PERFORMANCE EVALUATION OF A SIMPLE SOLAR DRAYER(GREENHOUSE-TYPE)

[*]Mona M. A. Hassan

ABSTRACT

Drying is simply the process of moisture removal from a product. It can be performed by various methods. In these methods, thermal drying is most commonly used for drying agricultural products. These drying systems are usually classified into low and high temperature dryers according to their operating temperature ranges. In low temperature drying systems, natural-circulation greenhouse-type dryers appear the most attractive option for use in rural locations. They are superior operationally and competitive economically to natural open sun drying. An experimental of natural solar drying system was constructed at Sharkia Governorate in order to study the drying behavior of some vegetables. Two agricultural crops were used in this experiment, fresh melokhia and red pepper. The obtained data showed that, the highest removal rate of moisture content was obtained at open holes number of 9 for the products at any product mass. The lowest mass of melokhia (0.3 kg/tray) was dried within 6 hours to an average moisture content of 4.9 and 34.7% wet basis in solar dryer and the open sun drying system respectively. For red pepper the lowest mass (0.5 kg/tray) was dried within 18 hours to an average moisture content of 9 and 21 % wet basis in solar dryer and the open sun drying system respectively. The higher thermal efficiencies of the dryer were 24.3 and 24.6% for melokhia and pepper respectively campared to the open sun drying which were 17.5 and 20.7% for melokhia and pepper respectively. The production costs for drying one ton of melokhia and pepper were 970 and 1280 LE/ Mg compared to the open sun drying system for both melokhia and pepper which were1680 and 1820 LE/ Mg.

***Keywords**: drying, solar dryers, melokhia, pepper*

---

[*]Lecturer of Agricultural Engineering, Faculty of Agriculture, Zagazig University

INTRODUCTION

Drying of agricultural products has a great importance for reservations of food by human beings. Egypt is one of countries which have solar energy in abundance. It lies within the tropical and subtropical region. It has a value of about 5 to 8 kW.h/m^2.day and that sun-shine duration per year extends to about 4100 hours **(Al-Awady et al.1993).** Thermal drying is the form most commonly used for drying agricultural products. Different heat sources are employed for the thermal drying of agricultural products, the most common being fossil fuels, electricity and solar energy. However, in many rural locations in most developing countries, grid-connected electricity and supplies of other nonrenewable sources of energy are either unavailable, unreliable or, for many farmers, too expensive. Thus, solar energy dryers appear increasingly to be attractive for rural farmers**.Turhan Koyuncu. 2005)**. He also added that the traditional open sun drying utilized widely by rural farmers has inherent limitations: high crop losses from inadequate drying, fungal attacks, insects, birds and rodents encroachment, unexpected down pour of rain and other weathering effects. All these problems result in a poor quality dried product and in post harvest losses. Sun drying is a useful application of solar energy with a low operating cost and can be used for many agricultural and food products. However, open sun drying has some disadvantages, i.e., contamination by dust and insects, cloudy weather and long drying periods. These problems can be solved by using a solar dryer. Solar dryers comprise a collector, a drying chamber and sometimes a chimney. Solar dryers have been used to preserve fruits, vegetables, foods and other agricultural products in many countries **(Kongdej Limpaiboon and Songchai Wirryaumpaiwong. 2009). MWPS (1981)** indicated that in clear days, the maximum amount of solar energy is available at mid–day and the maximum temperature rise in a solar collector occurs near noon time. Therefore, the solar collector delivers the largest friction of its total energy output during the period of high radiation under clear sky condition in which about 85% of solar radiation is direct and 15% is diffuse. **Muhlbauer (1986)** reported that using the solar dryers in developing countries could reduce crop losses and improve the quality of the dried product significantly as compared with traditional drying method. Solar drying systems must be properly designed in order to meet particular drying requirements of specific crops and give satisfactory performance with respect to energy requirement **(Steamfield and Segal. 1986).** Hot chili is dried to make chili powder and to store it for both short and long term storage. A large quantity of chili is lost during the production season when the supply is abundant in Bangladesh, which exposed chilies traditional industry to sun dried. The farmers exposed their chili to the open sun on a mat, floor, and cemented floor or on a tin shed. In this method drying can not be controlled and relatively low quality dried product is obtained. Drying rate is very slow and takes 7-15 days depending on the weather conditions.**(Hossain .2003)**

The specific objectives of this study are:

1- Design and construct a natural convection solar system able to dry some vegetables and compare it with sun open drying system.
2- Investigate the factors affecting the drying process.

MATERIALS AND METHODS

This study conducted in faculty of agriculture, Zagazig university July 2010.

