DRYING OF CUCUMBER SEEDS USING A FORCED AIR CABINET SOLAR DRAYER

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Abstract

This research work aims at studying the factors affecting the solar drying of cucumber seeds using a cabinet solar dryer. The experimental work was conducted on the roof of Agricultural Engineering Research Institute (latitude angle of 30º 2' 35.2"N and longitude angle of 31º 12' 20"E) during summer season of 2015. Three different layers thickness of cucumber seeds (5, 10, and 15 mm thick) were functioned during the experimental work. The thermal performance analysis of the cabinet solar dryer (forced convection system) was evaluated. The obtained results revealed that, the daily average solar radiation recorded on the horizontal surface during the experimental period was 7.215 kWh/m^2 while, the actual solar radiation recorded on the tilted surface of the cabinet solar dryer was 10.220 kWh/m^2. Accordingly, the stationary non-tracking cabinet solar dryer increased the actual received solar radiation during that period by 41.65%. The daily average solar radiation recorded outside and inside the cabinet solar dryer was 7.215 and 5.740 kWh/m^2, respectively, with cover effective transmittance of 79.56%. The solar radiation available inside the cabinet solar dryer was converted into useful heat gain for the drying process, resulting in increasing the dying air temperatures above the outdoor air (31.8ºC) by 16.2ºC, and reduce the air relative humidity under the outside (60.5%) by 20.4%. The daily average overall thermal efficiency of the cabinet solar dryer during the drying period was 46.64%, accordingly, 53.36% of the solar energy available was lost. The obtained results also showed that, the germination percentage of cucumber seeds dried by cabinet solar dryer was ranged between 97.1 and 97.4% under different drying times, drying air temperature, and air relative humidity. The minimum drying cost (292 LE/ton) was obtained by the dryer operated at layer thickness of 5 mm.

Keywords: cucumber seeds drying, cabinet solar dryer, thermal performance; germination.

INTRODUCTION

Since 1973, energy conflict became eminent. There had been shortage of fuels in many parts of the world and their prices steeply increases. It is now clear that the fossil fuel is gradually coming to an end. In addition, combustion of fossil fuels causes serious air pollution with harmful effect on the environment. The seriousness of most of the environmental problems had not really been foreseen. Nowadays, alternative sources of energy are sought to conserve the environment. Almost all the renewable energy sources originate from the sun. Solar energy is a very large inexhaustible source of energy. Egypt is one of the countries in the world which receives extremely high amounts of solar radiation. The daily average solar energy flux incident on Egypt varies from winter to summer seasons in a wide range of 3.7 to 8.8 kWh/m^2 with an average of sunshine duration of 9.2 to 12.8 hours (Kassem *et al.*, 2011). In addition to its magnitude, solar energy has two favorable factors; firstly, it is an environmentally clean source of energy, secondly it is in adequate quantities in almost all parts of the world, but still needs effective means for utilization.

Utilization of solar energy for drying different crops helps to eliminate the air pollution problems caused by using fossil fuels. Many solar dryers have been designed, constructed and utilized as alternative techniques to the traditional open-sun drying system, particularly in areas having a maximum possible of sunshine hours. According to the previous studies and researches these solar dryer systems can be classified in three forms as direct, indirect, and mixed modes, depending upon the arrangement of system components and mode of solar heat energy utilization (Afriyie *et al.*, 2009 and Chen and Qu, 2014). Greenhouse, types solar drayer comes in the category of the direct solar drying system and also sometimes mixed mode drying system. Khalil (2002) and Chaaban *et al.* (2002) constructed a solar drying system for drying agricultural products to conserve environment. They concluded that, the moisture content of rice grain decreased to a minimum value of 11.9% (wb) by the forced air tray dryer with cracking ratio ranged between 1.0 and 2.0% for the grain.. The applicability of greenhouses is limited due to high indoor air temperature during hotter months of the year (Condori and Saravia, 2003). An experimental analysis to study and investigate the thermal performance of a novel mixed mode solar greenhouse type solar dryer with forced convection for drying red pepper and sultana grape was executed by Elkhadraoui *et al.* (2015). They revealed that the drying rate in the greenhouse solar dryer could be much higher than that for the traditional open sun drying. Therefore, the drying times of red pepper and grape by the novel mixed mode greenhouse solar dryer were a 17 and 50 h., respectively. Thermal analysis was executed to study and test the thermal performance of a novel mixed mode modified-quonset solar dryer with solar collector air heater that could be used to dry seedless grape by Abdellatif *et al.* (2015). They concluded that, the daily averages solar energy available inside the flat-plate solar collector and the solar dryer were 16.217 and 9.141 kWh of which 10.895 and 5.514 kWh, respectively, converted into useful heat gain. These solar energy available inside the flat-plate solar collector and the solar dryer resulting in increasing the indoor air temperatures above the outdoor (31.1°C) by 10.5,to 16.1°C, and reduce the air relative humidity under the outside (60.8%) by 28.3%. Also, the daily average overall thermal efficiencies of the flat-plate solar collector and the solar tunnel dryer during the drying period were 66.64% and 59.52%, consequently, 33.36% and 40.48% of the solar energy available were lost, respectively.

