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DEVELOPMENT AND EVALUATION OF A GREEN-HOUSE TYPE SOLAR DRYER FOR DRYING EAR AND SHELLED CORN

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Abstract

A green house-type solar dryer was developed at the experimental farm of Rice Mechanization Center (R. M. C.), Meet El-Dyba, Kafer El-Sheikh Governorate. The dryer was tested and evaluated for drying high moisture ear and shelled corn of variety (three way - cross 310) and compared with natural sun drying method. The results show that, the developed dryer was able to dry ear corn from an initial level of 29.85% to a final level of 14.26% in 84 hours as compared to 187 hours for natural sun drying method. The corresponding drying times for shelled corn from an initial grain moisture level of 19.87% to a final level of 14.13% were 18 and 34 hours respectively.

Quality evaluation tests of the dried ear and shelled corn showed a lower percentage of kernels stress cracks for the solar dried kernels compared with natural sun drying of ear corn giving the lowest percentage of stress cracks kernels (SC) (9.10%),. While the natural sun drying produced the highest percentage of (SC) kernels (23.1 %). However the grain germination tests showed an average percentage of over 90% for both solar and natural sun drying methods of ear and shelled corn.

Cost analysis of the solar dryer showed a total cost of 28.76 LE/ ton for drying ear corn from an initial grain moisture level of 29.85% to a final moisture level of 14.26% and 8.00 LE / ton for drying shelled corn from an initial level of 19.87% to a final level of 14.13%. For the two stage drying system reduction the estimated drying cost from initial moisture level of 29.85% to a final level of 19.87% for ear corn and from initial level of 19.87 to a final level of 14.13% for shelled corn was about 20.68 LE/ton.

INTRODUCTION

Corn like wheat may be considered among the most important grain crops in Egypt. The cultivated area ranges between 1.6 to 1.7 million feddans yearly and a total production of about 5.431 million tons (EACA, 1999). Recently, the government tends is expand the growing area of corn to limit the shortage of wheat production and to approach self-sufficiency for bread by mixing corn with wheat at a rate of 20%. However, increasing productivity of corn per unit area needs more advanced techniques to achieve better environment for growth, ripening, harvesting and processing (Matouk *et al.* 1999).

Corn is usually harvested at a relatively high moisture levels to minimize field losses and give a chance to clear the field earlier after ripening and helps serving and preparing the field for the next crops (Mohamed, 2000).

Recently, the time of corn harvesting had been shortened from a matter of weeks to a matter of hours with the advent of using combine and corn picker machines.

(El-Taliawy, 1998). However, the time for desirable harvest conditions with this method is relatively short and in some cases has added to the problem of quick grain deterioration because of accumulation of large quantities of high moisture corn. The incomplete removal of husks and trash increases the chance for fungal growth and a specific physical and physico-chemical changes of grain at short time after harvest. (El-Sahrigi *et al.* 2000).

Therefore, There is, an urgent need for drying high moisture corn to a safe moisture level too low for fungi to grow. Aside from prevention of microbial growth, drying is also used to preserve the product from physical and chemical changes induced or supported by excess moisture (Adeyemo, 1993)

Drying may be achieved by either natural or artificial drying methods. However, there is no easy formula to decide whether the natural or the artificial drying methods is profitable for use. In Egypt, sun drying is still the most common method to preserve agricultural products. Due to the lack of sufficient preservation methods, farmers have to spread the crop to be dried in thin layers on paved grounds or mats where they are exposed to sun and wind. Considerable losses may occurred during natural sun drying due to various effects such as rodents, birds, insects, rain and microorganisms (Kamel, 1999).

The resulting decrease in product quality causes the products in question not to be marketable on domestic or international market (Lutz *et al.*, 1987). To overcome the existing preservation problem the introduction of solar dryers seems to be promising since in Egypt, the available amount of solar energy is sufficient to cover the heat requirements for small and medium dryers (Awady *et al.*, 1993). However, the energy resource for agricultural application is strongly dependent upon the development of solar energy systems that have optimum performance, good reliability and economic characteristics that compare favorably with conventional energy systems and other energy sources (Al-Amri, 1995)

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, Abd- Ellatif and Helmy, 1991, El-Sahrigi *et al.*, 1993). However, there is no readily available information about the utilization of the green-house type solar dryer for drying both ear and shelled corn. The main objective of the present work is to develop and evaluate a green-house type solar dryer for drying high moisture ear and shelled corn under Egyptian climatic condition. The system will be compared with natural sun drying method.