Description of the solar drying system:

The solar drying system was designed and manufactured in faculty of agriculture, Zagazig University 2010. (Longitude =35° 30° and latitude =31° 31°). The dryer mainly consists of a frame constructed from black coated wood bars, corrosion resistance plastic mesh, black coated solar radiation absorber surface, isolated by foam layer (0.03 m thickness), Polyethylene cover sheet, product door, air inlet and outlet channels. Fig. (1 and 2) and Tab. (1) show the configurations of the dryer. The greenhouse type dryer has two perforated trays that net surface area was 0.36 m^2. The width and the length of tray is 24 and 75 cm respectively. The trays consist of a frame made from black coated wood bars and the bottom is made from plastic mesh. The height of each tray is 25 mm and the trays are arranged one above the other. The corners of this dryer are connected to each other with 65° tilt angle. Some holes each 2.5 cm in diameter were added at the bottom of front side of the dryer for inlet air. Only one air outlet channel was located at the middle of dryer's top and covered by plastic mesh. The dimensions of this air channel were 5X30 cm. A 0.025 mm thickness Aluminum sheet was coated black and used as a solar radiation absorber surface. This Aluminum sheet was placed on the 3 cm thickness isolated material. Four 40-cm-length legs were connected at the corners of the bottom of the dryer to raise the body of the dryer from the ground.

Table 1: Specifications of solar dryer.

Gross dimensions of the dryer	110*70*50 cm
Net surface area available for drying	110*70 cm^2
Absorber material	Black painted aluminum sheet
Glazing material	Polyethylene (PE)
Thickness of glazing	0.15 mm
Insulation material	Foam
Thickness of insulation	3 cm
No. of product trays used	2
Outlet air dimensions	5*30 cm

The experiments design:

This experiment was carried out for drying melokhia and red pepper during the period of July and August 2010 .The product was spread out over the tray in a single layer in the dryer and in three masses 300, 400, 500 g/tray for melokhia and 500, 750, 1000 g/tray for red pepper. Some holes each of 2.5 cm in diameter were added at the bottom of front side of the dryer for inlet air were 6, 9 and 12 holes with all masses. To compare the performance of the solar dryer with the open sun draying, some samples were placed on trays in a single layer beside the dryer in the open sun. Drying was started at 10:00 am and discontinued at 6:00 pm. Weight loss of the samples was measured during the drying period at 2 hours. For red pepper the samples were kept in the dryer after 6:00 pm and put out again in the sun the next morning.

Energy balance in the solar dryer:

A microclimate energy balance can simply be developed to predict the air temperature inside the solar dryer, as shown in figure( ) (Ibrahim , 1999).

$$Q_i = \pm Q_{cd} \pm Q_v + Q_t$$

Q_i : solar heat gain , W, Q_{cd} : heat loss by conduction , W, Q_v : heat loss by ventilation , W, Q_t : heat loss by thermal radiation , W.

$$Q_i = \tau\, I\, A_c$$

τ : transmissivity of solar dryer cover for short wave radiation , decimal, I : outside solar radiation flux incident , W/m^2, A_c: the surface area of the solar collector.

$$Q_{cd} = U\, A_c\, (T_a - T_o)$$

U : overall heat transfer coefficient , W/m^2.K°, T_a: absolute temperature of inside air , K° , T_o: absolute temperature of outside air , K°

$$Q_t = \varepsilon\, \tau_t \sigma\, A_c (T^4{}_a - T^4{}_{sky})$$

ε: emittance factor of inside surface , decimal, τ_t: transmissivity of solar dryer cover for long wave radiation , decimal, σ:Steven Boltazman constant 5.67 W/m^2. K°^{4}, T_{sky}; sky temperature, K°.

The sky temperature can be determined with respect to the ambient air temperature as follows,(Swinbank,1963):

$$T_{sky} = 0.0552 (T_o)^{1.5}$$

Measurements

Mass: Electric balance was used to measure mass of product (accuracy 0.01 g and maximum mass 3000 g)

Solar radiation and temperature of ambient air were measured by "Watchdog" weather station model 900 ET. The Weather station measures wind speed (0-175 mph) ± 5%, wind direction (2° increments) ± 7°, temperature (-30° : 100° c), relative humidity (20-100%) ± 3%, rainfall (0.01-0.25 cm) ± 2% and solar radiation (1-1250 W/m^2). Air temperature inside the dryer was recorded at different positions using thermometers with accuracy of 1°c with maximum of 100° c. Moisture content was measured using the electric oven.

