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UTILIZATION OF SOLAR ENERGY FOR DRYING SUGAR BEET TOPS

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ABSTRACT

A study was carried out to test and evaluate a green house type solar dryer for drying sugar beet tops under three different levels of air velocity (0.4, 0.8, and 1.2 m/sec), three different lengths of beet tops (3, 6, 9 cm) and two different treating conditions (with crushing, and without crushing). The changes in sugar beet tops moisture content was monitored versus the drying time until reaching the proper moisture content of about (12-13 % w.b.). Solar radiation flux incident, bulk temperature of tops, air temperature and relative humidity, overall thermal efficiency of the dryer and the protein content of the dried tops were determined. The results showed that, the hourly average available solar radiations ranged from 598.26 to 663.85 W/m^2 during the experimental work. Also, the solar collector of the dryer could increase the air temperature by about 12.6, 12.31 and 12.81^{o}C and decrease the air relative humidity by about 26.06, 23.67 and 20.97 % for air velocity of 0.4, 0.8, and 1.2 m/sec respectively. The reduction rate in moisture content of sugar beet tops was varied and increased with the increase of drying air velocity, decrease of chopping length and for the crushed samples in comparison with the not crushed samples. Also, the constant drying rate period was not detected for all studied levels of drying air velocity, while all the drying process occurred during the falling rate-drying period. The result also show that the use of the green-house type solar dryer with chopping and crushing of the green tops could decrease the drying time of sugar beet tops by about 47 to 59 h in comparison with the traditional drying method which has been taken about 78 hours. The thermal efficiency of the dryer ranged from 34.12 to 22.96 % and the protein content of the dried tops ranged from 12.57 to 14.52 % on DM basis.

INTRODUCTION

The problem of animal feed shortage in Egypt is well recognized. Several efforts had been done to improve the nutritive value of agricultural by-products e.g. rice straw, wheat straw, corn stalk , sugar cane, basse vines of broad bean, squash vines and other vegetable wastes for increasing the available feed. (Ali 1996).

Forage crop residues and by-products are usually consumed fresh by domestic animals. However, it is possible to conserve them for use during future periods of feed shortage. Conservation can be achieved by sun drying (hay), artificial drying (meal), and addition of acids or fermentation (silage).

Sugar beet is one of the most important crops for Egyptian farmers; this is due to the yield for its roots and vines. The cultivated area of sugar beet on year 2008-2009 was 248,871 fed. yeilded about 5138190 tons sugar beet roots and 1493226 tons beet tops (MOA, 2009).

Sugar beet tops (SBT) considered as one of the important by-product after harvesting sugar beet crop. Salo (1978) found that when sugar beet grows in the Finnish climate, the weight of tops reached the same amount as for the beet crop, (about 25 - 30 ton./ha.).

Due to high moisture content in the fresh beet tops (about 80-85% w.b), it is imperative for the crop to be infested with fungus and other micro-organisms (Bendary *et al.*, 1992).

Drying is one of the common techniques for preservation of food and other products. The major advantage of drying process is the reduction of moisture content to a safe level that allows to extend the storage of dried products. The removal of water from foods provides microbiological stability and reduces deteriorative chemical reactions. Also, the process allows a substantial reduction in terms of mass, volume, packaging requirement, storage and transportation costs with more convenience (Okos *et al.*, 1992).

In Egypt, natural sun drying is one of the most common ways to conserve agricultural products. Considerable losses may occur during natural sun drying due to various influences, such as rodents, birds, insects, rain, storms and microorganisms. The quality of the dried products may also be lowered significantly (Lutz *et al.*, 1987; El-Sahrigi *et al.*, 1993).

Egypt is one of the countries, which has solar energy in abundance. It lies within the tropical and sub-tropical regions. It has a value of about 2.2 to 9.4 kW of solar energy per square meter per day, and sunshine duration per year extended to about 3000 to 4000 hours (Abdelatif, 1989; EL-Awady *et al.*, 1993).

To overcome the existing preservation problem of agricultural crops in Egypt, the introduction of solar dryers seems to be a promising way since the available amount of solar energy is sufficient to provide the heat requirements for small dryers. (Tayel and Wahby 1989).

Studying the possibility of utilizing solar energy for heating air inside a green-house and the use of that heated air in drying some agricultural crops under Egyptian conditions has been investigated by many investigators (Kamel 1991, Abdelatif and Helmy, 1992, El-Sahrigi, *et al.*, 1993). However, there is no readily available information about utilization of the green-house type solar dryers for drying agricultural residual especially sugar beet tops.

The objective of the present work is to study the possibility of using the green-house type solar dryer for drying high moisture sugar beet tops under Egyptian climatic condition. The system will be compared with natural sun drying method.

MATERIALS AND METHODS

The present work was carried out at Rice Mechanization Center, Meet El-Dyba, Kafr El-Sheikh Gov. in cooperation with Sakha Animal production Research Station during sugar beet harvesting season of 2007.

Testing Crop:

Sugar beet tops of variety (*monogerm*) were harvested and transported to the experimental station of Rice Mechanization Center (R.M.C) at moisture content of about 83% to 84 (w.b). The harvesting process was done manually immediately before each experimental run and the required amount of green tops for different drying runs were arranged in different sets for chopping and crushing processes.

Chopping and Crushing Machine:

The main sample of sugar beet tops of each experimental run was divided into two sub samples, the first sub sample was only chopped by the chopping unit of the Japan made forage chopper Model (Star –FC18C) at three different lengths of (3, 6 and 9 cm), while the second sub- sample was chopped to similar lengths and passed through the crushing unit of the machine for getting chopped and crushed pieces of tops.

The Green- House Type Solar Dryer:

Six identical units of the green-house type solar dryer were constructed at the workshop of Rice Mechanization Center, Meet El-Dyba, Kafr El-Sheikh Gov. The dimensions of the dryer vinyl house which used as solar collector are 100 cm wide, 200 cm long and 80 cm high. The dimensions of the drying chamber are 100 cm wide, 200 cm long and 10 cm high.

The dryer constructed of iron frame consists of curved pipes of 1/2" assembled in the circumference of a 2" rectangular iron base. The iron frame was covered by a clear plastic film with thickness of 200μ. Wire netting makes a floor was fixed at 20 cm over the bottom of the green-house forming a plenum chamber under the wire netted floor. An axial type suction fan and a duct for air suction were stetted at the back side of the dryer and a window for air inlet was opened at the front side. The window's dimensions were 30 x 15 cm, whenever the fan is rotated; the window must be opened and suspending with strings. To protect the direct exposure of the sugar beet tops to sunrays and to increase the collection efficiency of solar radiation, a perforated plastic black net was used for covering the surface of the drying chamber. Fig. (1) Presents a schematic diagram for the experimental scale green-house type solar dryer.