MATERIALS AND METHODS

High moisture ear and shelled corn variety (Three way-cross 310) were mechanically harvested at the Rice Mechanization Center (R.M.C), Meet ElDyba, Kafer El-Sheikh Governorate during the 2000 corn harvesting season. For the experimental work, a green-house type solar dryer was developed and installed at (RMC). Two different series of field experiments were conducted to test and evaluate the developed dryer. The first series of experiments dealt with ear corn at an average initial moisture content of (29.69% w.b). The second series dealt with shelled corn at an average initial moisture content of (19.87% w.b). In addition, laboratory tests were also conducted for evaluating the grain quality changes of the dried ear and shelled corn.

Structure of the green-house type solar dryer:

A green house type solar dryer with a full capacity of about 8 tons for ear corn and a full capacity of 6.9 tons for shelled corn was designed, built and installed at the experimental farm of Rice Mechanization Center (R.M.C). The gross dimensions of the vinyl house are 4.2 m wide, 6.2 m long and 3.6 m height with a net projected surface area of 26.04 m^2. Pipe frames are constructed in the circumference of four wooden walls for a batch and the frames are covered by clear plastic film. Wire netting covers the floor at the bottom of the batch forming an air chamber under the wire netted floor. An axial flow type fan of 0.58m diameter and a duct for air suction are set at one side of the green house with a window for air inlet on the opposite side. An electric motor of 1 kW was used to operate the fan at airflow rate of 1.75 m^3 / sec and a static head of 0.25 inch water.

To protect the exposure of grains to the direct sun rays and to increase the collecting efficiency of solar radiation, black net cloth was used to cover the grain surface. Figure (1) shows the structural features of the greenhouse type solar dryer.

Experimental measurements:

Grain moisture contents:

The moisture content of grains was hourly measured by using a drying oven set at 130°C for 16 h according to (AOAC, 1990). The calculated moisture content was expressed on wet basis unless otherwise specified.

Grain bulk and air temperature:

The universal measuring system (Model Kaye Dig. 14) connected to 48 scanning box with thermocouples was used to hourly measure the bulk temperature of ear and shelled corn and the ambient air temperature at different points inside and outside the dryer as shown in Fig. (2).

Air relative humidity:

The relative humidity meter model (HN-K) was used to measure the air relative humidity at adjacent points of temperature measurements.

Air flow rate:

A hot wire anemometer model (Kanomax 24-6111) was used to measure the inlet air speed at the dryer window in m/s. Which when multiplied by the area of the intake window will give the air flow rate in m^3 / s entering the solar dryer.

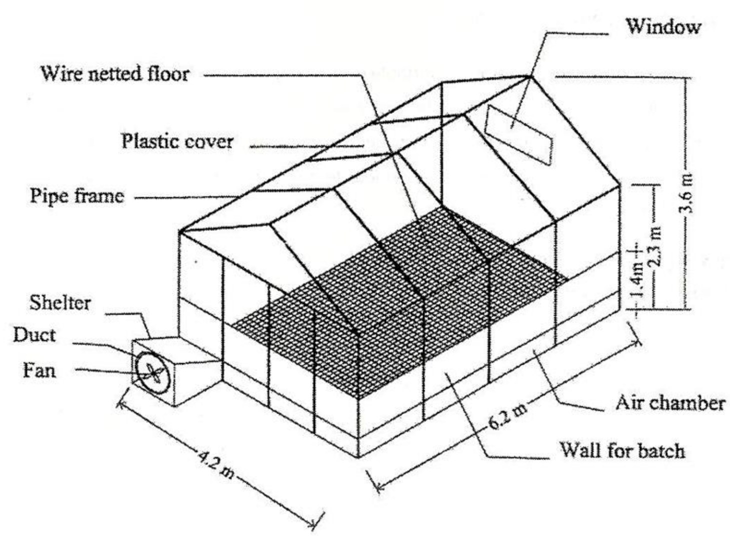

Fig. 1. Structure feature of the green-house type solar dryer.

