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DRYING CHARACTERISTICS AND QUALITY OF FIG FRUITS UNDER HEATED AIR DRYING CONDITION

Abd El-Hady, N.S.*; R.K. Gebreil * and S.M. Radwan*
*** Agric. Eng. Dept., Fac. of Agric., Suez Canal Univ.**

ABSTRACT

The objective of this study was to develop and evaluate an artificial portable fig dryer. The dryer was designed and constructed in the Agriculture Engineering Department, Faculty of Agriculture, Suez Canal University, Ismailia city. Freshly harvested fig samples (*Ficus Carica*), obtained from a local market were used for the experimental work.

Pre-treatments were conducted on the fig samples before the drying tests. The drying tests were performed under four levels of drying air temperature (45 - 55 - 65 and 75°C), four levels of drying air velocity (0.2 - 0.4 - 0.6 and 1.0 m/s) and two slice thickness of 0.5 and 1.0 cm. The results showed that the recommended pre-treatment for drying of figs was dipping in 1.5 % sodium metabisulfit for two minutes. The developed dryer showed a satisfactorily thermal efficiency and final quality of the dried figs at air temperature of 75°C and air velocity of 1.0 m/s.

INTRODUCTION

Figs (*Ficus Carica*) considered one of the most important fruits species in the Mediterranean area. Figs have a great importance in nutrition due to being an important source of carbohydrates. They contain essential amino acids and are rich in vitamins A, B1, B2 and C and minerals and they are well known for their laxative and digestive properties. However, they have high moisture content (approximately 80% w.b.) at harvest; therefore, they cannot be preserved for more than a few days under ambient condition. Moreover, fresh figs are very sensitive to microbial spoilage, even in cold storage conditions; thus, they must be preserved in some way so most of the world production is preserved in the dried form. Dried figs can be eaten as such or served with marzipan, nuts, cream, and pudding.

In Egypt, figs are widely grown in northwest coast and north Sinai. The annual production of fig fruits in Egypt is about 171062 tons, the total cultivated area is about 69865 acre, the fruitful area is about 68425 acre and the productivity per acre is about 2.5 tons/acre (Ministry of Agriculture, 2012). Most of the production is consumed as fresh at domestic market. Also, figs yield usually shoot up during harvest time thus forcing prices to dramatically fall. Drying of fig at this time can help to reduce price fluctuations while increasing incomes for the producers and losses can also be avoided. Also, drying of figs will improve storability which means that dried fig can be stored for months or even years without appreciable loss of nutrients and it can reduce the bulk weight thus facilitating ease of transportation and storage space requirements.

Sun drying is the conventional method used to obtain dried figs, requiring only low capital, simple equipment and low energy input (Lutz et al., 1987). However, hot air drying has gained importance because it has many advantages over sun-drying, these include (a) the process is under better sanitary conditions, because of a reduction in contamination by dust and other foreign matter; (b) drying parameters can be accurately set, controlled and changed over the entire processing time, thus more consistently uniform product can be achieved with less quality degradation; (c) drying is not conditioned by rain or weather changes; (d) shorter drying times could be achieved and (e) labor costs are lower.

Stamatios et al. (2005) investigated the influence of drying air characteristics on the drying performance of figs (*Ficus Carica*). The investigation revealed that the drying kinetics was most significantly affected by temperature while, the air velocity having a limited influence on the drying process.

Paine and Paine (1992) stated that, the mechanical drying varies according to the material being handled, but usually involves heated air (with controlled low relative humidity) or passed over the food to be dried. There are numerous types of drier, and many variations on each type. In view of the fact that there have been many studies on the hot air drying of various fruits, studies on hot air drying of figs under Egyptian conditions are scarce in the literature. Therefore, the objectives of this study were (1) to investigate the effect of air temperature, air speed, slice thickness, and pre-treatments on the drying characteristics of figs, (2) to determine the influence of the studied drying parameters on fig quality, and (3) to delineate energy consumption and thermal efficiency of the drying process using the developed laboratory scale heated air dryer.