The moisture content of cucumber seed was determined according to (AOAC,1990). It was determined by drying samples of cucumber seed (100 g) in electric oven at 40°C until reaching a constant weight. The seed germination test was carried out in laboratory by keeping 100 seeds on filter papers soaked with water in petri dishes (ISTA,1976). After 5 – 7 days, the germination seeds were counted to determine the percentage of germination.

The present study aims to; develop a low-cost cabinet solar dryer for drying cucumber seed and conserve the environment free from pollutions save non-renewable fuel resources, and utilize modern methods in seeds drying to improve the quality of the selected seeds in terms of high germination percentage.

MATERIALS AND METHODS

The cabinet solar dryer

A cabinet solar dryer (developed) work was installed on the roof of the AEnRi, Dokki, Giza. (latitude angle of 30º 2' 35.2"N and longitude angle of 31º 12' 20"E) and functioned for conducting the work. The cabinet solar dryer consists of eight components; inside and outside frames, transparent cover (glass), inlet air hole, insulation material, seed tray, blower, outlet air holes, and control box. The drying box consists of four double sides that have a layer of 20 mm thick insulation material (glass-wool) to reduce the heat losses from the sides and back of the drying box as shown in Fig. (1). The four sides are made of plywood sheets with 18 and 12 mm thick for outer and inner sheets, respectively. The inside sheet is painted with matt black paint to absorb the maximum possible amount of solar radiation flux incident. The front and back sides of the drying box having gross dimensions of 1220 mm long and 835 mm wide (each), and 340 and 585 mm high, respectively, with tilt angle of 30.2º. Each two tilted sides have four holes of 50 mm diameter for air inlet. The upper surface of the drying chamber has 7 holes of 50 mm diameter for hot drying air inlet into the seed tray. The back side of the drying chamber has two square gates of 155 x 155 mm which used to accumulate the blower. The cabinet solar dryer is mounted on a metallic frame of 365 mm high.

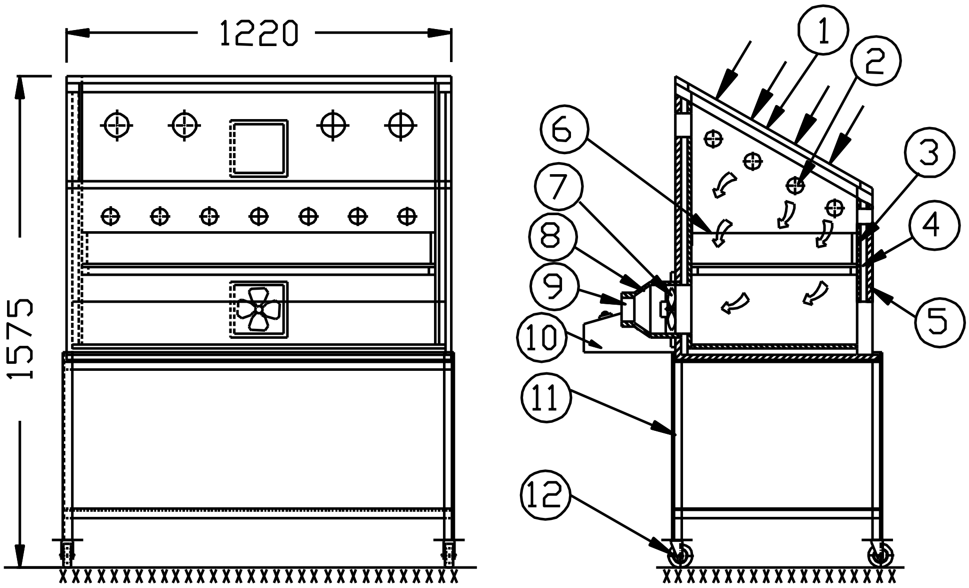

Fig. 1. Elevation and side view of the cabinet solar dryer.