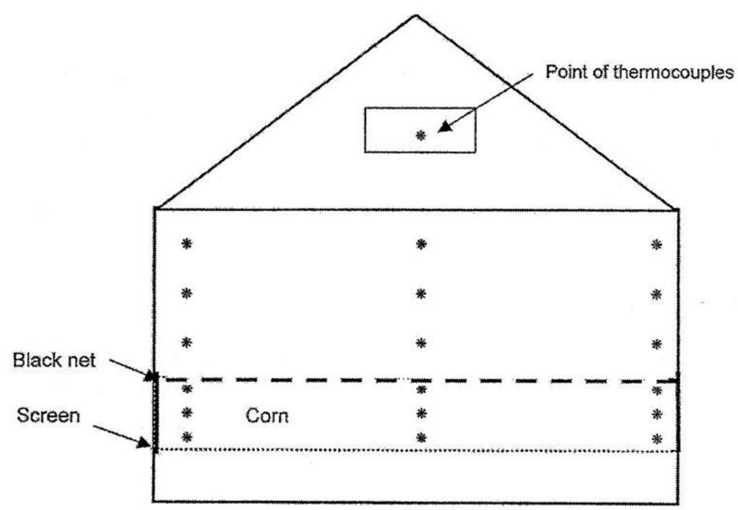

Fig. 2. Distribution points of thermocouples inside the solar dryer.

Solar energy measurement:

A solar energy meter with a portable recorder model (Y3057-11) with an output of approximately 0.5 mv per 100 W/m^2 was employed to measure the solar radiation flux incident on a horizontal surface outside the solar dryer. The solar meter was calibrated with the standard pyranometer under clear sky conditions according to (ASAE standards 1993).

Quality evaluation tests:

Stress cracks analysis:

Stress crack (SC) analysis was done on freshly harvested and dried samples. Depending on the extent of stress cracks, the kernels are categorized as having single, double, and multiple cracks. The stress crack index of each sample was also calculated according to the equation of Kirleis and Stroshine (1990) as follows:

$$SC_I = S+(Mx3) + (Cx5).$$

Where:

S is the percentage of single SC kernels, M is the percentage of double SC kernels and C is the percentage of multiple SC kernels.

Samples represented different positions of solar and natural drying methods were divided into 100 kernels sub samples and were placed germside down on a light glass surface and inspected from top only. Broken or chipped kernels were counted as rejects since this mechanical damage occurred prior to drying treatments. The results for each sub-sample were normalized by dividing the number of cracked kernels by the total number of acceptable kernels.

Grain germination test:

The standard germination tests were done to verify the effect of drying methods on percent of germination. Corn samples of solar and natural drying methods were divided into 100 kernel sub-samples in three replicates. Samples of each replicate were surface sterilized using 2% sodium and rinsed three times using distilled water. Germination tests were replicated three times in petri dishes containing moistened filter paper for a week and the corn kernel having both root and shoots were considered germinated.

RESULTS AND DISCUSSION

Grain moisture content:

Figures (3) and (4) illustrate the change in average grain moisture content as related to elapsed drying time during solar and sun drying methods of ear and shelled corn respectively.

As shown in Figure (3), grain moisture content of ear corn was decreased from an initial level of 29.85% (w.b) to a final level of about 14.26% in 84 and 187 h for solar and natural sun drying, respectively. This means that, solar drying could reduce the required time for drying ear corn by about 56.68% compared with natural sun drying. Similarly, for shelled corn, Figure (4) shows that, grain moisture content decreased from an initial moisture level of 19.87% to a final moisture level of about 14.13% in about 18 and 34 h for solar and natural sun drying respectively. This also means that, solar drying of shelled corn could reduce the drying time to about 47.05% compared with natural sun drying. However, when comparing the drying time of ear and shelled corn at similar initial moisture contents of about 19.87%, the recorded drying times for ear and shelled corn were 47 and 77 h for solar and natural sun drying respectively, while the corresponding times for shelled corn were 18 and 34 respectively.

The above mentioned results revealed that, in general the overall drying rate of solar drying was nearly double the drying rate of natural sun drying for both ear and shelled corn.

This could be attributed to the higher temperature and lower relative humidity of the drying air inside the solar dryer compared with the ambient air outside the dryer. On the other hand, when comparing the drying time of ear and shelled corn at similar grain initial moisture content, the longer drying time for ear corn compared with shelled corn, ear corn has taken longer drying time than shelled corn as a result of continuous moisture diffusion from ear cobs to the grains and the smaller exposure grain surface area of ear corn to the drying air in comparison with shelled corn. This means that, it is better to dry ear corn to a moisture level suitable for shelling (19% ±1) as ear corn then completing the drying process for shelled corn up to a final level of about 14% unless it was planned to store the corn as ears.