The efficiency of the solar dryer was calculated as follows:

$$Q_u = m_r L + m_p c_p \Delta t$$

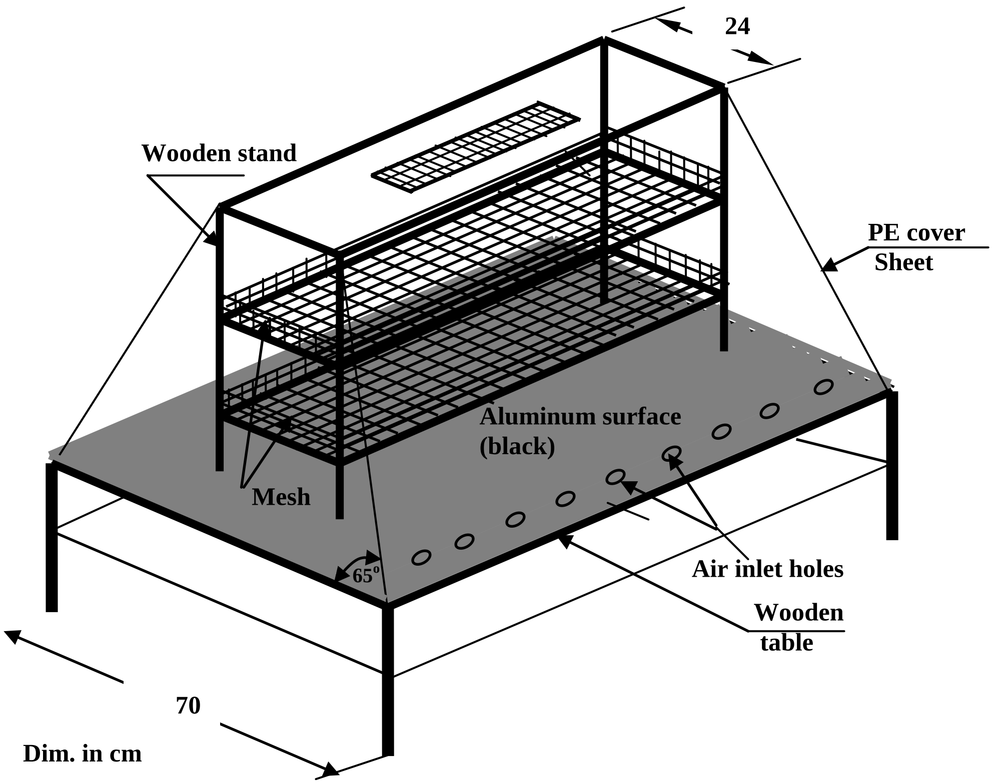

Figure 1: Isometric view of constructed dryer

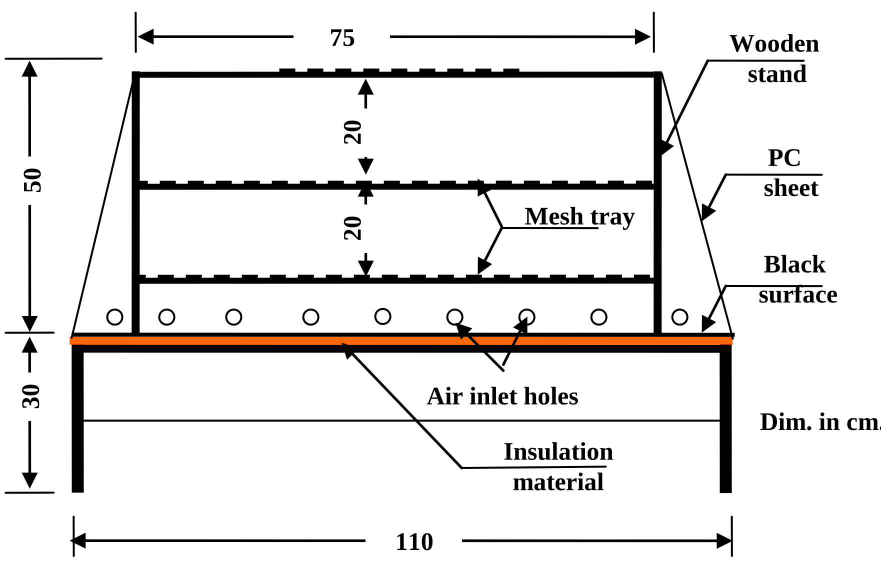

Figure 2: Sectional elevation of constructed dryer

Q_u: The useful heat**;** m_r: mass of moisture removal, kg, L: latent heat of water, 2257 kJ/kg (Awady,1993), m_p: mass of agricultural product, kg, c_p: specific heat of the agricultural product kJ/kg °C, Δt :temperature rise of agricultural product °C.

$$\eta = \frac{Q_u}{Q_i}$$

η: The thermal efficiency of the solar dryer.

The production cost was determined according to **(Awady 1978).** The total expected life is (5) years. The cost of the solar dryer is (200 LE) and the open sun draying is (50 LE).