(1) Transparent cover; (2) Inlet air holes; (3) inside frame; (4) Insulation material; (5) Outside frame; (6) seed tray; (7) Blower; (8) Blower frame; (9) Outlet air hole; (10) Control box; (11) Drying box stand; and ground wheels.

Seeds of cucumber (Beta-alpha variety) were used during the experimental work. The experimental work was carried out to study and test the parameters that affecting thermal performance and drying efficiency of the cabinet solar dryer. Theses parameters include; drying air temperature, drying air velocity, drying air relative humidity, intensity of solar radiation, and seeds moisture content. Three different thicknesses of cucumber seeds layers (5, 10, and 15 mm thick) were examined during the experimental work.

Instruments and Data Acquisition

During the experimental work, several measurements were executed using different measuring devices. Thermocouples (type K) with digital thermometer of 5 points were used to measure air temperature changes at different locations inside and outside the hourly cabinet solar dryer as shown in Fig. (2). Drying air velocities at the inlet holes and outlet hole were measured each hour to determine the mean drying air velocity using a digital hot wire type anemometer with measuring range from 0.1 to 10 m/s and accuracy of ± 0.1m/s. Drying air relative humidity was measured inside the cabinet solar dryer each hour. The intensity of solar radiation was taken from weather station far about 200 m from the location of the experiments. Moisture content of seeds was measured before and during the drying process using the method of (AOAC,1990). Samples were taken from different layers locations of the bed. The seed germination test was carried out in laboratory by keeping 100 seeds on filter papers soaked with water in petri dishes (ISTA,1976). After 5-7 days, the germination seeds were counted to determined the percentage of germination..

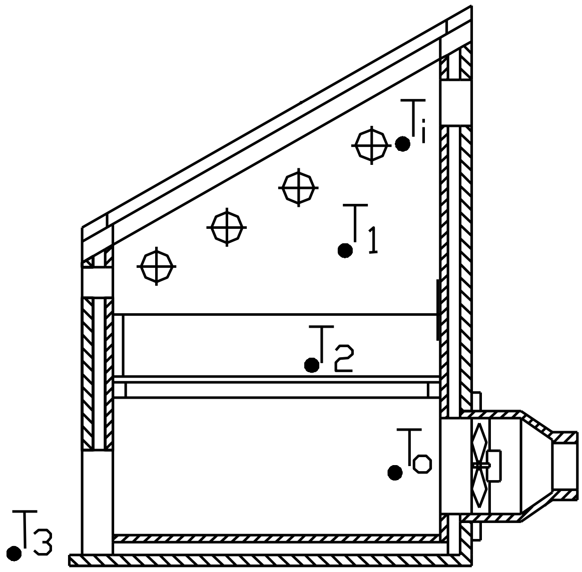

Fig. 2. Thermocouple sensors (type K) distributed at different locations inside and outside the cabinet solar dryer.

Experimental procedure

The experimental work was carried out during summer season of 2015 A cabinet solar dryer was functioned to analyse the thermal performance of the dryer during the experimental work. The thermal efficiency of the cabinet solar dryer (η_{th}) was computed using the following equation (Kalogirou (2004); ASHREA, 2005):

$$\eta_{th} = \frac{m\ C_P\ (T_1 - T_3)}{A_d\ R} \times 100\ ,\% \quad \text{-------------------------(1)}$$

$$m = A\ \ V\ \rho_{air}, \qquad kg\ s^{-1} \quad \text{-------------------------(2)}$$

Where, m, is the mass flow rate of drying air in kg s^{-1}, C_p, is the specific heat of drying air in J kg^{-1} $^oC^{-1}$, T_1 and T_3, respectively, are the air temperature inside the cabinet solar dryer and ambient air temperature in ^oC, A_d, is the net surface area of the cabinet solar dryer in m^2, R, is the solar radiation available in W m^{-2}, A, is the total area of inlet air holes in m^2, V, is the mean velocity of drying air in m s^{-1} and, ρ_{air}, is the density of drying air in kg m^{-3}.