Solar radiation:

The hourly average solar radiation available during solar drying of ear and shelled corn is illustrated in Figure (5).The daily average available solar radiation were 544.06 and 536.22 W/m^2.h during ear and shelled corn drying, respectively. The figure also shows that, the solar radiation gradually increases from sunrise till it reaches the maximum average values of 853.73 and 836.17 W/m^2.h at noon for ear and shelled corn drying periods respectively. It then decreases gradually until it reaches the minimum values of 261.71 and 256.24 W/m^2.h at sunset. The hourly variation in solar energy available during the drying time affects the solar dryer effectiveness for heating air and the differences between air temperature and relative humidity inside and outside the dryer.

Air temperature and relative humidity:

The air temperature and relative humidity inside the vinyl-house were found to be a very important parameter affecting the drying rate of both ear and shelled corn. Figures (6) and (7) present the change in average air temperature and relative humidity during solar and natural sun drying methods of ear corn respectively. The recorded hourly average ambient air temperature and relative humidity outside the dryer were 27.92°C and 55.80% and the corresponding values inside the dryer were 35.44°C and 42.99 % respectively. This means, that, the solar collector could increase the average drying air temperature by about 7.62°C and decrease the average relative humidity by about 12.81%. Similarly, for shelled corn drying, figures (8) and (9) show that, the hourly average ambient air temperature and relative humidity outside the dryer were 25.1°C and 56.01% and the corresponding values inside the dryer were 31.69°C and 45.3% respectively. This also means that, the dryer solar collector could increase the average air temperature by about 6.89°C and decrease the relative humidity of air by about 10.71%. The observed differences in air temperature and relative humidity inside and outside the dryer were effective parameters increasing the drying rate of solar drying methods for both ear and shelled corn.

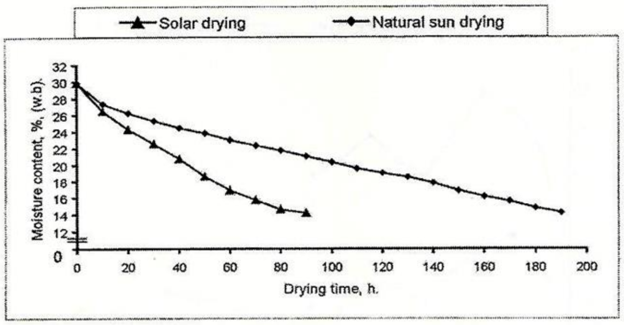

Fig. 3. Change in average grain moisture content as related to drying time during sun and solar drying methods of ear corn.

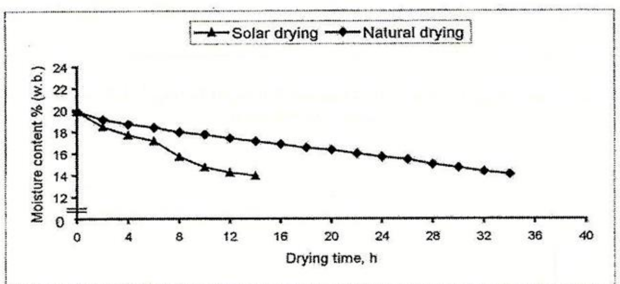

Fig. 4. Change in average grain moisture content as related to drying time during sun and solar drying methods of chelled corn.

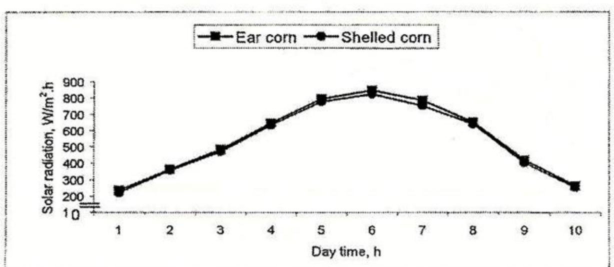

Fig. 5. Average solar radiation as related to day time during ear and shelled corn drying

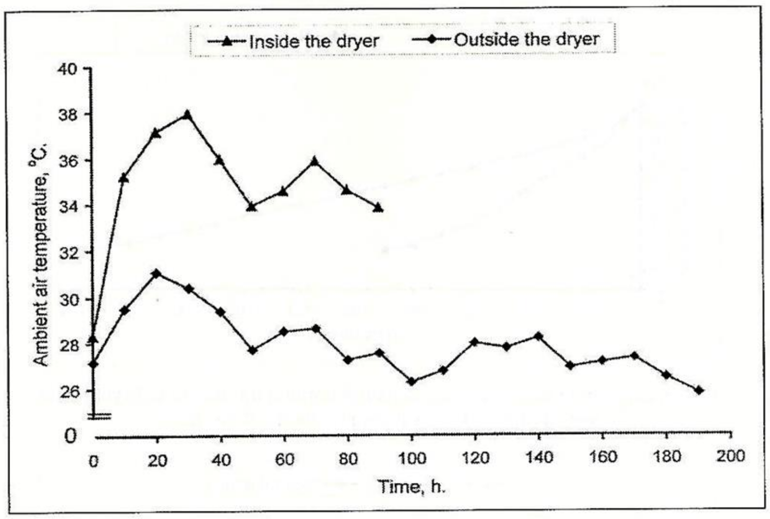

Fig. 6. Air temperature inside and outside the dryer during solar and natural sun drying of ear corn.