MATERIALS AND METHODS

1. Hot Air Dryer Set up

The dryer comprised of three components, drying cabinet, heating unit and centrifugal air fan. As shown in fig. (1) the drying cabinet was made from wood with dimensions of 54 cm long, 34 cm wide and 48 cm high. The cabinet included one drying tray fixed over a plenum chamber of 24 cm high with loading capacity of 1.5 kg. The tray was made of stainless steel screen mesh with dimensions of 50 cm long and 40 cm wide. The drying air was supplied to the cabinet plenum chamber via a PVC pipe with diameter of 5.08 cm. The proportion between the cabinet dimensions and air pipe diameter was chosen to achieve uniform air distribution inside the drying cabinet. The heating unit was used to heat the air before it was bowled to the drying cabinet. The unit consists of an insulated metal box made of iron with dimensions of 40 cm long, 30 cm wide and 25 cm depth, respectively. Five electric heaters of 2 kW each were used as heat source. They were fixed in parallel positions inside the metal box and the cover of the sheet material was installed by brick thermal withstand high temperature and acts as a buffer. The heating unit was facilitated with a temperature control device (precise thermostat and a conductor). The temperature setting on the heater was changed to obtain desired levels of drying air temperature.

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The metal box was surrounded by another wooden box with dimensions of 53 cm long, 43 cm wide and 43 cm high. The metal and the wooden boxes were separated with insulation layer filled with 1.5 cm thick thermal wool. Air was blown via the heating unit using a pip made from iron with diameter of 5.08 cm. The pipe part at the distance between the heating unit and the dryer plenum chamber was insulated by 1.5 cm thick thermal wool. A centrifugal fan model (SMB-10, USA) with power of 0.75 Hp was used to pump the air through the heating unit thereby to the dryer plenum chamber. A PVC pipe with diameter of 5.08 cm was used to carry out the air form the fan to the heating unit. The pipe was equipped with a valve to control the air flow rate during the drying process.

2. Sample Procurement

Freshly harvested fig samples (*Ficus Carica*), obtained from market during 2010, 2011 and 2012 harvesting seasons were used for conducting the experimental work. The samples were harvested at the end of August at commercial maturity and immediately transported to the laboratory. The samples were cleaned to remove damaged and improper figs. Physical properties, including weight, size, shape, dimensions (diameter and thickness), and number of fruits per kilogram were determined.

3. Pre-Treatments

Before drying, the samples were pre-treated in order to reduce the non-enzymatic browning and speed up the drying process by improving moisture diffusion through the waxy cuticle layer (Pangavhane et al., 1999; Doymaz and Pala, 2002). Two methods were applied to conduct the pre-treatment (B): the samples were blanched in boiling water for 1 min and cooled to ambient air temperature (33.8^{o}C) using tap water. The ratio between the blanching water and fruit sample was 9:1 and pre-treatment (C): the samples were blanched by dipping in 1.5 % sodium metabisulfit solutions for 2 min. The pre-treated samples using (B) and (C) methods were compared with those of untreated or control samples (A).

4. Measurements

During the course of the experimental work, several measurements were conducted, either directly or indirectly, depending on the nature of the measurement itself.

Velocity and temperature of drying air

The velocity of drying air was measured at different points over the surface of the drying tray and the average of the readings was considered using a digital Van type- Anemometer (MT- 4005, Korea). The anemometer has measuring range from (0.1 to 30 m/s) and accuracy of (± 0.1 m/s)

The drying air temperature and relative humidity were measured using a digital thermo-hygrometer. The Thermo-hygrometer (Taiwan) measures temperature ranging from -40 to 90°C with an accuracy of (± 0.8°C and relative humidity ranging from 1 to 99 % with an accuracy of (± 3%).

Moisture content determination

The moisture content of the fig samples was determined using the standard method of (AOAC, 1970). Accordingly, the samples were placed in an electric oven and set at 70^{o}C for 24 hr. The oven accuracy was ± 1.0^{o}C. After the samples reached the dry weight, the weight was measured using an electric balance with accuracy of 0.001 g. Then the initial M.C of the samples was calculated on dry basis (d.b).