The cabinet solar dryer receives solar radiation and converts it into useful heat energy to evaporate moisture from the cucumber seeds. The ratio of useful heat energy (Q_u) to the solar radiation flux incident on the surface of the cabinet solar dryer (Q) is the efficiency of drying process (η_d). It can be calculated from the following equation (ASHRAE, 2005):

$$\eta_d = \frac{Q_u}{A_d\,R} \times 100 \quad \text{--- (3)}$$

$$Q_u = (M_w\,h_{fg} + M_s\,C_p\,\Delta T)/3.6, \text{ Watt} \quad \text{---------------------------(4)}$$

Where, M_w, is the mass of moisture removed in kg h^{-1}, h_{fg}, is the latent heat of moisture vaporization in seeds in kJ kg^{-1}(2265 kJ kg^{-1}), M_s, is the mass of cucumber seeds in the solar dryer in kg, C_p, is the specific heat of the cucumber seeds in kJ kg^{-1} $^oC^{-1}$ (1.89 kJ kg^{-1} $^oC^{-1}$ according to (Food and Foodstuff, 2013) and, ΔT, is the temperature rise of cucumber seeds in ^oC.

The operating costs of the cabinet solar dryer for drying cucumber seeds at optimum conditions (C) was computed according to a modified form of the following equation (Awady *et al*., 1993):

$$C = (P/H)\,(1/y + I/2 + t + m) + e + (s/144) \quad \text{------------------------- (5)}$$

Where, P, is the initial price of cabinet solar dryer in LE, H, is the estimated yearly-operation in hours, y, is the estimated life-expectancy of solar dryer in years, I, is the investment or overhand rates, t, is the taxes and overhead rates, m, maintenance and repairs ratio to capital head, e, is the electric-energy costs in LE, s, is the monthly salaries and, 144, is the estimated working hours per month.

RESULTS AND DISCUSSION

The cabinet solar dryer has been operated satisfactorily for approximately ten days without any malfunction. For the duration of the experimental work there were 128 hours of bright sunshine of which 80 hours (62.50%) were recorded and used in the drying process of cucumber seeds. Air was continually cycled through the cabinet solar dryer in clear sky conditions. The daily average solar energy available during the experimental period was 16.217 kWh (58.381 MJ). There were obvious differences in solar energy available for the days recorded during the drying period. The differences in daily solar energy available can be attributed to the effect of the atmospheric conditions during the experimental period. There were also clear differences in the hourly average solar energy available from 9 to 16 h. These obvious differences can be attributed to the variation in solar altitude angle from early morning to late afternoon. The daily average solar energy available during the test period was 9.664 kWh (34.790 MJ) of which 5.830 kWh (20.988 MJ) was converted into useful heat energy collected. The relationship between air temperature (drying air temperature (T_1), seeds temperature (T_2) ambient temperature (T_3)) and drying time for the studied three different layers thickness of cucumber seeds is shown in Fig. (3). It can be observed a variation in air temperatures with solar time. It evidently revealed that, the diurnal variations amplitude under solar cabinet dryer were more significant. The maximum air temperature inside the solar cabinet dryer during the experimental period reached 50.ºC, which was achieved at and around noon. The drying air temperature was ranged between 39 and 50°C while; the seeds temperature ranged from 29 – 40, 28 – 37 and 22 – 34 for the layer thicknesses of 5 , 10 and 15 cm, respectively in the days had 13 sunshine hours with intensity of solar radiation ranged between 435 and 675 W/m^2 for all layers thickness. During the daylight the temperature of the drying air was usually greater than that outside the solar dryer (ambient air temperature).