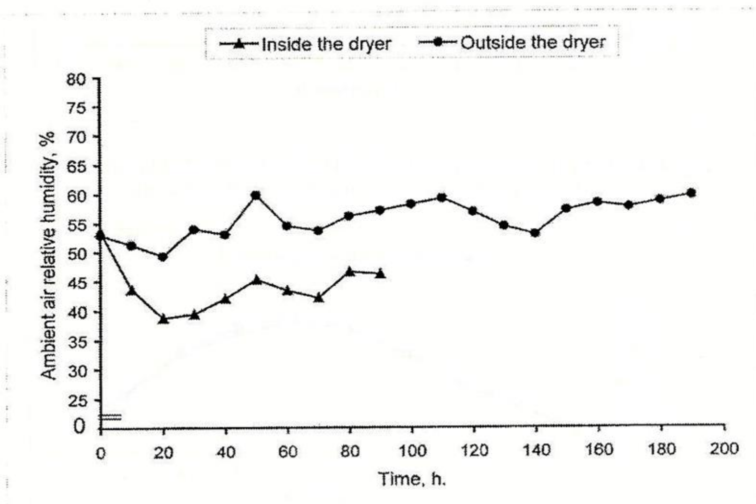

Fig. 7. Ambient air relative humidity inside and outside the dryer during solar and natural sun drying methods of ear corn.

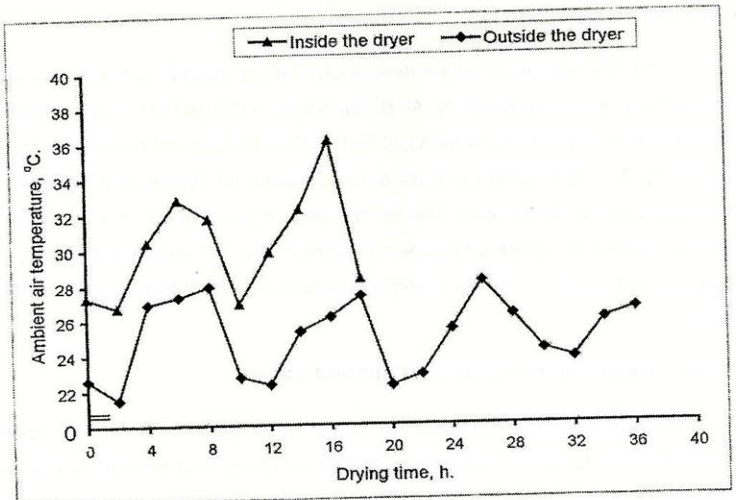

Fig. 8. Air temperature inside and outside the solar dryer during solar and sun drying of shelled corn.

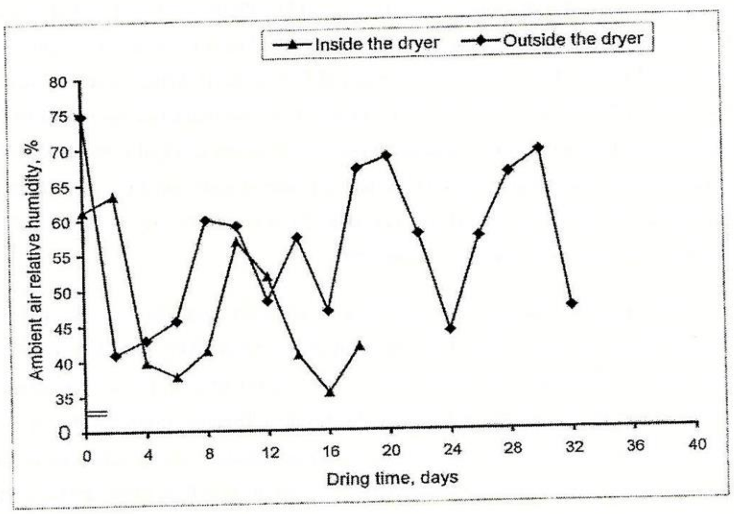

Fig. 9. Air relative humidity inside and outside the dryer during solar and sun drying of shelled corn