Fruit weight

An electrical digital balance with a maximum capacity of 150 g and an accuracy of 0.001 g was used to measure the sample weight. The weight of samples was measured just before conducting the drying test and periodically during the drying process (Gikuru and Joseph, 2005).

Rehydration ratio and sugar content

To investigate the ability of the dried figs to re-absorbing the water, rehydration ratio (RR) was determined using a method recommended by (Von Loesecke, 1955).

While, the sugars content of figs was evaluated according to a method described by Bernfeld (1975) and Miller (1979).

Determination of thermal efficiency of the dryer

The thermal efficiency was calculated using the following relationship according to (Reys and Jindal, 1986).

$$E_t = \left(W_w \times \frac{Lh}{Q}\right) \times 100 \quad \text{.......................................} \quad (1)$$

Where:

E_t = Thermal efficiency, %
W_w = Water evaporated from fig fruit, kg
Lh = Latent heat of evaporation of water, kJ/kg
Q = Total energy consumption, kJ.

RESULTS AND DISCUSSION

1. Physical Characteristics of Fig Fruit

Table (1) presents the physical characteristics of fig fruits. As shown in the table, the diameter of the local figs variety "Sultani" ranges from (2.6 to 5.2 cm), the fruit density was 1.2 g/cm^3 and the initial moisture content ranged from 223 to 400% (d.b). The selected fruits for conducting the drying tests were taken to be about 4.8 cm ± 2 mm in diameter.

Table (1) some physical characteristics of fresh fig fruits "Sultani"

Characteristics	**Average value**
Fruit diameter, cm	4.80
Slice thickness, cm	0.5 , 1.0
Slice weight, g/ slice	7.0 , 14.0
Fruit density, g/cm^3	1.2
Initial moisture content, d.b ($g_{water}/g_{dry\ material}$)	223 - 400 %

2. Effect of Air Temperature and Velocity on Relative Humidity of the Drying Air

As shown in table (2), at the minimum air velocity of 0.2 m/s the recorded average drying air relative humidity at the air temperature of 45, 55, 65 and 75 °C were 23.47, 21.09, 19.73 and 17.65 %, respectively. While at the maximum air velocity of 1 m/s, the corresponding values of air relative humidity were 23.93, 21.92, 20.18 and 19.09 %, respectively. This means that, as the air temperature increased, the air relative humidity decreased for all levels of heating air temperature. Meanwhile, as the air velocity increased from 0.2 m/s to 1.0 m/s the air relative humidity increased at all levels of heating air temperature due to the decrease of air temperature as a result of lower contact time between the drying air and the heaters.

Table (2) Effect of drying airtemperature and velocity on relative humidity at different drying conditions.

Pre-treatment	Sample thickness, cm	Air temp., °C	Air velocity, m/s			
			0.2	0.4	0.6	1.0
			R.H, %	R.H, %	R.H, %	R.H, %
A	0.5	45	23.47	23.71	23.88	23.93
		55	21.09	21.43	21.83	21.92
		65	19.73	19.86	19.89	20.18
		75	17.65	17.90	18.32	19.09
	1.0	45	23.52	23.75	23.91	23.95
		55	21.45	21.74	21.99	22.08
		65	19.82	20.17	20.24	20.53
		75	17.80	18.27	18.42	19.45
B	0.5	45	23.87	23.93	24.08	24.34
		55	21.63	21.92	22.25	22.95
		65	19.84	20.35	20.65	21.31
		75	18.50	18.65	19.17	20.46
	1.0	45	23.91	24.49	24.68	24.75
		55	21.85	22.03	22.64	23.16
		65	19.93	20.62	20.73	21.94
		75	18.52	18.73	19.40	20.59
C	0.5	45	23.52	23.85	23.91	24.26
		55	21.18	21.50	21.96	22.83
		65	19.78	20.14	20.38	20.97
		75	18.31	18.54	18.82	19.75
	1.0	45	23.78	23.84	24.15	24.32
		55	21.53	21.99	22.26	22.64
		65	19.90	19.95	20.33	20.75
		75	17.84	18.52	18.83	19.82

3. Drying Characteristics of Figs under Hot Air Drying Conditions

Moisture content of fig fruits

The change in moisture content of fig samples over drying time under different pre-treatments and different levels of drying air temperature and velocity are illustrated in fig. (2). as shown in the figure the reduction rate in figs moisture content was increased with the decrease of slice thickness and the increase of drying air temperature and air velocity.

