum of square	df	Mean square	F
Temperature (T)	11280.241	2	6540.12	402866**
Air flow rate (F)	1344.435	2	672.217	48016**
Bed depth (D)	244.85	2	122.425	8744.6**
T*F	64.425	4	16.106	1150**
T*D	33.919	4	8.48	605.7**
F*D	12.807	4	3.302	228.7**
T*D*F	64.398	8	8.05	575**
Error	0.74	54	0.014	
Total	13045.815	80		

1% significant

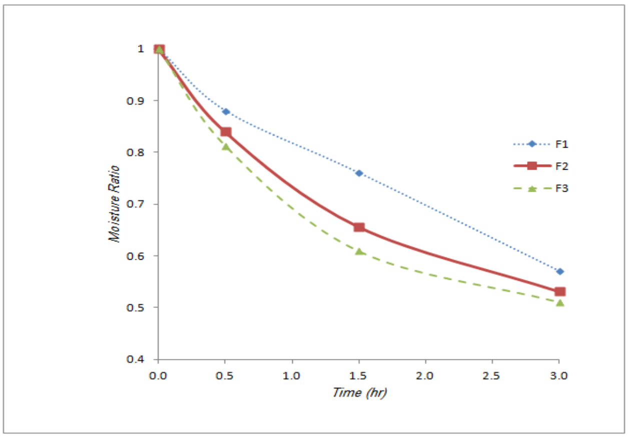

Fig. 4- Graphical representation of moisture ratio vs drying time at different air flow rates

Data analysis was performed using SPSS software (Duncan test in $p<0.05$). The results were displayed in table 7. The experimental results showed that, the effect of temperature on walnut moisture loss is very tangible in different layers. The amount of average moisture loss reductions were 11.03% for 2 layers, 10.67% for 4 layers and for 6 layers 10.55% of the initial drying bulk weight. In a given depths, the amount of moisture loss boosted with an increase in drying air temperature during the course of experiments (10.7% at T1, 13.42% at T2 and 15.26% at T3) and finally the different air flow rate caused reduction of moisture content of walnut reported to be 11.91% at F1, 10.84% at F2 and 10.04% at F3.

Conclusion

An indirect solar dryer was designed, fabricated and evaluated for drying walnut. It can be concluded that an indirect solar dryer is more suitable for producing high quality walnut. Maximum performance of dryer was occurred at the maximum air flow and drying air temperature and 6layer bed depth.

Nomenclature

M_{wb}	moisture content (%)
W_f	final sample mass (kg)
W_i	initial sample mass(kg)
F	air flow rate (m^3/s)
D	bed depth (layer)
T	drying air temperature (^oC)

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