RESULTS AND DISCUSSION

The discussion covers the obtained results under the following heading:

-Effect of number open holes and mass of product on moisture content in solar dryer compared to the open sun drying:

Results from Figure (3,4and5) showed that the highest removal rate of moisture content was obtained at open holes number of 9 for the products at any product mass. The lowest mass of melokhia (0.3 kg/tray) was dried within 6 hours to an average moisture content of 4.9 and 34.7% wet basis in solar dryer and the open sun drying system respectively. Results from Figure (6,7and8) for red pepper the lowest mass (0.5 kg/tray) was dried within 18 hours to an average moisture content of 9 and 21 % wet basis in solar dryer and the open sun drying system respectively. The other masses of melokhia (0.4 and 0.5 kg/tray) were dried within 6 hours to an average moisture content of 2.53 and 3.53 % wet basis, while in the open sun drying system these masses were dried within 6 hours to an average moisture content of 24.20 and 25.80 % wet basis. For red pepper, the other masses (0.75 and 1 kg/tray) were dried within 18 hours to an average moisture content of 12.85 and 16.07 % wet basis, while in the open sun drying system these masses were dried within 18 hours to an average moisture content of 23.64 and 28.90 % wet basis.

-Effect of number open holes and mass of product on thermal efficiency in the solar dryer compared to the open sun drying:

The conrertation efficiency of solar energy into more useful forms is one of the most important parameters concerning its utilizations as available source of energy. In order to evaluate the efficiency of the dryers, various parameters, such as solar radiation and drying air temperatures were measured at an interval of 2 hours. Also parameters as temperature differences between outlet and inlet of the dryer, useful heat gain were calculated to determine the thermal efficiency of the dryer.Results in Fig. (9) show the measured temperatures and solar radiation in 15 July 2010. The maximum values of measured temperature and measured solar radiation were 37.1 °C and 923.5 W/m^2 at 15 O‹clock. and 11 O‹clock respectively. Fig. (10) showed temperatures records for solar dryer and open sun drying on melokhia (400 g) with 9 holes. Fig.(11) showed that the maximum efficiency of solar drying values for drying Melokhia was 24.32% at open holes number of 9 and (0.3 kg/tray) while in the open sum drying the efficiency was 17.5% at the same mass. Fig. (12) showed that the maximum dryer efficiency of solar drying values for drying red pepper was 24.59% at open holes number of 9 and (0.5 kg/tray) while in the open sun drying the dryer efficiency was 20.70% at the same mass.

Cost analysis:

Fig.(13) illustrate the production costs for drying one Mg of Melokhia and red pepper were 970 and 1280 LE/ Mg compared to the open sun drying system for both of Melokhia and they were 1680 and 1820 LE/ Mg for the red pepper.