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Drying rate of fig fruits

Fig. (3) shows the variation of drying rate with the change in moisture content of figs. It can be seen that, the drying rate of figs decreased continuously with the increase of drying time due to the reduction in figs moisture content.

Also, the drying rate was affected by air temperature, when air velocity was constant. After an initial short period of drying process which practically coincides with the heating up period, the drying rate reaches a maximum value and then the product dries following a falling drying rate. The period of constant drying rate came out to be either very small or not to exist at all. For all the combinations of the studied parameters, a typical behavior for fruits drying was detected. This shows that diffusion is dominant physical mechanism governing moisture movement in the figs. These results are in agreement with those reported by (Babalis and Belessiotis, 2004) for fig drying.

The obtained results also showed that increasing the drying air temperature resulted in decreased drying time, and increased drying rate of fig fruits. However increasing the air velocity decreased the drying time. At a certain level of air temperature, increasing the air velocity decreases the air temperature with slight increase in relative humidity which causes a reduction in drying rate as was expected especially at higher levels of air velocity (over 0.4 m/s).

4. Final Moisture Content of Dried Figs

The values of final moisture content (M_f) could be acquired from the change in moisture content of figs as related to drying time. The measured values of final moisture content (M_f) are shown in table (3).

In general, the final moisture content (M_f) was decreased with the increasing of drying air temperature and air velocity and it was ranged from14.01 to 14.99 % (d.b) with an overall average value of14.41% (d.b).

5. Effect of Hot Air Drying Conditions on Fig Quality

Results presented in table (4) demonstrated that the organoleptic properties of dried figs were affected by different drying parameters and pre-treatments. The overall acceptability of the dried figs was evaluated by panal test and 20th tick mark sheets distributed among 50 members for sensory analysis.

Regarding the rehydration process, the obtained results revealed that a lower rehydration ratio was observed for pre-treatment (B) while, higher value was recorded with pre-treatment (C) for all drying tests. This may be attributed to higher drying air temperature and air velocity produced lower final moisture content of the dried figs and higher skin permeability which increase the water absorbability of the dried figs. These results are agreed with those reported by (Mayor and Sereno, 2004) for food materials.

For sugar content of the dried sample it well known that, sugars among several components are considered to be the most important in determining the quality of fruits. The initial concentration of reducing sugar for fig was 67.55 %. The high damage of reducing sugar was occured by pre-treatment (A), while the low damage was occurred by pre-treatment (C).

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Table (3): Average of final moisture content of fig slices under different studied parameters.

Pre-treatment	Sample thickness, cm	Air temp., °C	Air velocity, m/s			
			0.2	0.4	0.6	1.0
			M_f % (d.b)	M_f % (d.b)	M_f % (d.b)	M_f % (d.b)
A	0.5	45	14.183	14.249	14.058	14.675
		55	14.268	14.364	14.513	14.230
		65	14.901	14.336	14.521	14.228
		75	14.732	14.451	14.269	14.998
	1.0	45	14.267	14.018	14.529	14.336
		55	14.185	14.275	14.126	14.127
		65	14.338	14.168	14.635	14.750
		75	14.036	14.336	14.613	14.838
B	0.5	45	14.180	14.314	14.790	14.274
		55	14.784	14.623	14.643	14.358
		65	14.219	14.428	14.154	14.361
		75	14.209	14.251	14.375	14.358
	1.0	45	14.572	14.238	14.345	14.118
		55	14.663	14.109	14.832	14.257
		65	14.075	14.293	14.092	14.251
		75	14.329	14.164	14.542	14.625
C	0.5	45	14.556	14.410	14.388	14.393
		55	14.416	14.403	14.319	14.255
		65	14.385	14.371	14.247	14.116
		75	14.282	14.265	14.250	14.108
	1.0	45	14.628	14.604	14.537	14.415
		55	14.525	14.452	14.303	14.383
		65	14.472	14.330	14.289	14.115
		75	14.385	14.263	14.117	14.007

These results may be due to leaching out of sugars in lye solution as reported by (Amin, 1983).