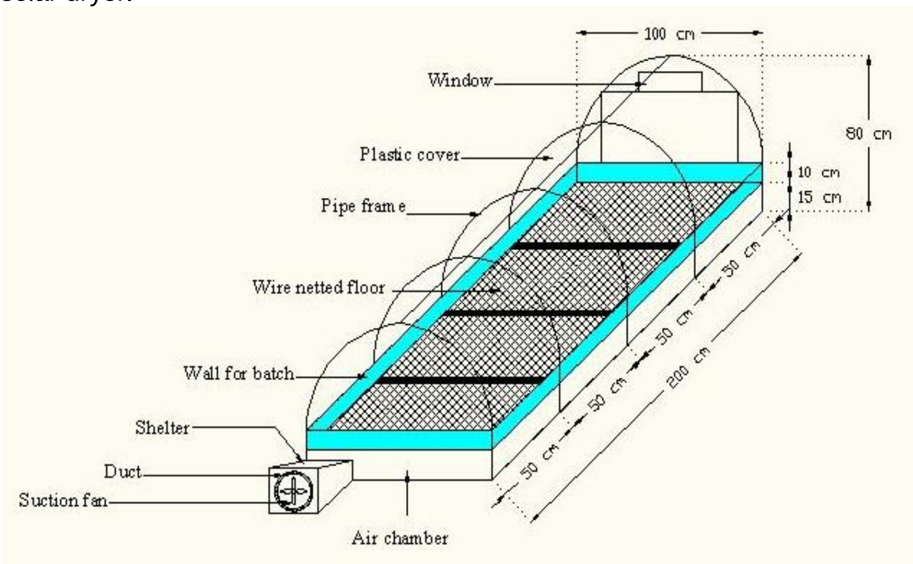

Fig.(1): Schematic diagram of the green-house type solar dryer

Experimental Treatments:

The experimental treatments of the drying process included two different drying methods (forced convection solar drying and traditional sun drying), three different cutting lengths of sugar beet tops (3, 6 and 9 cm), two different chopping conditions (with crushing and without crushing) and three different air velocities (0.4, 0.8 and 1.2 m/s).

Test Procedure:

Before each during run, the initial moisture content of the freshly harvested sugar beet tops was determined and a sample of green tops was divided into two sub-samples. The first sub-sample was divided into three sub-sub samples each one was poured through the cutting unit of the cutting and crushing machine to get three different tops lengths of 3, 6 and 9 cm without crushing, while the second sub sample was also divided into three sub-sub samples and poured through the cutting and crushing units to get cut and crushed samples of 3, 6 and 9 cm. Prior to each experimental run, the developed six identical dryers were adjusted for the required levels of air velocity using a hot wire type anemometer by taking different readings at the dryer window and the average of the readings was considered as air velocity. After making sure that the dryers working at stable condition, the dryers beds were loaded with the obtained six different samples conditions of sugar beet tops and distributed uniformity in a single layer at capacity of 15 kg/dryer. All the tested treatments were covered by similar black nets to protect direct exposure of sugar beet tops to sunrays and to increase the collection efficiency of solar radiation. Air temperature, velocity and relative humidity were measured every hour during the drying process at different point as shown in Fig. (2). Moisture content was measured before the drying process and throughout the drying period at one hour intervals at different places of each drying bed. The drying process was kept running until the moisture content almost ceased to approach the proper final moisture content of samples (around 12 to 13% (w.b).

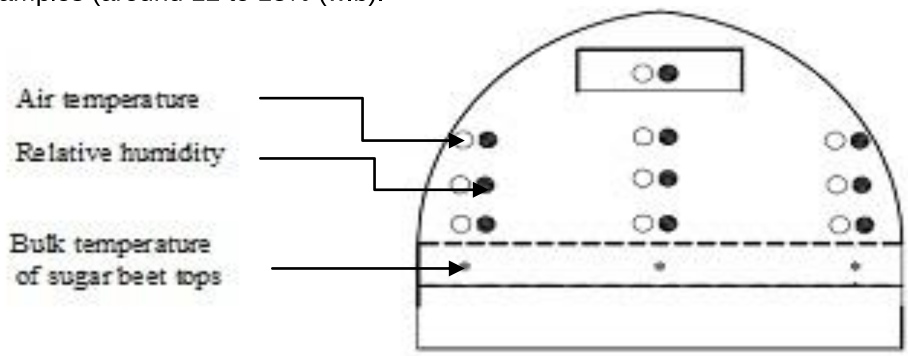

Fig. (2): Measuring points of air temperature and relative humidity inside and outside the green house type solar dryer and the bulk temperature of sugar beet tops.

The Traditional Drying Method:

The traditional drying method used in this study was similar to the method used by farmers to dry sugar beet tops in the field. At this method, the freshly harvested sugar beet tops are spread on the floor and turned several times until it reaches the desired moisture content.

Experimental Measurements & Measuring Instruments:

Solar energy flux incident:

A solar radiation sensor, Model (H-201) was used for sensing the solar radiation. It was connecting to a chart recorder Model (YEW 3057) to convert the voltage signal to an equivalent reading in kWh/m^2. The solar radiation was measured and recorded during the period started from 8 am to 5 pm.

Moisture Content of Sugar Beet Tops:

The moisture content of sugar beet tops was measured every one hour at three different positions of each experimental dryer using the air oven method at 60 ^oC for 48 h, as recommended by (ASAE, 1998). The average of three readings was taken as an overall average of hourly change of moisture content.

Sugar beet tops bulk temperatures:

Thermocouples were used to measure the drying air temperatures passed through the bulk of sugar beet tops. The thermocouples were connected with an interface analog digital converter, CHINO Model (TE-1500) to record the temperature readings every hour. The used thermocouples were of type (K) with accuracy of ± 0.1°C.

Air temperature and relative humidity:

The air temperature and relative humidity inside and outside the greenhouse type solar dryer were measured by a digital temperature and humidity meter, CHINO Model (HN-K). The measurements were done every one hour.

Air velocity:

A hot wire anemometer model (Kanomax 24-6111) was used to measure the inlet air velocity at different points of the dryer window in m/s the average of 6 readings was taken as air velocity.

Over-all thermal efficiency of the dryer:

The overall efficiency was calculated for different drying runs using the equation of (Jindal and Reyes, 1987) as follows:

$$\eta = \frac{W_W * L}{Q * 3600} * 100 \qquad \text{……………………………………} (1)$$

Where:

η = thermal efficiency, %

W_W = water evaporated from the sugar beet tops, kg

L = latent heat of vaporization of water, (2668) kJ/kg

Q = total energy flux incident on the dryer, kW.