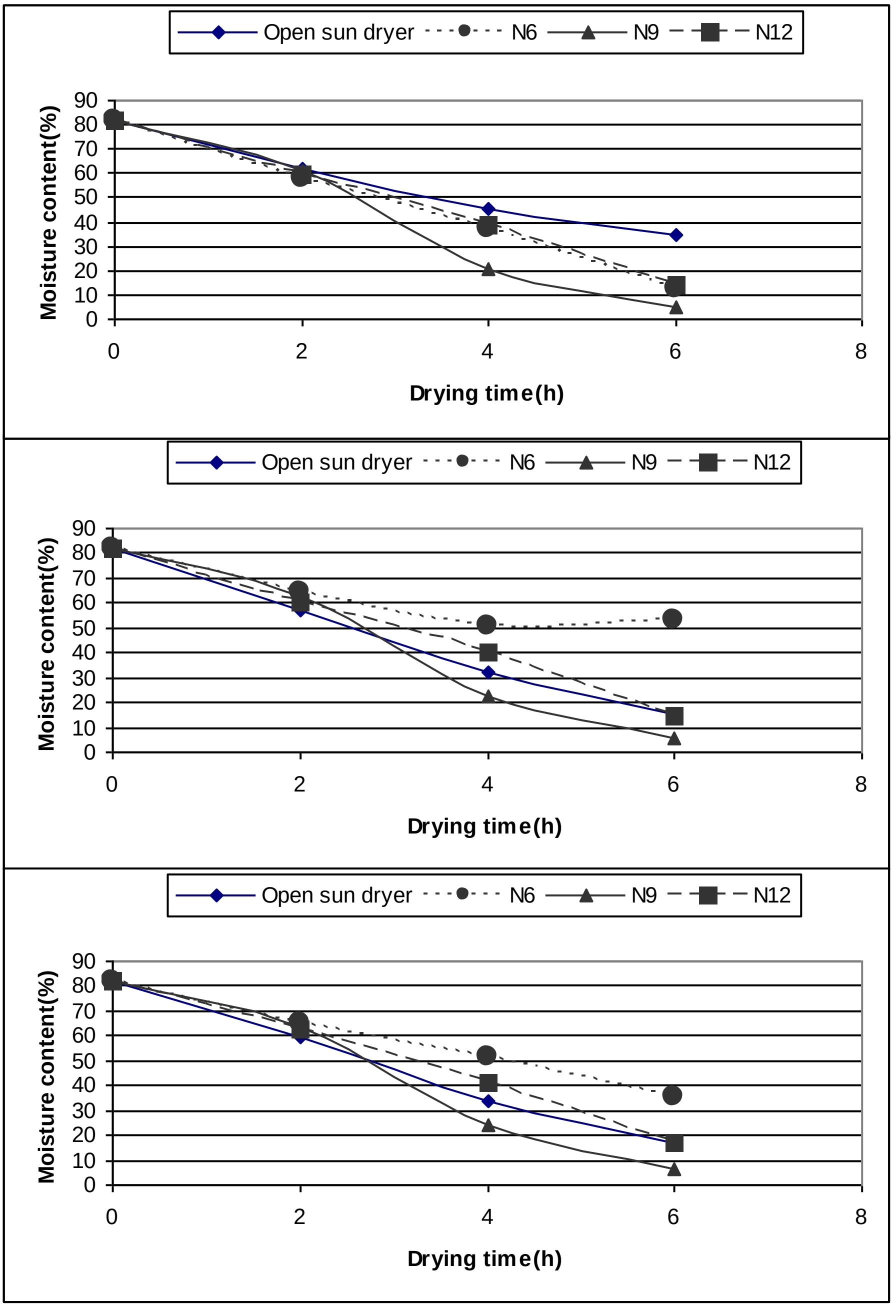

Figure 3, 4 and 5: Effect of time and number of open holes on moisture content of melokhia at (300 m 400 and500 g) in the solar dryer compared to the open sun drying

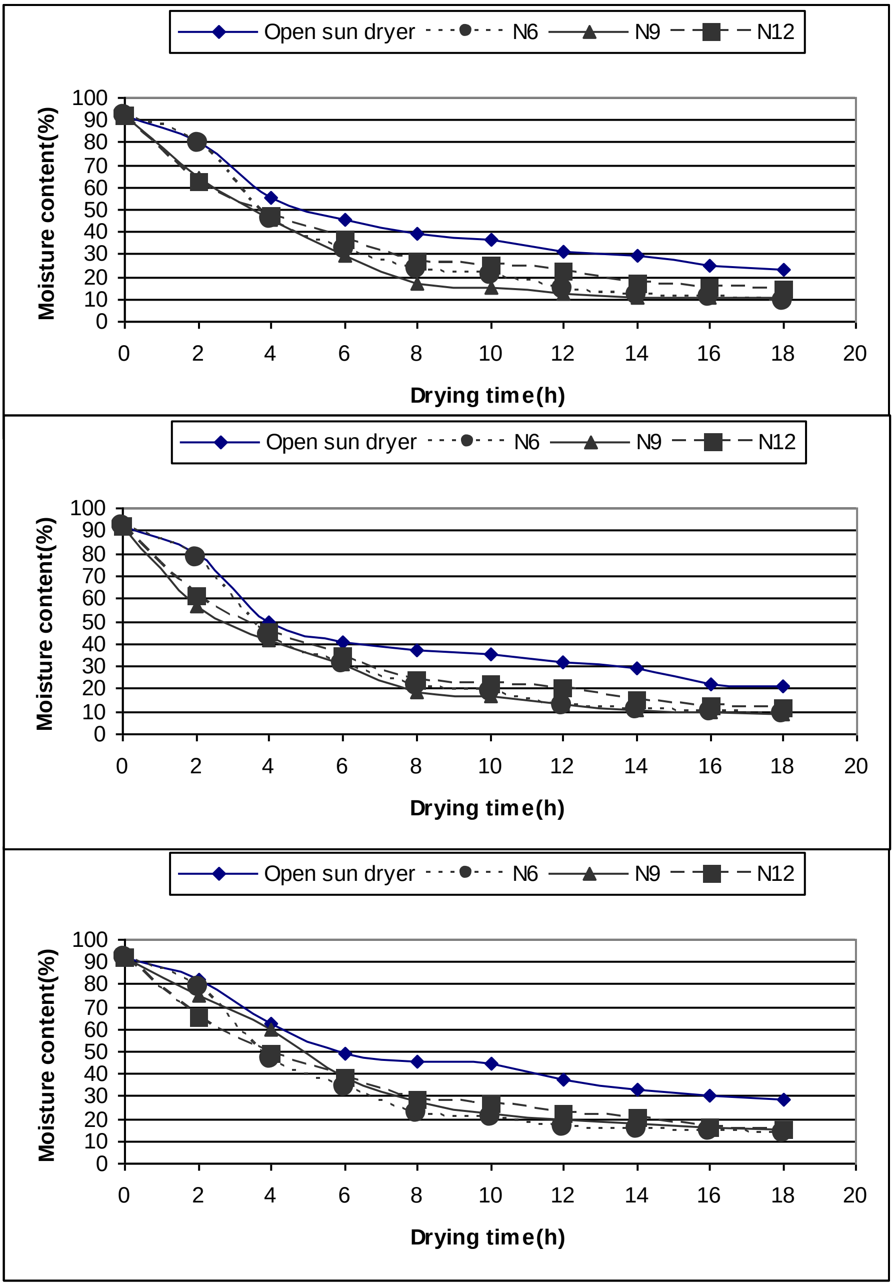

Figure 6 ,7 and 8: Effect of time and number of open holeson moisture content of red pepper at (500 , 750 and1000 g) in the solar dryer ompared to the open sun drying