The pre-treatment (C) of figs was the best pre-treatment which ranks 70– 91 degree of overall acceptability of panal test. This may be due to the high rehydration ratio of the samples. Additionally, the dried figs produced by this pre-treatment was also distinguished for light-color and gummy texture. These results are consistent with those reported by (Gabas et al, 1999 for fig drying and Abd El-Aal, 1998 for apricot drying).

According to Notter et al. (1970), the quality is characterized as follow: Poor: From 40 to less than 50 degree, Fair: From 50 to less than 70 degree, Good: From 70 to less than 80 degree and Excellent: From 80 to 100 degree.

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6. Thermal Efficiency of Developed Hot Air Dryer

The effect of drying process parameters including, drying air temperature and velocity and sample thickness on thermal efficiency was evaluated at the suitable pre-treatment. The obtained results are presented in table (5). It can be seen from the results that the thermal efficiency was affected by temperature and velocity of drying air. The thermal efficiency increased by increasing the velocity and temperature of drying air. For example, the thermal efficiency increased from 41.10 % to 63.54 % by increasing the air temperature from 45 ºC to 75 ºC at air velocity of 0.2 m/s. Also, at the air temperature of 65ºC the thermal efficiency increased from 57.02 % to 67.44 % by 0.2 m/s to 1.0 m/s. The slice thickness had a slight effect on thermal efficiency. The thermal efficiency at slice thickness of 0.5 cm was higher than that of 1.0 cm.

Table (5): Thermal efficiency of the developed dryer under different drying parameters and pre-treatments (C).

Sample thickness, cm	Air velocity, m/s	Air temp.., °C	Final moisture content of fig, % (d.b)	Latent heat of evaporation of water, KJ/Kg	Total energy consumption, KJ	Thermal efficiency, %
0.5	0.2	45	١٤.٥٥٦	2395.3	460.410	41.10
		55	١٤.٤١٦	2370.7	٤٣٠.٥٦٠	٤٥.٢٦
		65	١٤.٣٨٥	2346.2	٣٥٥.٥٠٩	٥٧.٠٢
		75	١٤.٢٨٢	2311.4	٣١٦.١١٦	٦٣.٥٤
	0.4	45	١٤.٤١٠	2395.3	٤١٦.٥٢٩	٤٦.٨١
		55	١٤.٤٠٣	2370.7	٣٨٥.٩٨٧	٥٠.٦٤
		65	١٤.٣٧١	2346.2	٣٤٥.٩١٣	٥٨.٨٨
		75	١٤.٢٦٥	2311.4	٣٢٠.٨٥٦	٦٤.٩٦
	0.6	45	١٤.٣٨٨	2395.3	٣٨٧.٥٧٩	٥١.٣٢
		55	١٤.٣١٩	2370.7	٣٦٢.٥٦٠	٥٥.٨٦
		65	١٤.٢٤٧	2346.2	٣٢٤.٦١٤	٦٢.١٦
		75	١٤.٢٥٠	2311.4	٣٠٨.٦٣١	٦٧.٧٦
	1.0	45	١٤.٣٩٣	2395.3	٣٨٣.٨١٠	٥٤.١٢
		55	١٤.٢٥٥	2370.7	٣٣٩.٨٣٣	٦١.١٨
		65	١٤.١١٦	2346.2	٢٨٦.٧٢٧	٦٧.٤٤
		75	١٤.١٠٨	2311.4	٢٨٤.٥٧٣	٧٢.٠٢
1.0	0.2	45	١٤.٦٢٨	2395.3	512.536	٣٩.٢١
		55	١٤.٥٢٥	2370.7	٤٨٢.٥٥٠	٤٣.٩٧
		65	١٤.٤٧٢	2346.2	395.663	٥٤.٥٦
		75	١٤.٣٨٥	2311.4	٣٧١.١٩١	٦٠.١٦
	0.4	45	١٤.٦٠٤	2395.3	٤٦٣.٢٢٨	٤٤.١٨
		55	١٤.٤٥٢	2370.7	٤٤٩.١٠٩	٤٨.٠٢
		65	١٤.٣٣٠	2346.2	٣٨٣.٤٣٦	٥٦.٩٣
		75	١٤.٢٦٣	2311.4	٣٦١.٩٤١	٦٢.٢٢
	0.6	45	١٤.٥٣٧	2395.3	٤٤٣.٦٦٩	٤٧.٣٥
		55	١٤.٣٠٣	2370.7	٤١٥.٩١٦	٥٢
		65	١٤.٢٨٩	2346.2	٣٦٢.٠٣٥	٦١.٤٨
		75	١٤.١١٧	2311.4	٣٤٣.٩٦٥	٦٤.٦٩
	1.0	45	١٤.٤١٥	2395.3	٣٩٥.٤٤٨	٥٣.٥٠
		55	١٤.٣٨٣	2370.7	٣٦٨.٤٢٣	٥٩.٧٠
		65	١٤.١١٥	2346.2	٣٤٦.٣٦٨	٦٥.٨١
		75	١٤.٠٠٧	2311.4	٣٣٠.٣٩٢	٦٨.٤٣