RESULTS AND DISCUSSION

Solar Radiation:

To study the thermal performance of the solar dryer it was imperative to consider the amount of solar radiation during the drying process .The hourly average solar radiation available during the period of experimental work in Meet El-Dyba area (Kafr El-Sheikh Gov.) were measured and recorded. The hourly average available solar radiations during the experimental work ranged from 598.26 to 663.85 W/m^2. Figs (3) through (5) show the measured solar energy flux incident during the experimental work at air velocity of 0.4, 0.8 and 1.2 m/sec respectively. In general, the solar radiation gradually increased from sunrise till it reached the maximum value at noon, it then decreased gradually until it reached the minimum value at sunset. The observed variation in solar energy available during the drying period affected the dryer effectiveness in heating air and the differences in air temperature and relative humidity inside and outside the solar collector.

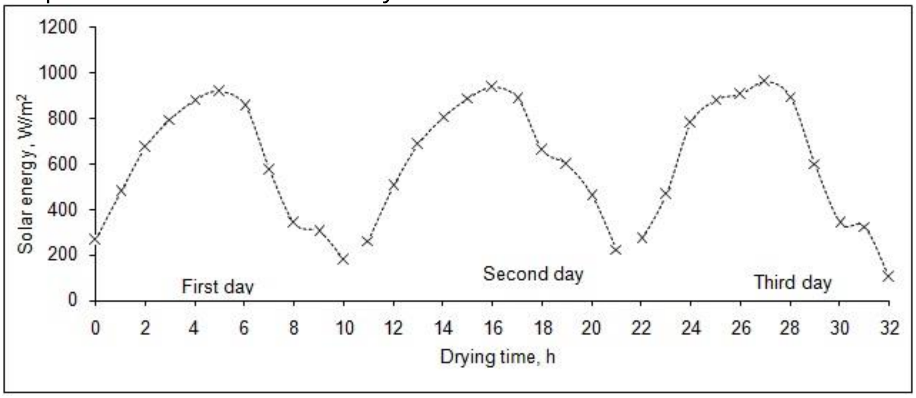

Fig. (3): Solar radiation flux incident as related to drying time during the period of experimental work at air velocity of 0.4 m/sec.

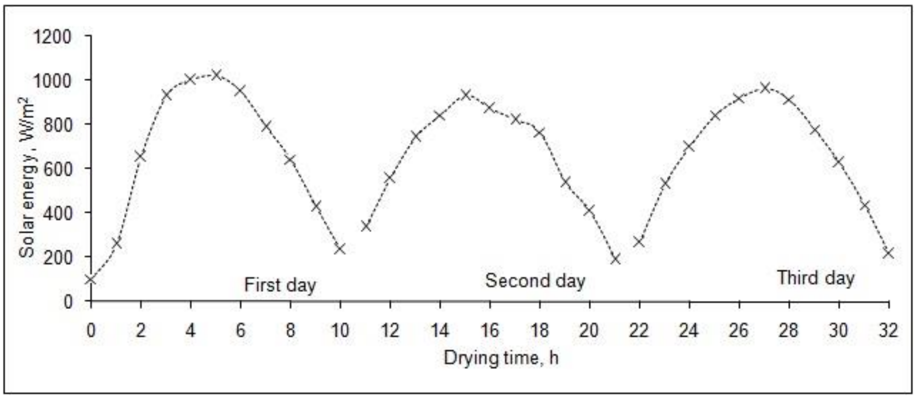

Fig.(4): Solar radiation flux incident as related to drying time during the period of experimental work at air velocity of 0.8 m/sec.

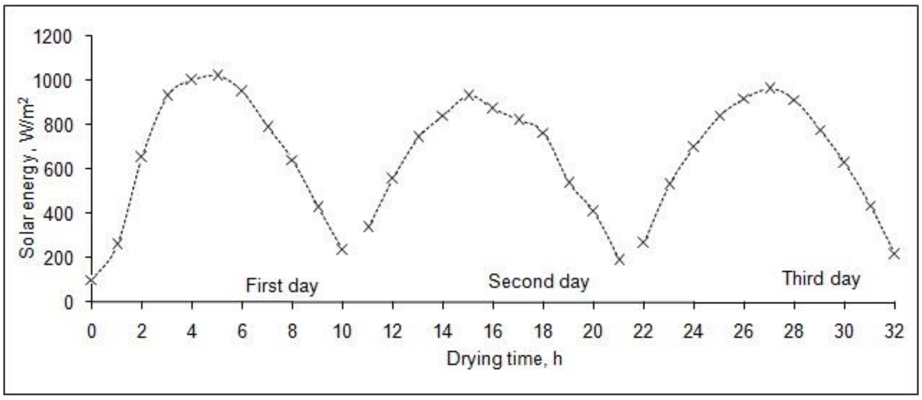

Fig. (5): Solar radiation flux incident as related to drying time during the period of experimental work at air velocity of 1.2 m/sec.

Air Temperature and Relative Humidity:

As air pass through the dryer it was first heated in the solar collector (green house), then it was cooled and humidified as it pass through the drying bed containing the green tops. Following this, the air moves downwards through the wire net of the drying bed and exhaust out of the dryer through the suction fan. Figures (6) and (7) present the temperature and air relative humidity profiles at different positions outside and inside the dryer (ambient, solar collector and plenum chamber). As shown in the figures the average measured ambient air temperature outside the dryers was 29.89^{o}C while the air relative humidity was 54.26%. As the air pass through the solar collectors of the tested dryers containing chopped green tops the average air temperature increased to 41.49, 41.2 and 41.7^{o}C while the air relative humidity decreased to 28.2, 30.59 and 33.29% for air velocities of 0.4, 0.8 and 1.2 m/sec respectively. This means that, the solar collectors of the dryers increased the air temperature by about 12.6, 12.31 and 12.81^{o}C and decreased the air relative humidity by about 26.06, 23.67 and 20.97%.

Bulk Temperature of Sugar Beet Tops:

Bulk temperature of sugar beet tops was measured at different position of the drying bed, (shown in Fig. 2). In general, the bulk temperature of all tops lengths steadily increased with time till approaching the drying air temperature inside the solar collector. Then, it was gradually decreased with the drying time. Following this stage and near the end of the drying process a noticeable increase of bulk temperature was observed as the moisture content of the drying tops decreased and approached the final moisture content as shown in Figures (8) and (9). At the minimum air velocity of 0.4 m/s, the recorded average bulk temperature for the chopped tops at chopping lengths of 3, 6, and 9 cm were 38.06, 36.68, and 39.03 °C, respectively. The corresponded values for the chopped with crushing tops were 36.25, 37.38, and 37.99 °C respectively. While at the maximum air velocity of 1.2 m/s the recorded average bulk temperature for chopped tops were 35.95, 36.58, and 37.60°C, respectively and the corresponded values for chopped with crushing tops were 34.39, 35.17, and 36.16 °C, respectively.