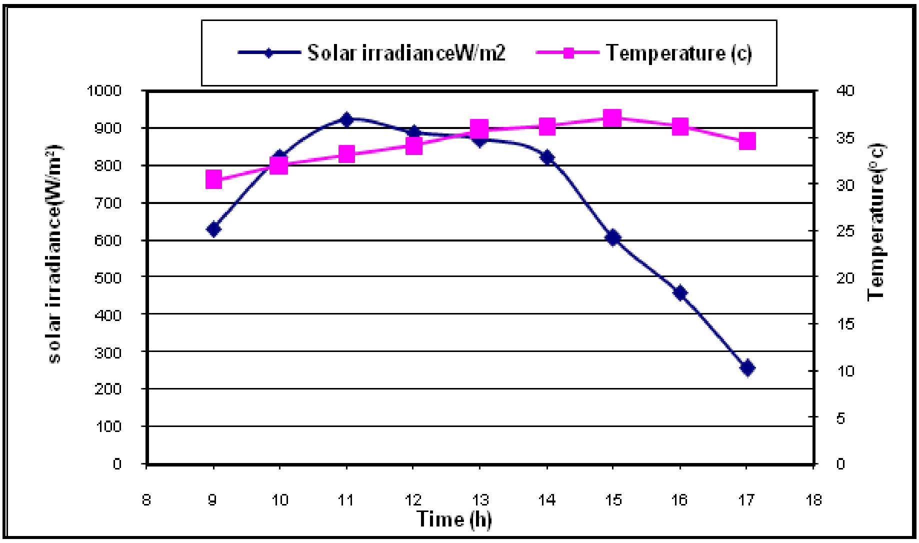

Figure 9: solar irradiance and temperature in 15 July 2010

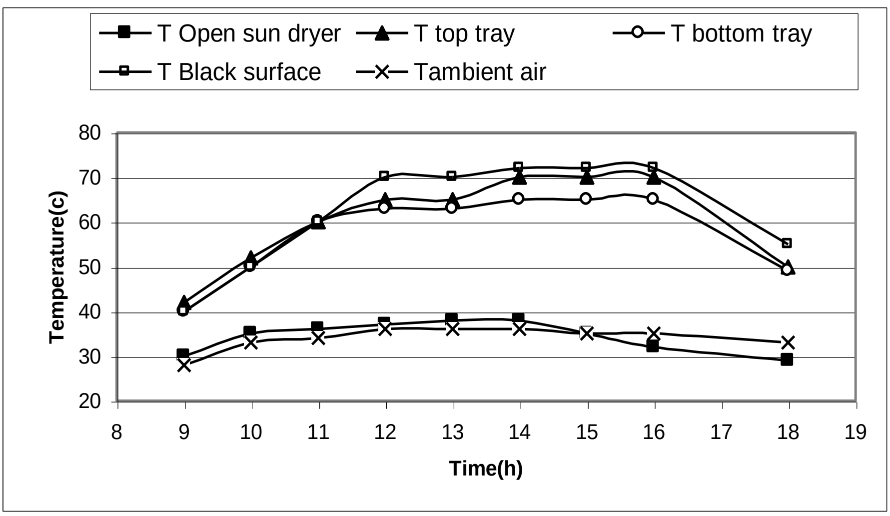

Figure 10: Temperature records for solar dryer and open sun drying on melokhia (400 g) with 9 holes.

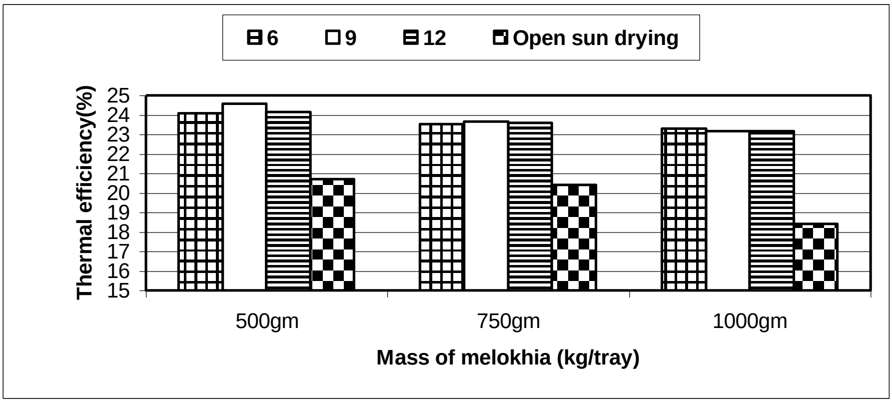

Figure 11: Effect of number of open holes and mass of melokhia on thermal efficiency of the solar dryer compared to the open sun drying.

