CONTENTS

5- Summary and Conclusions

Rice is one of an important food crop in many parts of the world. In Egypt, it is not only a stable food but also a major source of livelihood. The rice is harvested at relatively high level of moisture content to minimize the field losses and maximize the quality of milled rice. Therefore, drying process of the grains is very important where, it reduces the moisture content of the kernels down to a level at which it can be stored safely without risk of mould growing.

Solar energy has considered an important source for the conservation and drying agricultural crops in the last decade, because its unique advantages as a clean energy. The main objective of present study was to utilize the greenhouse as a solar collector for heating the air and use it to reduce the initial moisture content of rough rice harvested for several periods. A solar heated air system was used for different airflow rates during different drying periods and compared with an ambient air system for similar drying conditions.

The effects of drying systems, airflow rates and drying periods at three different grain layers on the drying process of rough rice grain (Sakha 101) and its quality were investigated. The data and the results are summarized in the following main items:

5.1. Weather conditions:

5.1.1. Air temperature:

The air temperature inside the greenhouse was affected by many parameters, such as greenhouse area, air temperature outside the greenhouse and the incident solar radiation flux. As the available solar radiation increased inside the greenhouse, the air temperature is thus increased. The heating capacity of the drying air is measured through the difference between the air temperatures inside and outside the greenhouse. When this difference is increased, the useful heat for drying the grains is increased and the removed moisture from the grains in addition to the drying rate were thus increased, making the drying process in the case of solar heated air system more efficient than the ambient air drying system.

5.1.2. Relative humidity:

There was a reverse relationship between the air temperature and its relative humidity as the air temperature increased its relative humidity decreased. The minimum values of the hourly air relative humidity were obtained during the first drying period, which began from 1 to 15 October in comparison with the other drying periods (16-31 October and 1-15 November). The relative humidity of the ambient air outside the greenhouse decreases with solar time from sunrise until it reaches the minimum value after the solar noon. It then increases gradually until it reaches the maximum value before sunrise next day.

5.1.3. Solar energy:

The highest values of the daily solar energy inside the greenhouse were 10.30, 9.16 and 8.01 kWh during the drying periods 1-15, 16-31 Oct. and 1-15 Nov. respectively. The minimum value of the incoming solar energy inside the greenhouse was found 3.15 kWh during the drying period 1 to 15 Nov. The hourly average solar energy of the air inside the greenhouse increased gradually with solar time from 9 a.m. until it reached a maximum value after the solar noon (1 p.m.). It then decreased gradually until it reached the minimum value at 5 p.m. The obtained values of hourly average solar energy inside the greenhouse were 4.89, 7.25, 9.04, 6.65 and 4.5 kWh during the drying time of 9 and 11 a.m., 1, 3 and 5 p.m. respectively.

5.1.4. Useful heat gain:

The maximum and minimum values of daily useful heat gain for drying process were found 5.47 and 1.95 kWh during the drying periods of 1-15 Oct. and 1-15 Nov. respectively. The hourly average useful heat gain for the drying process increased gradually from sunrise until it reached the highest amount (4.06 kWh) after the solar noon (at 1 p.m.). It then decreased gradually until it reached the minimum value (2.42 kWh) at sunset (5 p.m.).

5.1.5. Efficiency of greenhouse:

The maximum values of the daily greenhouse efficiency, which were obtained during the drying periods 1-15, 16-31 October and 1-15 November, were 69.87 , 54.72 and 44.01 %, respectively. The greenhouse efficiency increased by 27.7 and 58.8 % when the drying process was run during the period from 1 to 15 October when compared with the other drying periods. The average of hourly greenhouse efficiency were 62.4 , 50.6 , 44.9 , 47.1 and 53.8 % at drying times of 9 and 11 a.m., 1, 3 and 5 p.m., respectively. The greenhouse efficiency decreased gradually from sunrise until it reached the minimum value (44.9 %) at solar noon and then it increased gradually until it reached the maximum value (53.8 %) at sunset.

5.2. Drying process:

5.2.1. Grain bulk temperature:

The grain bulk temperature at higher value of airflow rate (4.8 m^3/ min. Mg) was found close to that of the ambient air temperature while, it was not close to it at lower value of airflow rate (3.2 m^3/ min. Mg). It was found higher in the case of solar heated air system compared with ambient air system. Generally, the drying periods affected the grain bulk temperature for both the drying system, airflow rate and grain layers. The higher values of grain bulk temperatures were obtained during the drying period from 1 to 15 October compared with the other drying periods from 16 to 31 October and 1 to 15 November.

5.2.2. Grain moisture content:

Decreasing the airflow rate tended to increase the drying time for both the drying systems and periods. The reduction of grain moisture content needed 45, 37 and 29 hours at airflow rates of 3.2, 4.0 and 4.8 m^3/ min. Mg for the solar heated air system and for the drying period from 1 to 15 October. However, the drying time decreased by 17.8 and 35.6 % as a result of increased airflow rates from 3.2 to 4.0 and from 4.0 to 4.8 m^3/ min. Mg, respectively, at the same pervious conditions.

The solar heated air system consumed less drying hours than that of the ambient air system for all airflow rates and drying periods. The drying hours required to decrease the grain moisture content from 22 to 14 % ((w. b.)) were 59 and 95 hours for solar heated air and ambient air systems respectively, at airflow rate of 3.2 m^3/ min. Mg and for the drying period from 16 to 31 October.

The drying time was 29, 35 and 43 hours during the drying periods 1-15, 16-31 October and 1-15 November respectively, at airflow rate of 4.8 m^3/ min. Mg for solar heated air system. The drying time increased by 20.7 and 48.3 % when delayed the drying period from 1-15 October to 16-31 October and from 16-31 October 1-15 November, respectively.