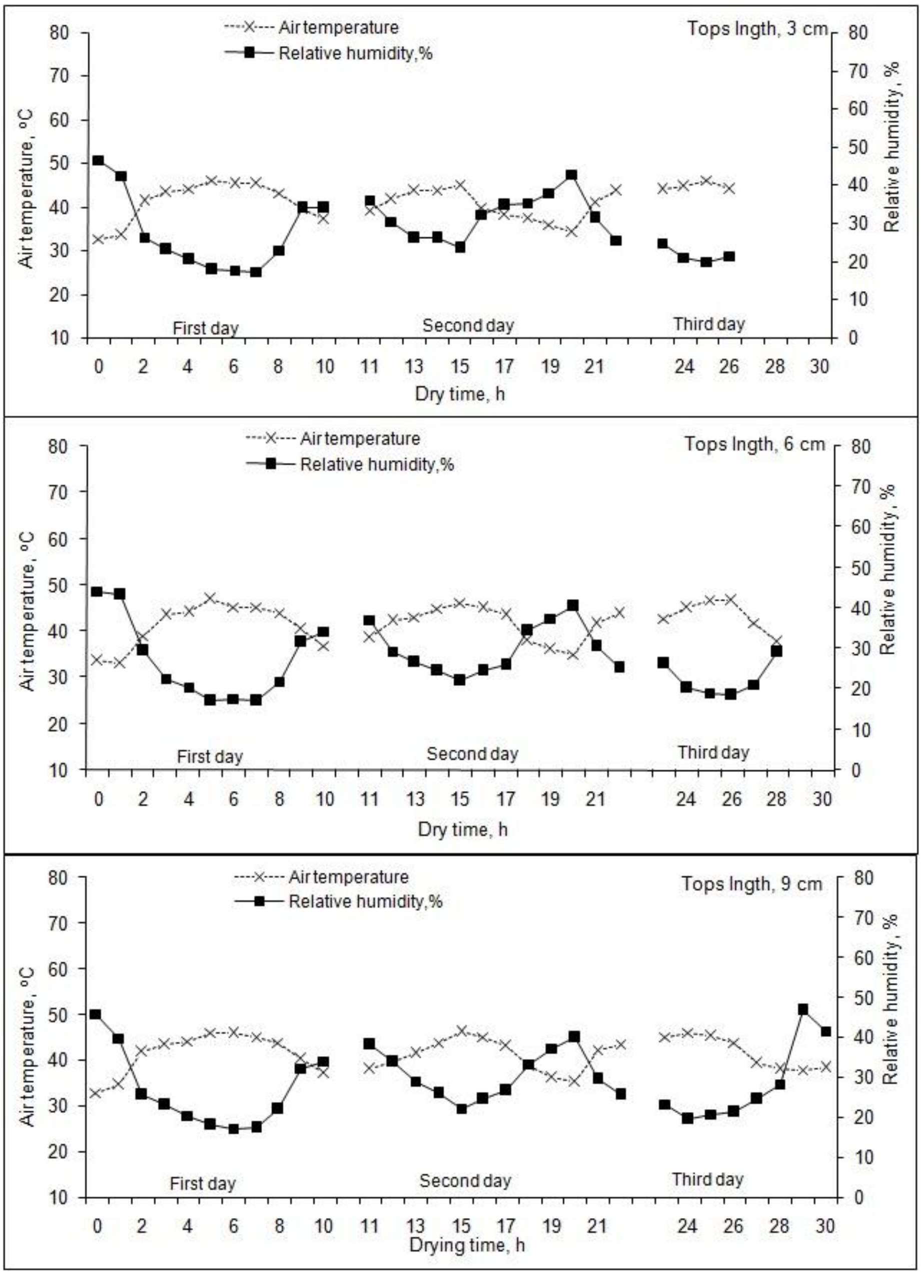

Fig. (6): Air temperature and relative humidity as related to drying time using the minimum air velocity of 0.4 m/sec (chopped green tops).

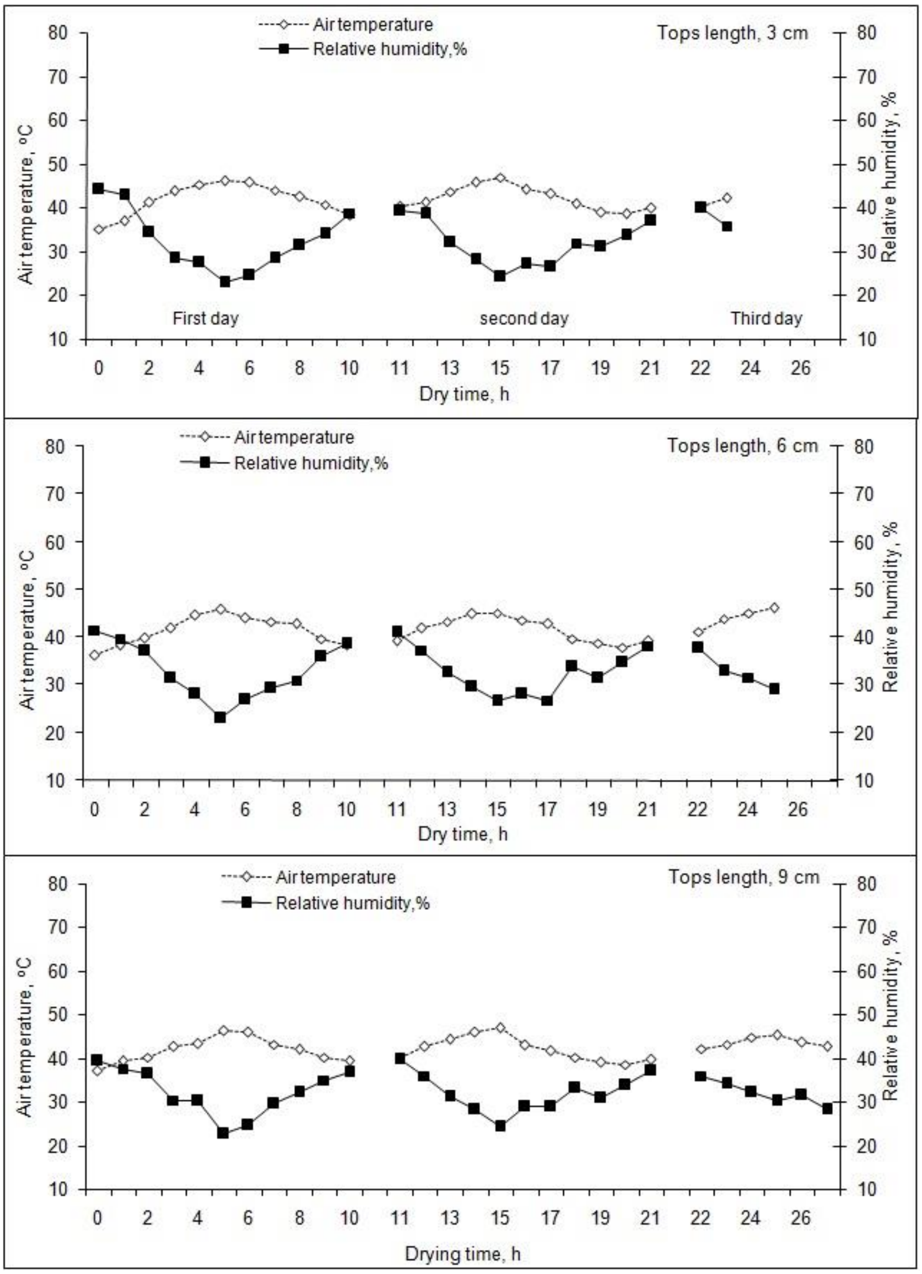

Fig. (7): Air temperature and relative humidity as related to drying time using the maximum air velocity of 1.2 m/sec (chopped green tops).