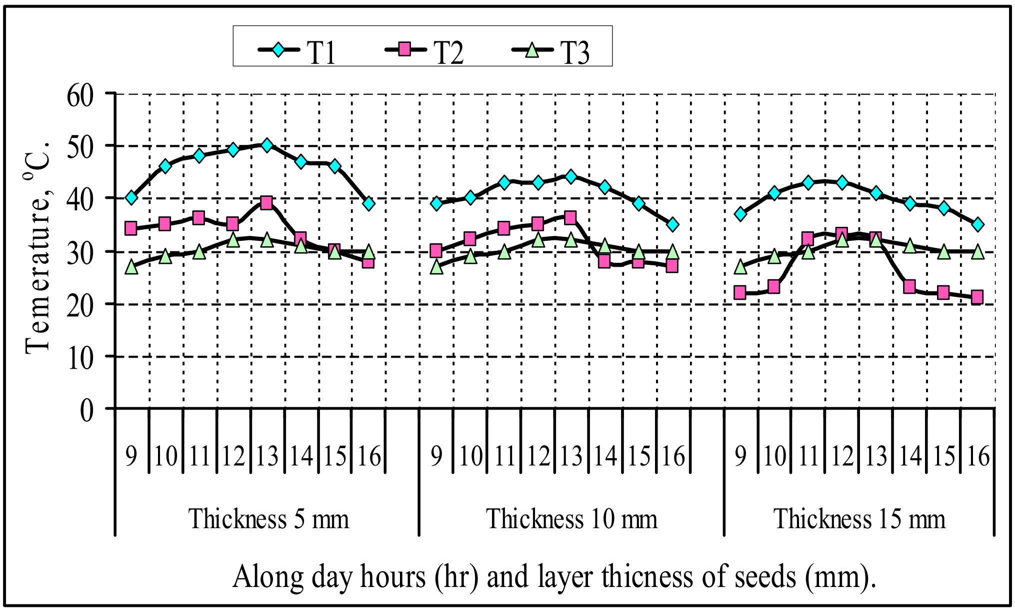

Fig. 3. Drying air temperatures (T_1), seeds temperature (T_2) and ambient air temperature (T_3) as a function of drying time for the three different layers thickness (5, 10, and 15 mm thick).

The daily average total heat loss from the solar cabinet dryer during the drying period was 3.747 kWh (13.489 MJ). The daily average heat energy losses by conduction and convection, and thermal radiation were 1.297 kWh (4.669 MJ), 2.070 kWh (7.452 MJ), and 0.380 kWh (1.368 MJ), respectively. Accordingly, the heat lost due to conduction and convection, air exchange by the extracting fan, and thermal radiation, respectively, represented 34.62%, 55.25%, and 10.13% of the total heat losses (3.747 kWh) from the solar cabinet dryer.

During the drying period, the inside and outside air relative humidity of the solar cabinet dryer ranged from 43.8 to 84.3% and 46.7 to 94.8%, respectively. The daily average inside and outside air relative of the solar dryer during the drying period, , was 54.7% and 68.6%, respectively. This means that, the inside air relative humidity of the solar dryer was lower than that of the outside by 13.9%. These variations in air relative humidity occurred due to the air temperature inside the solar dryer was higher than that of the outside and the mass flow rate of air passing through the solar dryer. Fig. (4) illustrates the relations between the temperature of drying air (T_1) and air relative humidity (RH) for the three different layers thickness of of cucumber seeds during the drying process. The air temperature inside the solar dryer at that time was sufficient to diffuse more moisture from the inside air. Similar cyclic changes in air relative humidity occurred at the peak of the heating cycle of air inside the solar cabinet dryer. The air relative humidity inside the solar dryer was decreased by 13.9%, at the peak of solar heating cycle (at and around noon) as illustrated in Fig. (4). Lowering the inside air relative humidity of the solar cabinet dryer playing an important role in the drying process. As the air relative humidity inside the solar dryer is decreased the ability of that air to carry on more moisture is increased and thus the drying process is more efficient.

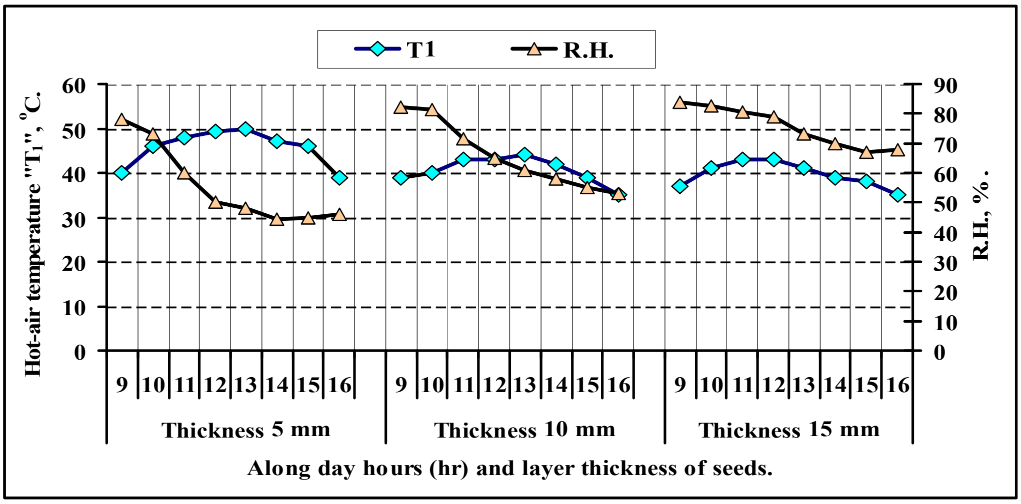

Fig. 4. Drying air temperatures and air relative humidity as a function of drying time for the three different thickness of layers (5, 10, and 15 mm).