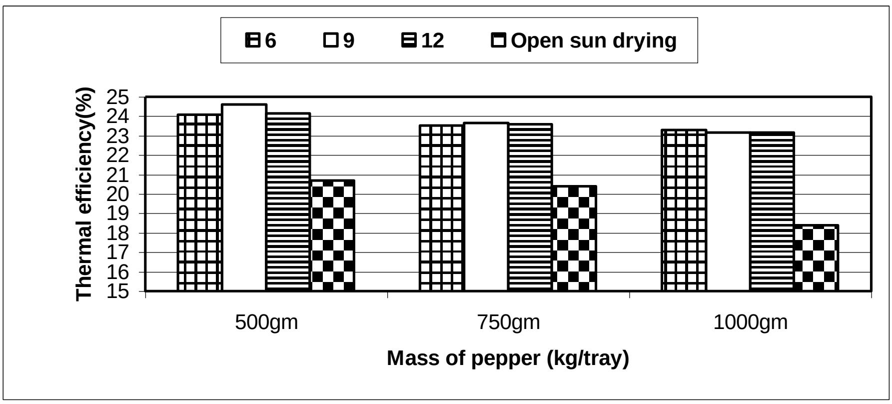

Figure 12: Effect of number of open holes and mass of pepper on thermal efficiency of the solar dryer compared to the open sun drying.

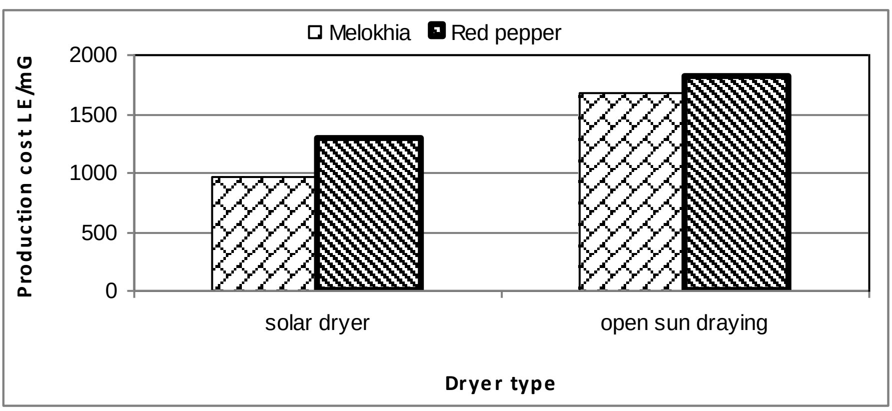

Figure 13: Production costs for solar dryer and open sun draying in melokhia and red pepper.

CONCLUSION

This research was carried out to study the possibility of drying melokhia and red pepper using heated air by solar energy and to study the factors affecting the drying process such as the product mass and the number of air inlet holes. This research included these points:

1. The optimum mass to dry melokhia and pepper were 0.3 and 0.5 kg/tray respectively.
2. The ideal numbers of air inlet holes were 9 holes for both melokhia and pepper under all investigated masses.
3. The average thermal efficiencies were 24% and 24.5% for both melokhia and pepper respectively.
4. This method saves both cost and time required for the drying process.

REFERENCES

Al-Awady, M. N. (1978). Engineering of tractors and agricultural machinery. Text book. Agri. Ain Shams Univ: 289.

Al-Awady, M. N; S. A. Mohamed; A. S. El-Said and A. A. Hassanain (1993). Utilization of solar energy for drying process of agriculture products. Misr J. Agric. Eng. 10(4): 794-804.

Hossain, M. A. (2003). Forced convection solar drying of chili. PhD. Thesis, Bangladesh Agriculture University, Mymensingh, Bangladesh.

Ibrahim,M.H.(1999) predicting microclimatic condition on greenhouses.Misr J.Ag.Eng.,16(1):67-82.

Kongdej, L.and S. Wirryaumpaiwong (2009). Drying kinetics of steam Glutinous rice with a free convective solar dryer. Walailak J. Sci. and Tech.6 (2): 217-229.

MWPS (1981). Low temperature and solar grain drying handbook. Mid West Plan Service-22. Iowa State University, Ames. Iowa.