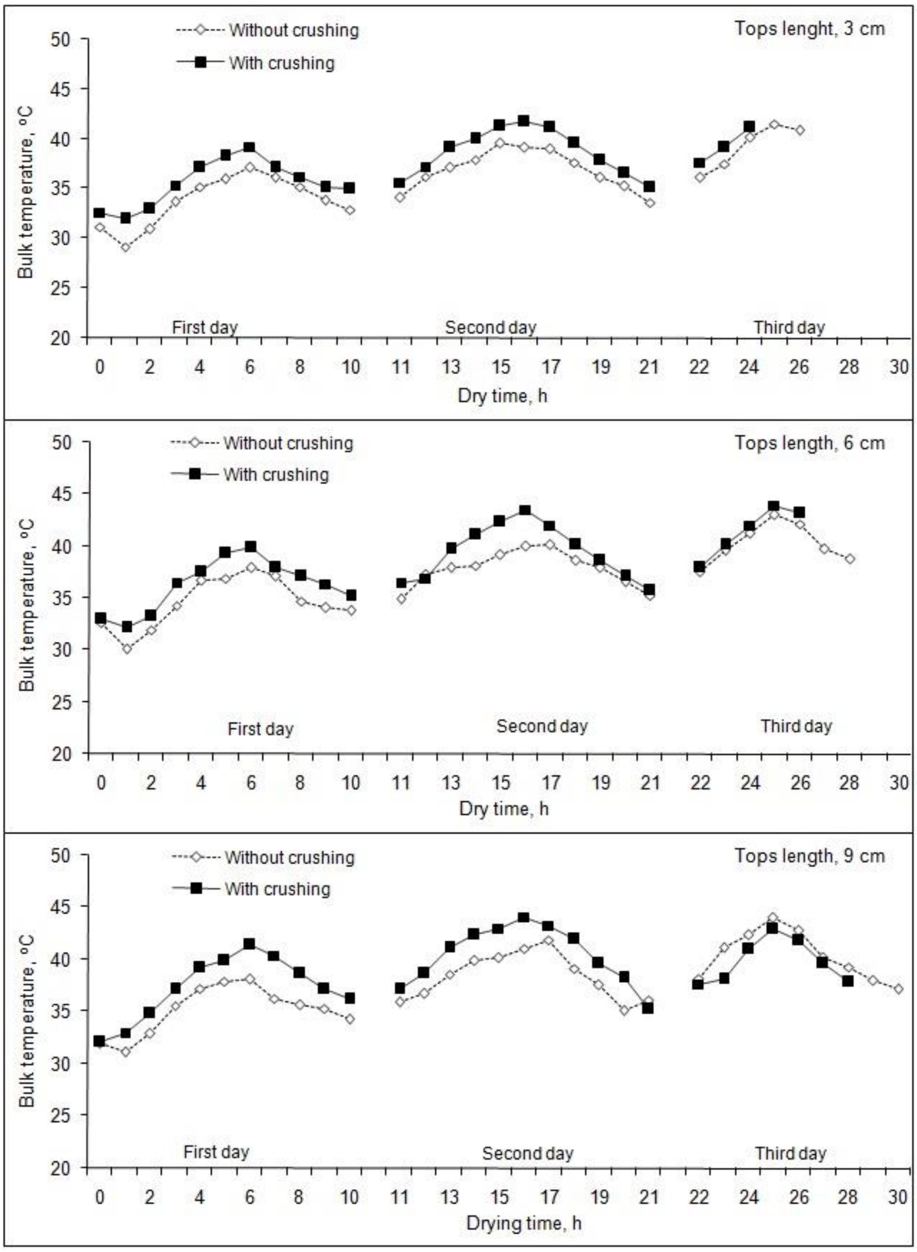

Fig.(8): Bulk temperature of sugar beet tops as related to drying time at air velocity of 0.4 m/sec.