The effect of layers thickness of cucumber seeds (5, 10 ,and 15 mm thick) on drying air velocity as a function of drying time is plotted in Fig.(5). The minimum and maximum air velocities during the experimental work were 0.26 and 1.12 m/s which recorded in sunny days (13 sunshine hours) at temperatures of 41 and 50°C, respectively. . The inlet air-velocity increased by increasing the drying air temperature and decreasing the layers thickness of cucumber seeds due to decreasing the air density and air flow resistance. Air velocity is also playing an important role in the drying process. As the air velocity inside the solar dryer is increased the ability of that air to carry on more moisture is increased and thus the drying process is more efficient.

The relationship between moisture content of cucumber seeds and drying air temperature as a function of drying time is shown in Fig (6). The initial moisture content of the cucumber seeds was constituted of 0.1890 gram of water per one gram of wet matter under the three different thicknesses. The initial moisture content during the drying period for the three different seeds layers thicknesses was reduced to the final moisture contents of 0.0630, 0.1350, and 0.1690 gram of water per one gram of wet matter for the three different thicknesses (5, 10, and 15 mm), respectively. In reality, the solar dryer reduces drying times in two ways. Firstly, the translucent or transparent glazing materials over the collection area traps heat energy inside the solar dryer, causing an increase in the temperature of drying air. Secondly, the flexibility of enlarging the solar collection area allows for greater collection of the solar energy as occurred in shape of cucumber seeds.

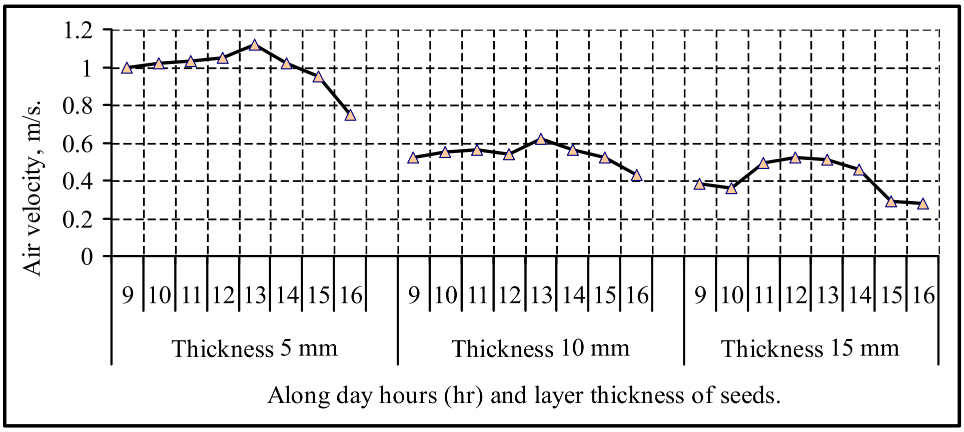

Fig. 5. Effect of layers thickness on the air velocity as a function of drying time.