Muhlbauer, W. (1986). Present status of solar crop drying. Energy in Agriculture, 5:121-137.

Sukhatme,S.P.(1981).SOLAR Energy:Principal of Thermal Collection and Storage. New Delhi,India:Tata McGraw-Hill Publishing Limited.

Steamfield, A. and I. Segal. (1986). A simulation model for solar thin layer drying process. Drying Technology, 4:535-542.

Swinbank,W.C.(1963) Long wave radiation form clear skies , cited by state University, Bulletin 792:1-10.

Turhan, K (2005). An Investigation on the performance Improvement of greenhouse-type agricultural dryers. Renewable Energy.31 (2006) :1055-1071.

الملخص العربى

تقييم أداء مجفف شمسى بسيط (طراز الصوبة)

منى محمود عبد العزيز حسن*

يهدف البحث إلى تصنيع و اختبار نظام للتجفيف الشمسي طراز الصوبة ذو حمل طبيعي لاستخدامه في تجفيف الخضروات. و يتكون هذا النظام من إطار من الخشب المدهون باللون الأسود و يوضع بداخله صواني التجفيف وسطح امتصاص مصنوع من الالومنيوم بسمك ٠.٠٢٥ ملليمتر و مبطن بطبقة عازلة من الفوم بسمك ٣ سم و المجفف أبعاده (١١٠*٧٥*٥٠) سم وغطى بغطاء من البلاستيك الشفاف في أعلى الغطاء فتحة لخروج الهواء أبعادها (٥*٣٠) سم و مغطاة بغطاء من البلاستيك المثقب وفى احد جوانب المجفف من أسفل تم عمل مجموعة من الفتحات لدخول الهواء بقطر ٢.٥ سم. والمجفف مزود بصنيتين لوضع المنتج مصنوعة من إطار من الخشب و القاع من البلاستيك المثقب أبعادها (٢٤*٧٥) سم و المجفف محمول على أربع أرجل على ارتفاع ٤٠ سم من سطح الأرض .

وتم اخذ عدة معاملات هي:

١- تم اخذ ثلاث أوزان من الملوخية (٣٠٠-٤٠٠-٥٠٠) جرام للصينية الواحدة وثلاث أوزان من الفلفل (٥٠٠-٧٥٠-١٠٠٠) جرام للصينية الواحدة.

٢- تم عمل ثلاث مجموعات من فتحات دخول الهواء (٦-٩-١٢) فتحة وذلك بالمقارنة بالتجفيف الطبيعي مع نفس الأوزان.وقد أوضحت النتائج ما يلي :

١- أقل محتوى ر طوبى للملوخية المجففة كان (٤.٩) و (٣٤.٧) %عند الوزن الرطب عند استخدام المجفف و التجفيف الطبيعي على التوالى ذلك عند استخدام وزن (٣٠٠) جرام ، ٩ فتحات دخول للهواء و ذلك بعد فترة زمنية استغرقت ٦ ساعات بالمقارنة.

٢- أقل محتوى رطوبى للفلفل المجفف كان (٩) و (٢١) %عند الوزن الرطب عند استخدام المجفف و التجفيف الطبيعي على التوالى و ذلك عند استخدام وزن (٥٠٠) جرام ، ٩ فتحات دخول الهواء وذلك بعد فترة زمنية استغرقت ١٨ ساعة.

* مدرس الهندسة الزراعية - كلية الزراعة- جامعة الزقازيق

٣- المجفف أعطى أعلى كفاءة حرارية (٢٤.٣%) عند استخدام وزن (٣٠٠) جرام من الملوخية و ٩ فتحات دخول للهواء بالمقارنة بالتجفيف الطبيعي الذي أعطى (١٧.٥%) لنفس الوزن.

٤- المجفف أعطى أعلى كفاءة حرارية (٢٤.٦%) عند استخدام وزن (٥٠٠) جرام من الفلفل و ٩ فتحات دخول للهواء بالمقارنة بالتجفيف الطبيعي الذي أعطى (٢٠.٧%) لنفس الوزن.

٥- تكلفة واحد طن من الملوخية و الفلفل كانت (٩٧٠) و (١٢٨٠) جنية على التوالي بالمقارنة بالتجفيف الطبيعي الذي يتكلف (١٦٨٠) و (١٨٢٠) على التوالي.

٥- يمكن استخدام المجفف بواسطة المزارعين الصغار أو ربات البيوت باستخدام خامات بسيطة و متوفرة.

٦- يمكن استخدام المجفف لتجفيف منتجات زراعية أخرى مثل العنب و المشمش و النعناع و غيرة.

٧- لزيادة كفاءة المجفف زيادة أبعاده و زيادة عدد الصواني بداخله و تزويده بوحدة تخزين الطاقة بالنهار للاستفادة منها ليلا.