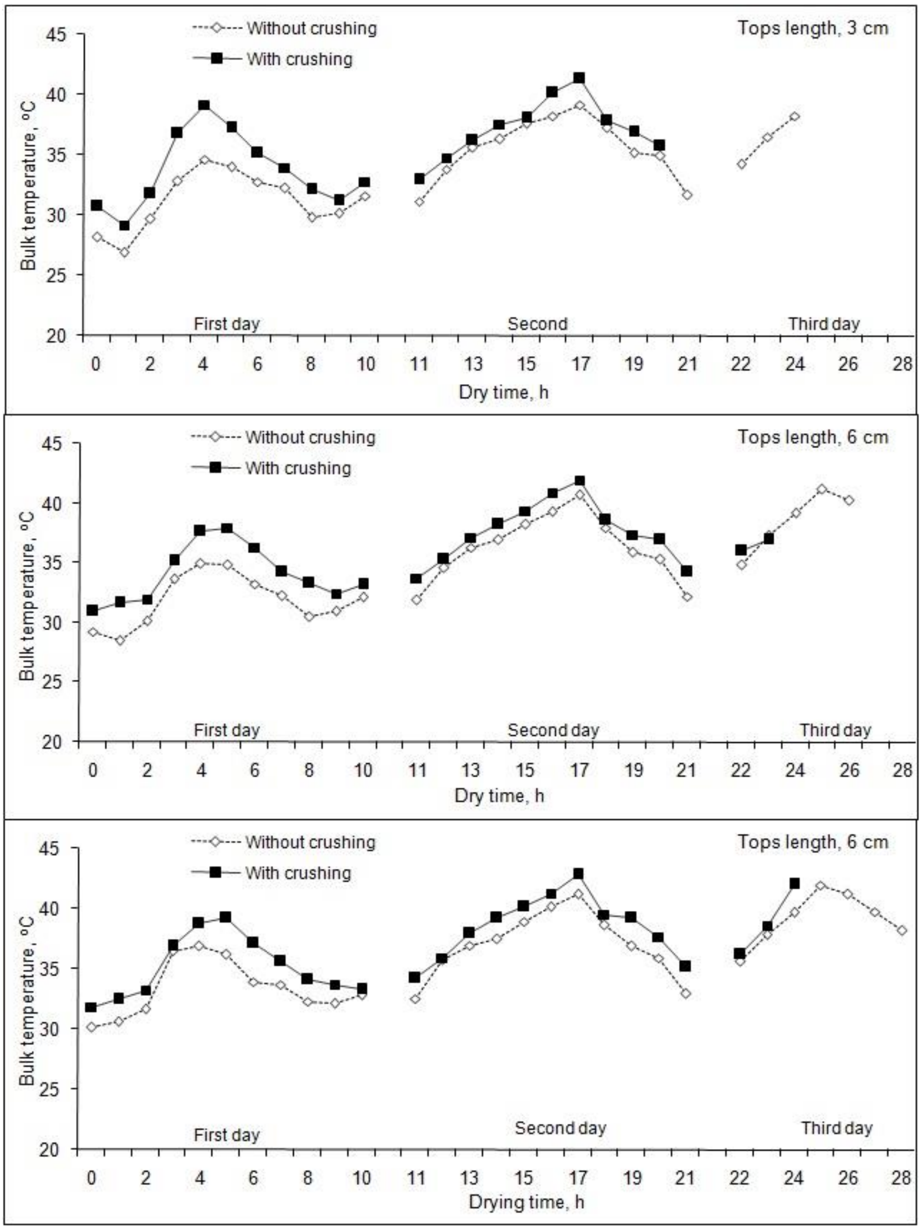

Fig. (9): Bulk temperature of sugar beet tops as related to drying time at air velocity of 1.2 m/sec.

Moisture Content of Sugar Beet Tops:

Figs. (10) and (11) illustrate the change in sugar beet tops moisture content as related to drying time at different levels of drying air velocity, different top lengths, and different tops conditions (with crushing and without crushing).

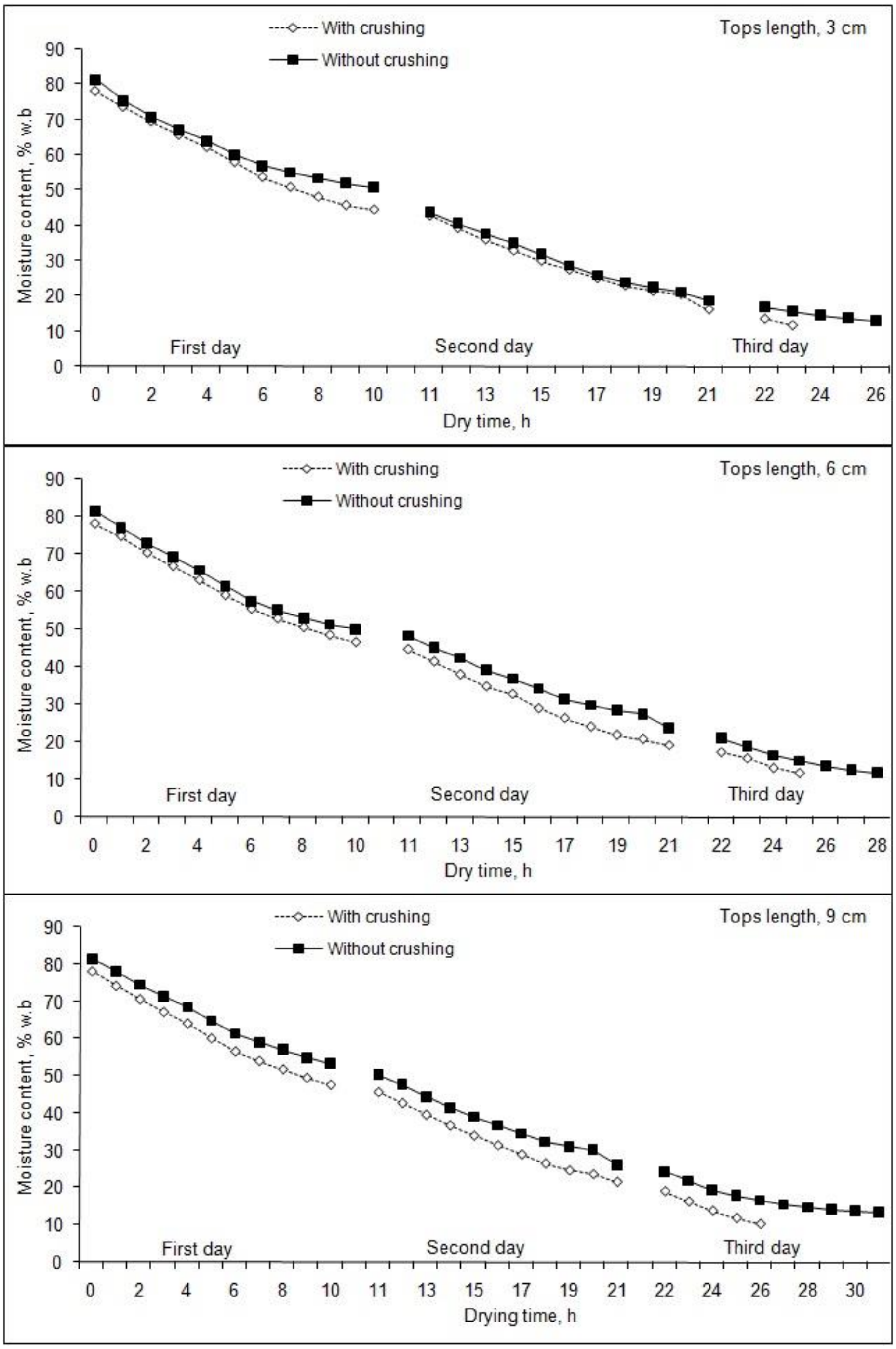

Fig.(10): Change in moisture content of sugar beet tops as related to drying time at air velocity of 0.4 m/s.