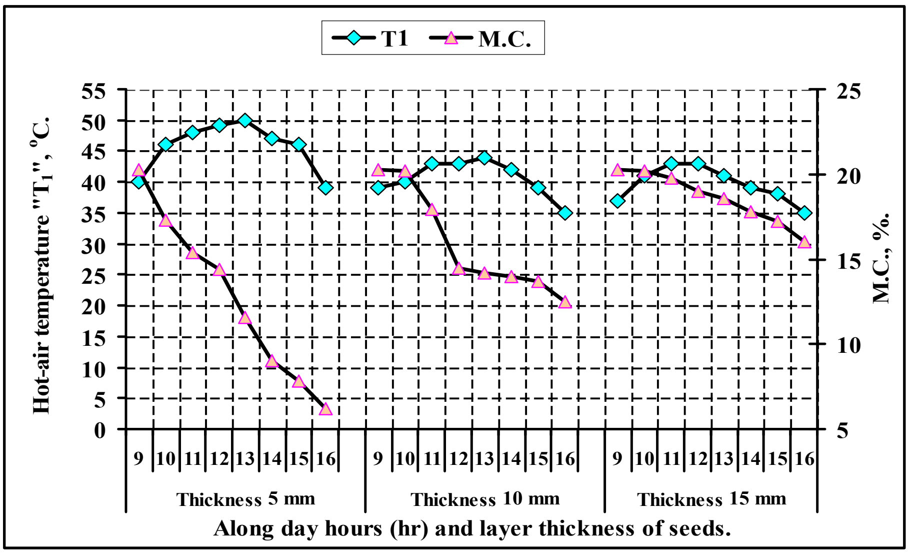

Fig. 6. Effect of drying air temperature on moisture content of cucumber seeds during the drying process.

In the solar cabinet dryer, a part of the incidence solar radiation on the glass cover was reflected back to the surrounding atmosphere and the remaining part was transmitted inside the solar dryer. Further, a part of transmitted solar radiation is reflected back from the surface of the cucumber seeds. The remaining part was absorbed by the surface of the seeds. Due to the absorption of solar radiation, seeds temperature increased and emitted long wavelength radiation which was not allowed to escape to the atmosphere because of presence of glass cover unlike open sun drying. Solar radiation passed through the glass cover converted into low-grade heat when it struck an opaque surface. This low-grade heat was then trapped inside the solar dryer by what is known as the "greenhouse effect" phenomenon. Thus the temperature above the cucumber seeds inside the solar dryer became higher. The glass cover serve one more purpose of reducing direct convective losses to the surrounding atmosphere which further became beneficial for rising drying air temperature. However, convective and evaporative losses occurred inside the solar dryer from the heated seeds. The moisture was taken away by the air entering into the solar dryer by the mass flow rate from the top and leaving through another opening provided at the bottom of the dryer.

The relationship between the thermal efficiency (η_{th}) and the drying air temperature during the drying process for the three different thicknesses of cucumber seeds is illustrated in Fig. (7). The thermal efficiency of the solar cabinet dryer is the ratio of useful heat gain to the solar energy available. The daily average thermal efficiency of the solar dryer during the drying time was 48.52%, 43.34%, and 37.13% for the three different thicknesses of cucumber seeds, respectively. Consequently, 51.48%, 56.66%, and 62.87% of the solar energy available inside the solar dryer was lost respectively. The highest overall thermal efficiency (63.76%) was achieved at 10 am and drying air temperature of 48.6°C with thickness 5 mm of cucumber seeds, while, the lowest value (25.50%) occurred before sunset (at 16.00 h) with thickness of 15 mm. The highest thermal efficiency was 63.7 % at hot-air temperature 48°C. The highest thermal efficiency is due to increase hot-air temperature difference and ambient temperature.

The dried cucumber seeds from different thicknesses of drying process were assigned to test the germination percentage of seeds using an electric incubator and the method of (AOAC,1990) was conducted.. The obtained results showed that, the germination of cucumber seeds dried by the cabinet solar dryer was ranged between 97.1 and 97.4% under different seed drying times, drying air temperature, and air relative humidity. The high level of germination percentage of cucumber seeds may be due to the seeds bulk temperature not exceeded 40% during the drying process. The drying costs using layer thickness of 5 mm was found to be 292 LE/ton.