Grain bulk temperature:

Grain bulk temperature was hourly measured for ear and shelled corn during solar and natural sun drying, respectively. As shown in figures (10) and (11), the average recorded ear bulk temperatures were 30.20 and 27.05°C for solar and natural sun drying, respectively. The corresponding values of temperatures for shelled corn drying were 28.71 and 25.35°C, respectively. The results revealed that, the changes in bulk temperature of both ear and shelled corn was affected by the solar radiation available, the temperature of drying air and the changes in grain moisture content during the drying process.

Kernel stress cracks of ear and shelled corn:

The effect of solar and natural sun drying on the percentage of stress cracks kernels (SC) and the stress cracks Index (SCI) of ear and shelled corn after drying process are tabulated in table (1). Initial SC levels out of the field ranged from 0% to 7.2% with an average of 3.1% for ear corn and from 2.1% to 11.3% with an average of 5.2% for shelled corn. As shown in table (1) solar drying of ear corn produced corn with the lowest percentage of SC kernels (9.1%) in comparison with (12.8%) for natural sun drying. While the natural sun drying of shelled corn produced the highest percentage of SC (23.1%) in comparison with (16.3%) for solar drying. A stress-crack Index (SCI) reflecting the effect of (SC) categories on the breakage susceptibility (BS) will be more useful than just the total percentage of stress cracked kernels. As shown in table (1) the solar drying method of ear corn yielded corn with SCI value of 20.9 in compared with 30.2 for natural sun drying and the corresponding values of SCI for shelled corn were 41.2 and 55.7, respectively.

The results revealed that, both drying methods and type of corn (ear and shelled) affect the final quality of dried kernels. Natural sun drying recorded higher (SC) and (SCI) in comparison with solar drying. This may be attributed to the longer drying period of natural sun drying method and the resulting frequent grain moisture absorption and description from the surrounding humid air specially during early morning and late after noon. Also the longer the exposure time of grain to high solar radiation intensity during natural sun drying increases the risk of over heating and stress cracks production on grain surfaces, which was avoided in solar drying method by using a black

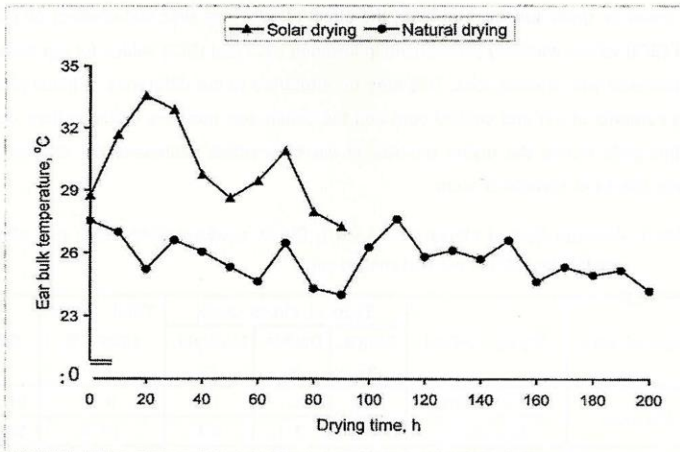

Fig. 10. Ear bulk temperature as related to drying time during natural and solar drying methods of ear corn.

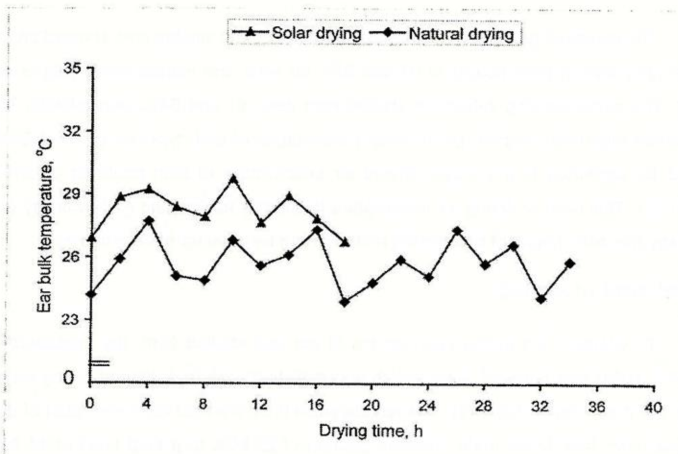

Fig. 11. Change in average grain bulk temperature as related to drying time for sun and solar drying of shelled corn.

net cover on grain surface. However, the effect of corn type (ear and shelled) on (SC) and (SCI) values was very pronounced in lowering (SC) and (SCI) values for ear corn in comparison with shelled corn. This may be attributed to the difference of initial moisture contents of ear and shelled corn and the continuous moisture diffusion from cobs to the grain during the drying process of ear corn which decreases the chance for stress cracks of kernels to occur.