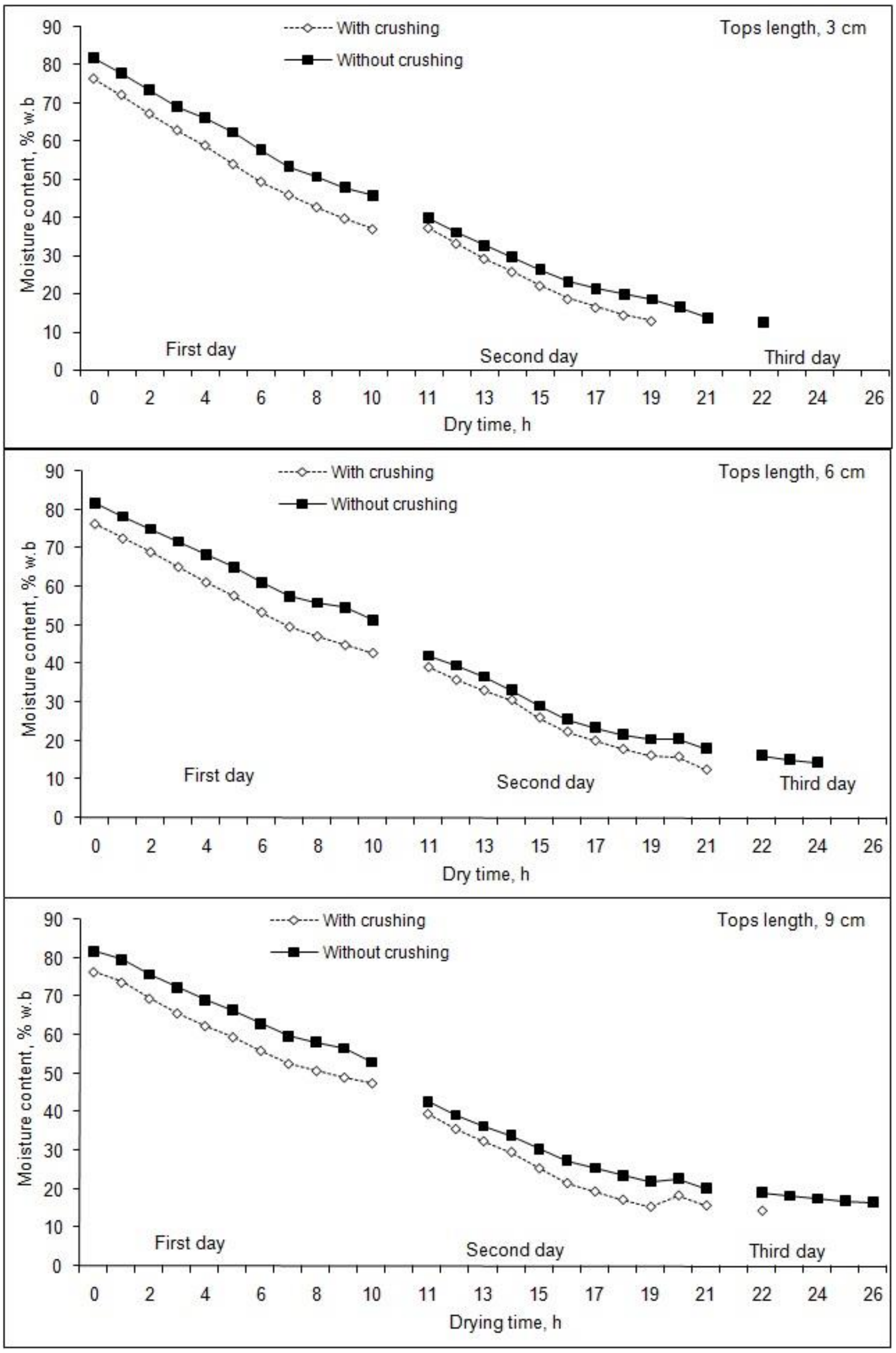

Fig. (11): Change in moisture content of sugar beet tops as related to drying time at air velocity of 1.2 m/s.

As shown in the figures, the reduction in moisture content of sugar beet tops was varied and increased with the increase of drying air velocity, decrease of chopping length and for the crushed samples in comparison with the non crushed samples. Also, the constant drying rate period was not detected for all studied levels of drying air velocity, while all the drying process occurred during the falling rate-drying period. This phenomenon is common for most of crops having high initial moisture content such as green fodder crops, fruits and vegetables, since at the beginning of the drying process, the moisture diffusion from the crop interior toward the surface where it evaporates has been limited.

Drying Time of Sugar Beet Tops:

The drying time of sugar beet tops was varied and it was decreased with the increase of drying air velocity, decrease of chopping length and for the chopped and crushed samples in comparison with the chopped samples. As shown in Figures (12) and (13, the minimum air velocity of 0.4 m/s, the recorded drying time for the chopped tops at chopping lengths of 3, 6, and 9 cm were 26, 28, and 31 h respectively.

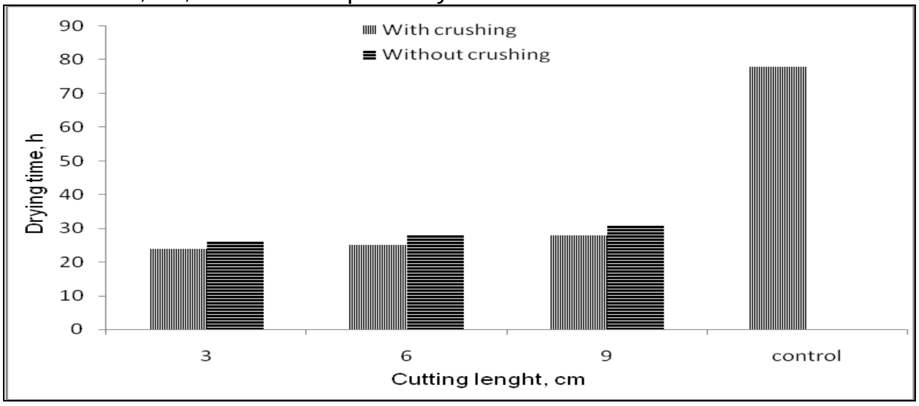

Fig. (12): Drying time of sugar beet tops dried at the minimum air velocity of 0.4 m/sec.

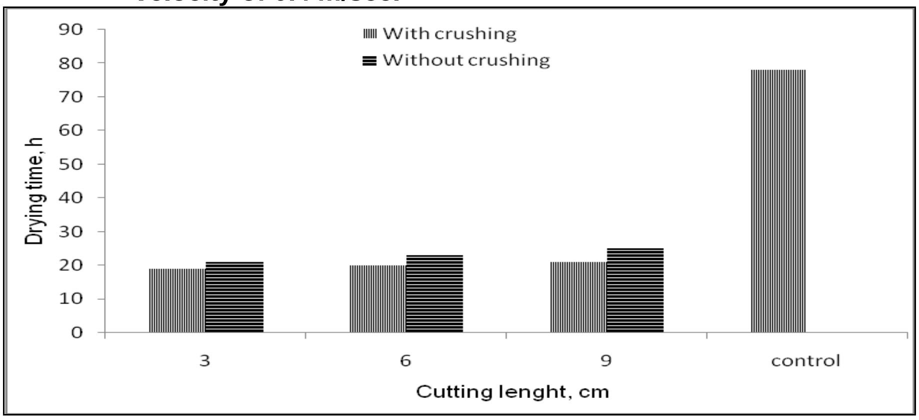

Fig. (13): Drying time of sugar beet tops dried at the maximum air velocity of 1.2 m/sec

The corresponded times for the chopped with crushing tops were 24, 25, and 28 h respectively. While, at the maximum air velocity of 1.2 m/s the recorded drying times for chopped tops were 21, 23, and 25 h respectively and the corresponded drying time for chopped with crushing tops were 19, 20, and 21 h respectively. The above mentioned results revealed that using the green-house type solar dryer could decrease the drying time of sugar beet tops by about 47 to 59 h in comparison with the traditional drying method which has been taken about 78 h. Also the effect of crushing process on reducing the drying time was more obvious at the chopping length of 9 cm followed by 6 and 3 cm lengths, respectively.