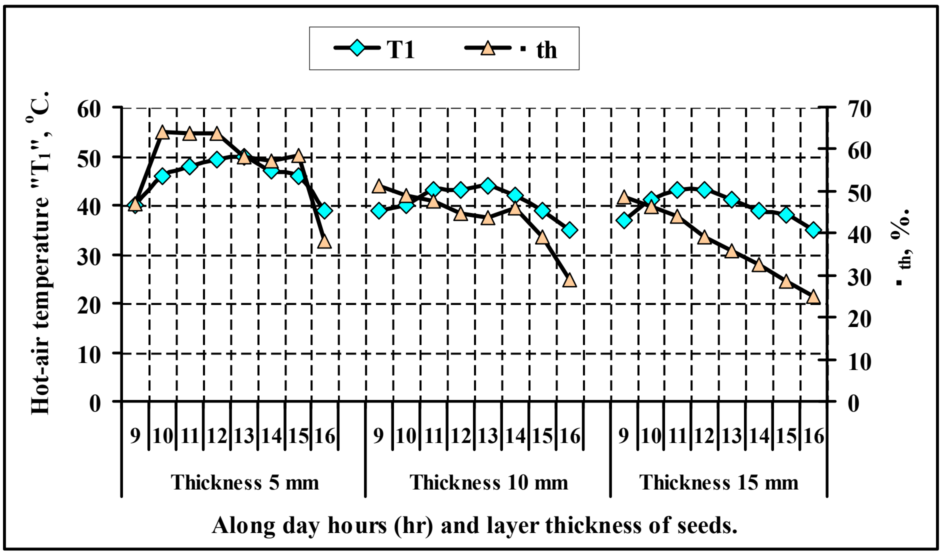

Fig. 7. Effect of drying air temperature (T_1) on the thermal efficiency of solar cabinet dryer "η_{th}" for the three different thicknesses of cucumber seeds during the drying period.

CONCLUSION

The solar cabinet dryer has been operated satisfactorily during the experimental work without any malfunction. During this research work there were 128 hours of bright sunshine of which 80 hours (62.50%) were recorded and used in the drying process of cucumber seeds. From the present research study, it can be drawn the following conclusions:

(1) The minimum and maximum air velocities during the experimental work were 0.26 and 1.12 m/s which recorded in sunny days (13 sunshine hours) at temperature 41 and 50°C.

(2) The initial moisture content of the cucumber seeds was constituted of 0.1890 gram of water per one gram of wet matter under the three different thicknesses. The initial moisture content during the drying period for the three different thicknesses was reduced to the final moisture contents of 0.0630, 0.1350, and 0.1690 gram of water per one gram of wet matter for the three different thicknesses (5, 10, and 15 mm), respectively.

(3) The daily average thermal efficiencies of the solar dryer during the drying time were 48.52%, 43.34%, and 37.13% for the three different studied types thickness of cucumber seeds, respectively.

Ultimately, It can be recommended that, the cabinet solar grain dryer is appropriate dryer for small farmer because it provides drying air temperature ranges between 41 and 50°C This dryer gave a germination percentage ranged from 97.1 to 97.4 and a minimum drying cost (292 LE/ton of cucumber seeds) by using a layer thickness of 5 mm.

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تجفيف بذور الخيار بإستخدام مجفف شمسى يعمل بنظام الدفع الجوى للهواء

أحمـــد عزت خاطر

معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – الدقى – الجيزة

يهدف هذا البحث إلى دراسة بعض العوامل المؤثرة على تجفيف بذور الخيار كتقاوي منتقاة باستخدام مجفف شمسي يعمل بمروحة لسحب الهواء من أسفل المنتج بأقصى كفاءة ممكنة، وذلـــك للحفاظ على تقاوي منتقاة بالإضافة إلى الحفاظ على البيئة من التلوث، و الاســـتفادة مـــن الأســـاليب الحديثة في تجفيف البذور مع زيادة نسبة الإنبات لاستخدامها كتقاوي عالية الجودة و تتلخص النتـــائج الرئيسية لهذه الدراسة فى التالي :-

١- يتراوح الحد الأدنى والحد الأقصى لدرجة حرارة الهواء داخل المجفف أثناء وجود البذور بين ٤١ و ٥٠° درجة مئوية بينما تراوحت درجة حرارة البذور بين ٢٢- ٤٠° م.

٢- تراوحت الرطوبة النسبية للهواء داخل المجفف أثناء وجود المنتج بين ٤٨ – ٧٣ ٪ وسرعة الهواء بين 0.51 و ١.١٢ متر / ثانية.

٣- تم الحصول على أقل محتوى رطوبى للبذور ٧.٢ ٪ على مدار اليوم أثناء عملية التجفيف في طبقة بذور ذات سمك ٥ مم و كانت أعلى كفاءة حرارية ٦٣.٧ ٪ .

٤- تراوحت كفاءة التجفيف الشمسي بين ٣٩ ٪ و ٦٤ ٪ من الساعة ١١ صباحاً حتى الساعة ٣ مساءاً على التوالي. وكان متوسط قيم كفاءة التجفيف لبذور الخيار هي ٣٢.٣ ٪ طوال اليوم.

٥- تراوحت نسبة إنبات بذور الخيار بين ٩٧،١ – ٩٧،٤ ٪. كما تم الحصول على الحد الأدنى لتكلفة عملية التجفيف (٢٩٢ جنيه / طن) باستخدام طبقة بذور ذات سمك ٥ مم.