Table 1. Average type of stress cracks (SC), Stress cracked percentage, and stress crack index SCI) of ear and shelled corn.

Type of corn	Drying method	Type of stress crack			Total stress crack, %	SCI
		Single, %	Double, %	Multiple, %		
Ear corn	Solar drying	4.8	2.7	1.6	9.1	20.9
	Sun drying	6.9	3.1	2.8	12.8	30.2
Shelled corn	Solar drying	8.3	4.8	3.7	16.8	41.2
	Sun drying	11.7	6.5	4.9	23.1	55.7

Grain germination:

The results of grain germination tests of both ear and shelled corn showed an average germination percentages of 95 and 97% for solar and natural sun drying of ear corn. The corresponding values for shelled corn were 91 and 94%, respectively. The observed high level of grain germination percentages of both types of grains (>90%) could be attributed to the proper drying air temperature of both methods of drying (<40 °C). This level of drying air temperature is suitable for keeping grain viability and thereby the dried grains of both drying methods can be used for seed production.

Total cost of drying:

To estimate the drying cost per ton of ear and shelled corn, the procedure of (ASAE, 1984) was followed. Data, which accomplished each investigated drying condition, are presented in table (2). The results show that, the total estimated cost of drying ear corn from initial grain moisture content of 29.85% to a final level of 14.26% was 28.76 LE/ton. While it was 8.0 LE/ton for drying shelled corn from an initial grain moisture content of 19.87% to a final level of 14.13%. However, in case of two stage drying of corn from 29.85% to about 19.80% as ear corn and from 19.80% to about 14.0% as shelled corn, the estimated drying cost was about 20.68 LE/ton. This means that the two stage drying method could save about 8.08 LE/ton as compared to one stage drying for ear corn.

Table 2. cost analysis for solar drying of ear and shelled corn.

No	Items of comparison	Ear corn	Ear corn	Shelled corn
	Assumptions :			
1 -	Price of dryer, L.E.	5865	5865	5865
2 -	Dryer capacity, ton/h	0.0952	0.216	0.3889
3 -	Operational life of dryer, year	10	10	10
4 -	Operational hours	900	900	900
5 -	Total weight of fresh corn, ton	85.71	194	350
6 -	Initial moisture content, % (w.b).	29.85	29.80	19.87
7 -	Final moisture content, % (w.b).	14.26	14.00	14.13
	A- Ownership cost:			
1 -	Depreciation and maintenance cost, L.E./h	1.165	1.165	1.165
	Taxes and insurance, L.E./h	0.130	0.130	1.130
2 -	**Total in LE/h**	**1.295**	**1.295**	**1.295**
	in LE/Ton	**13.603**	**5.995**	**3.329**
	B- Operating costs:			
1 -	Repair and maintenance cost, L.E./h	0.122	0.122	0.122
2 -	Fuel cost, L.E./h	-	-	-
3 -	Lubricate cost, L.E./h	-	-	-
4 -	Electricity cost, L.E./h	0.9636	0.9636	0.236
5 -	Labour cost, L.E./h	0.357	0.357	1.458
	Total in LE/h	**1.443**	**1.443**	**1.816**
	in LE/Ton	**15.153**	**6.681**	**4.670**
	C- Total costs:			
1 -	**in L.E./h**	**2.378**	**2.738**	**3.111**
2 -	**in L.E./Ton**	**28.76**	**12.68**	**8.00**

*One stage drying (reduction moisture content of ear corn from 29.85% to 14.26%.

**Two stage drying (reduction moisture content from 29.85% to 19.87% as ear corn and then from 9.87% to 14.13% as shelled corn.