Thermal efficiency expresses the amount of heat required to evaporate the moisture inside the products being dried. Consequently, the input energy for drying process decreased with the increasing of drying air temperature and air velocity due to the reduction in drying time. Thus, the thermal efficiency positively correlated with air temperature and velocity of drying air. These results are in agreement with those reported by (Mustafa *et al.*, 1989).

CONCLUSIONS

1. The drying temperature of 75°C at air velocity of 1.0 m/s showed the lowest drying time and highest quality characteristics of the product in terms of color and taste, as well as the rehydration ratio.
2. The treatment which the fruits were dipped in a solution of 1.5 % sodium metabisulfit for two minutes is recommended for shortest drying time, safely moisture content, less drying rate and highest rehydration ratio.

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خصائص التجفيف والجودة لثمار التين تحت ظروف التجفيف بالهواء الساخن

نسمة سعد الدين السيد عبد الهادى*، رجب خير عبد القادر جبريل* و شريف محمد عبد الحق رضوان*

*** قسم الهندسة الزراعية – كلية الزراعة – جامعة قناة السويس.**

أجريت دراسة لتطوير وتقييم مجفف لثمار التين. تم تصميم المجفف في قسم الهندسة الزراعية، كلية الزراعة، جامعة قناة السويس بمدينة الإسماعيلية. ولإجراء هذة الدراسة تم إستخدام عينات طازجة من التين تم الحصول عليها من السوق.

تمت معاملة عينات التين قبل إجراء إختبارت التجفيف كالآتى:(أ) التين غير المعامل، (ب) غمر التين في الماء المغلي لمدة دقيقة واحدة ثم التبريد إلى درجة الحرارة المحيطة بواسطة ماء الصنبور (ماء التبييض إلى نسبة الفاكهة ٩: ١)، (ج) غمر التين في محلول ١.٥ ٪ ميتا سلفيت الصوديوم لمدة دقيقتين. أجريت إختبارات التجفيف بإستخدام أربعة مستويات لدرجة حرارة هواء التجفيف (٤٥ ـ ٥٥ ـ ٦٥ و ٧٥ درجة مئوية) وأربعة مستويات لسرعة هواء التجفيف (٠.٢ - ٠.٤- ٠.٦- ١.٠ م / ث) وسمكين للشرائح (٠.٥، ١.٠سم). يوصى بإستخدام المعاملة (ج) لتجفيف التين. كما أظهرت النتائج أن مجفف التين أعطى أفضل نتائج من حيث الكفاءة الحرارية والجودة النهائية للمنتج عند إستخدام درجة حرارة الهواء ٧٥ درجة مئوية وسرعة ١.٠ م / ث.