Thermal Efficiency of the Solar Dryer:

To evaluate the overall performance of the dryer, the thermal efficiency was determined for actual drying tests at different levels of drying air temperature and air velocity. The obtained results are presented in table (1). As shown in the table, the dryer thermal efficiency increased with the increase of air velocity and it was relatively higher for the smaller cutting lengths and for the crushed samples in comparison with non crushed samples. In general, the calculated thermal efficiency of the dryer ranged from 22.96 to 34.12 %.

Table (1): Thermal efficiency of the solar dryer at different drying velocity.

Air velocity m/sec	Cutting lengths of sugar beet tops, cm					
	3		6		9	
	With crushing	Without crushing	With crushing	Without crushing	With crushing	Without crushing
0.4	28.62	25.72	25.72	24.47	24.47	23.93
0.8	30.42	27.32	27.32	24.64	25.88	22.96
1.2	34.12	31.57	32.72	29.43	31.57	26.90

Protein Content of Sugar Beet Hay:

Protein content of sugar beet hay (on DM basis) was determined for different levels of air velocity, cutting lengths and pre-treating conditions (with and without crushing). The obtained results are presented in table (2). As shown in the table, protein content of sugar beet tops hay ranged from 12.57 to 14.52 %. On the same time the protein content of the traditionally dried sample was about 11.58 %. The lower protein content of the sample dried in open air may be attributed to the loss of tops leaves which contain he highest levels of protein.

Table (2): Protein content in Sugar beet tops hay at different drying velocity.

Air velocity m/sec	Cutting lengths of sugar beet tops, cm					
	3		6		9	
	With crushing	Without crushing	With crushing	Without crushing	With crushing	Without crushing
0.4	14.36	13.32	14.76	12.97	12.44	12.65
0.8	14.41	13.5	14.56	13.17	12.57	12.63
1.2	14.52	13.57	14.66	12.87	12.70	12.79

Conclusion:

1- The hourly average available solar radiations during the experimental work ranged from 598.26 to 663.85 W/m^2.
2- The solar collectors increased the air temperature by 12.6, 12.31 and 12.81 ^{o}C and decreased the average air relative humidity by about 26.06, 23.67 and 20.97 % at air velocity of 0.4, 0.8 and 1.2 m/sec, respectively.
3- The reduction in moisture content of sugar beet tops was varied and increased with the increase of drying air velocity, decrease of chopping length and for the crushed samples in comparison with the not crushed samples.
4- The use of the green-house type solar dryer could decrease the drying time of sugar beet tops by about 47 to 59 hours in comparison with the traditional drying method which has been taken about 78 hours.
5- The dryer thermal efficiency increased with the increase of drying air velocity and it was ranged from 22.96 to 34.12 % .
6- The protein content of sugar beet tops hay ranged from 12.57 to 14.52 % on DM basis for the samples dried by the solar drying method. While, it was about 11.58 % for the traditionally dried samples.

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استخدام الطاقة الشمسية فى تجفيف عرش بنجر السكر

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أجريت هذه الدراسة لاختبار وتقييم مجفف شمسي يعمل بنظام الهواء المدفوع (Green-house type) لتجفيف عرش بنجر السكر لاستخدامه كعلف حيواني. وتمت الدراسة عند ثلاث مستويات مختلفة لسرعة الهواء 0.4، 0.8 ، 1.2م/ث ، ثلاث أطوال مختلفة للعرش المقطع 3، 6، 9سم وحالتين للعرش المقطع (مفدغ ، بدون تفديغ) مع مقارنة ذلك بالطريقة التقليدية المستخدمة فى تجفيف العرش الكامل تحت أشعة الشمس. وشملت القياسات الخاصة بالتجارب الحقلية في قياس التغير في المحتوى الرطوبى للعرش، كمية الأشعة الساقطة ، درجة حرارة كتلة العرش ، درجة الحرارة والرطوبة النسبية للهواء خارج وداخل المجفف ، كما تم أيضا حساب الكفاءة الحرارية للمجفف والتغير في نسبة البروتين للعرش المجفف تحت المعاملات التجريبية المختلفة. وأظهرت النتائج المتحصل عليها أن قيم الأشعة الشمسية الساقطة خلال التجارب الحقلية تراوحت بين 598.26، 663.85 وات/م2 .

أمكن للمجمع الشمسي زيادة متوسط درجة حرارة الهواء الجوى داخل المجففات المحتوية علي عينات مقطعة بحوالي 12.6، 12.31، 12.81 ^{5}م مع خفض رطوبته النسبية 26.06، 23.67، 20.97% خلال التجارب الحقلية عند سرعات هواء 0.4، 0.8 ، 1.2م/ث على التوالي. في حين زادت درجة حرارة هواء التجفيف داخل المجففات المحتوية علي عينات مقطعة ومفدغة الي حوالي41.49، 41.2، 41.7 ^{5}م بينما إنخفضت الرطوبة النسبية للهواء إلي حوالي 28.2، 30.59، 33.29% عند نفس السرعات علي التوالي.

تغير معدل التجفيف للمعاملات المختلفة حيث زاد بزيادة سرعة الهواء، إنخفاض طول القطع للعرش، إجراء عملية التفديغ كما لم تظهر فترة التجفيف الثابت لجميع منحنيات التجفيف بينما تمت عملية التجفيف خلال فترة التجفيف المتناقص نتيجه لإرتفاع المحتوي الرطوبي الابتدائي للعرش والتي تراوحت بين83 -84% علي أساس رطب من ناحية أخري انخفض زمن التجفيف للعينات المجففة بالمجفف الشمسي والمعاملة سواء بعملية التقطيع أو بعمليتي التقطيع والتفديغ معا حيث تراوحت بين 19إلي 31ساعه بالمقارنة بالطريقة التقليدية لتجفيف للعرش والتي وصلت الي حوالي 78 ساعة.

تراوحت أيضا الكفاءة الحرارية للمجفف بين 34.12-22.96% حيث زادت بزيادة سرعة الهواء، وإنخفاض طول القطع كما كانت أعلي للعينات المفدغة مقارنة بالعينات الغير مفدغة.

أظهرت ايضا نتائج التحليل الكيميائي أن نسبة البروتين في العرش تراوحت بين 12.57 الي 14.52% علي الأساس الجاف للعينات المجففه بالمجففات الشمسية مقارنة بـ 11.58 % للعينة المجففة بالطريقة التقليدية وذلك نتيجة لفقد الاوراق والتي تحتوي علي أعلي نسبة للبروتين في العرش.

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