CONCLUSIONS

The major conclusions drawn from this investigation were:

1. The developed green-house type solar dryer was able to dry ear corn from an initial moisture content level of 29.85% to a final level of 14.26% in 84 hours in comparison with 187 hours for natural sun drying. The corresponding drying time for shelled corn from an initial level of 19.87% to a final level of 14.13% was 18 and 34 hours, respectively.
2. The temperature of air inside the solar dryer rises about 7.62 °C and 6.89 °C over the ambient air temperature during ear and shelled corn drying respectively. While, the air relative humidity was decreased by about 12.81 and 10.71%, respectively.
3. Solar drying of ear corn produced corn with the lowest percentage of stress cracks kernels (SC) (9.10%), While the natural sun drying of shelled corn produced the highest percentage of (SC) kernels (23.1%).
4. Grain germination of ear and shelled corn showed an average percentages of over 90% for all samples dried with solar and natural sun drying . This level of grain germination may be considered suitable for corn seed production.
5. The calculated total cost for drying ear corn from an initial grain moisture level of 29.85% to a final level of 14.26% was 28.76 LE / ton. While the calculated total cost for drying shelled corn, from an initial level of grain moisture contents of 19.87% to a final level of 14.13 %, was 8.00 LE / ton. For two stages drying, the estimated drying cost was 20.68 LE/ton.

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تطوير وتقييم مجفف شمسى لتجفيف الذرة فى صورة كيزان أو حبوب مفرطة

أسامة محمد كامل[١] ، محمد مصطفى الخولي[٢]

١ *باحث أول ومدير مركز ميكنة الأرز بميت الديبة - كفر الشيخ - معهد بحوث الهندسة الزراعية*

٢ *باحث بمعهد بحوث الهندسة الزراعية - الدقى - جيزة*

تمت هذه الدراسة لاختيار وتقييم مجفف شمسى (green-house type) تم تطويره وتصنيعه بمركز ميكنة الأرز بميت الديبة لاستخدامه فى تجفيف محصول الذرة ذو المحتوى الرطوبى المرتفع سواء فى صورة كيزان أو فى صورة حبوب مفرطة. شملت الدراسة مقارنة المجفف الشمسى بطريقة التجفيف الطبيعى وذلك من حيث الزمن الكلى لعملية التجفيف وكذلك التغير فى جودة الحبوب المجففة بالإضافة إلى حساب التكلفة الكلية لكل طن. أظهرت النتائج المتحصل عليها انخفاض زمن التجفيف الكلى للحبوب فى حالة استخدام المجفف الشمسى بالمقارنة بطريقة التجفيف الطبيعى، ففى حالة الذرة الكيزان وصل الزمن الكلى لتجفيف الحبوب من محتوى رطوبى ابتدائى ٢٩,٨٥٪ إلى محتوى رطوبى نهائى ١٤,٨٦٪ فى حوالى ٨٤ ساعة فى حالة استخدام المجفف الشمسى بالمقارنة بحوالى ١٨٧ ساعة فى حالة التجفيف الطبيعى، بينما وصل الزمن الكلى المماثل لتجفيف الذرة المفرط من محتوى رطوبى ابتدائى ١٩,٨٧٪ وحتى محتوى رطوبى نهائى ١٤,١٣٪ فى حوالى ١٨, ٣٤ ساعة على التوالى. وبالأخذ فى الاعتبار جودة الحبوب المجففة بكلا الطريقتين أظهرت الاختبارات العملية انخفاض نسبة الحبوب المتشققة فى حالة استخدام المجفف الشمسى بالمقارنة بطريقة التجفيف الطبيعى لكلا من الذرة الكيزان والمفرطة بينما تجاوزت نسبة الإنبات أكثر من ٩٠ ٪ لكلا الطريقتين وذلك لعدم تأثر حيوية الجنين بحرارة التجفيف والتى لم تتجاوز ٤٠°م فى المتوسط مما يؤكد إمكانية استخدام تلك الحبوب كتقاوى. كانت التكلفة الكلية حوالى ٢٨,٧٦ جنيه/طن فى حالة التجفيف الكامل للحبوب فى صورة كيزان من محتوى رطوبى ٢٩,٨٥٪ وحتى محتوى رطوبى ١٤,٢٦٪ بينما وصلت إلى حوالى ١٢,٦٨ جنيه / طن فى حالة تجفيف الذرة المفرط من محتوى رطوبى ١٩,٨٧ ٪ وحتى محتوى رطوبى ١٤,١٣ ٪، فى حالة التجفيف على مرحلتين من محتوى رطوبى ٢٩,٨٥ إلى محتوى رطوبى ١٩,٨٪ فى صورة كيزان ثم من محتوى رطوبى ١٩,٨ ٪ إلى محتوى رطوبى ١٤ ٪ فى صورة حبوب مفرطة فقد وصلت التكلفة الكلية إلى حوالى ٢٠,٦٨ جنيه / طن.