5.2.3. Drying rate:

The drying rate increased by increasing the airflow rate for both the drying systems and periods. The percentages of increase was 62.5 and 112.5 % when the airflow rate increased from 3.2 to 4.0 and 4.8 m^3/ min. Mg respectively, for solar heated air system and for first drying period after two drying days at the top layer of grain. For all the airflow rates and drying periods, the solar heated air system needed less drying hours than that of the ambient air system. The drying time decreased by 43.2 , 34.8 and 30.6 % when the solar heated air system was used instead of the ambient air system at the three drying periods with airflow rate of 4.0 m^3/ min. Mg.

The drying times were 29, 35 and 43 h for the three drying periods respectively, for solar heated air at airflow rate of 4.8 m^3/ min. Mg. The higher values of drying rate were observed with smaller values of drying times and the lower values of it were observed with higher values of drying time for all the treatments. Also, the maximum values of drying rate were observed at the beginning of drying process and it decreased after that until it reached to the minimum values at the end of drying process.

5.2.4. Moisture ratio:

The values of grain moisture ratios were 0.69, 0.50, 0.32, 0.24 and 0.15 after drying hours of 10, 20, 30, 40 and 50 hours, respectively, for solar heated air system at the bottom layer of grain for airflow rate of 3.2 m^3/ min. Mg during the first drying period. The grain moisture ratio decreased very rapidly at the beginning of drying process and very slowly at the end of drying process for all the drying variables.

The observed values of grain moisture ratio were 0.61, 0.41 and 0.24 at airflow rates of 3.2, 4.0 and 4.8 m^3/ min. Mg, respectively, after 30 hours from beginning of drying process for solar heated air system and at the top layer of grain layer during the first drying period. Increasing the airflow rate tended to decrease the grain moisture ratio which decreased by 32.8 and 60.6 % when the airflow rates increased from 3.2 to 4.0 and from 4.0 to 4.8 m^3/ min. Mg.

The grain moisture ratio decreased by 35.5 % when the solar heated air system was used instead of ambient air system for airflow rate of 3.2 m^3/ min. Mg and at the bottom layer of grain in the second drying period. The three drying periods gave grain moisture ratios of 0.18, 0.35 and 0.61 after 60 hours from the beginning of drying process, respectively for ambient air system, at the top layer of grain and for airflow rate of 3.2 m^3/ min. Mg.

5.2.5. The removed water from the grains:

The drying time required for removing water (moisture) of the grain moisture decreased by increasing the airflow rate for both drying systems and periods. The mass of removed water increased by 22.1 and 57.4 % when the airflow rate increased from 3.2 to 4.0 and from 4.0 to 4.8 m^3/ min. Mg respectively, for the solar heated air system during the first drying period.

The daily averages of masses of removed water were 26.9 kg. and 19.2 kg. per Mg grains for solar heated air and ambient air systems at airflow rate of 4.0 m^3/ min. Mg during the second drying period. The solar heated air and ambient air systems needed of 35 h and 49 h for removing the water from the grains at airflow rate of 4.0 m^3/ min. Mg during the second drying period. The obtained values of the daily averages of removed water were 17.8, 13.5 and 10.9 kg per Mg of grains during the drying periods of 1-15, 16-31 October and 1-15 November, respectively, for ambient air system and for airflow rate of 4.0 m^3/ min. Mg.

5.3. Grain quality:

5.3.1. Total yield and head yield:

The results showed that increasing the airflow rate tended to increase both the total yield and head yield for both the drying systems and periods. The solar heated air system gave higher total yield and head yield than that of the ambient air system for all the treatments. The shade drying gave the higher values of total yield and head yield which were 73.6 and 72.5 %. The sun drying gave the lower values of total and head yield which were 72.5 and 66.8 % compared with the other drying systems and periods.

The values of total yield were 73.3 , 73.0 and 72.6 % during the drying periods of 1-15, 16-31 October and 1-15 November respectively for ambient air system for airflow rate of 4.8 m^3/ min. Mg. The values of head yield were 71.1 , 69.0 and 68.8 % during drying periods of 1-15, 16-31 October and 1-15 November, respectively for solar heated air system for airflow rate of 4.0 m^3/ min. Mg.

5.3.2. Broken milled grains and cracked grains:

For all drying systems and periods, increasing the airflow rate tends to decrease the broken grains and increase the cracked grains. The broken grains decreased by 53.6 % when the airflow rate increased from 3.2 to 4.8 m^3/ min. Mg for ambient air system at the bottom layer of grain during the first drying period. The cracked grains increased by 50 and 33.3 % as the airflow rate increased from 3.2 to 4.0 and from 4.0 to 4.8 m^3/ min. Mg for solar heated air system during the third drying period at the bottom layer of grain.

The sun drying gave the higher values of broken and cracked grains (4.4 and 12 %) while the lower values of them (1 %) was obtained for shade drying. The drying period from 1 to 15 Nov. gave the higher percentages of broken grains which were 4.0 , 4.2 and 4.3 % at bottom, middle and top layer of grain, respectively, for ambient air system for airflow rate of 3.2 m^3/ min. Mg.

5.3.3. Grain hardness:

Increasing the airflow rate tended to increase the hardness for both the drying systems and periods. The grain hardness increased by 23.5 % when the airflow rate increased from 3.2 to 4.8 m^3/ min. Mg. The values of grain hardness was higher for the grains, which were dried by using the shade drying, followed by solar heated air, ambient air and sun drying. The first, the second and the third drying periods indicated values of grain hardness of 56, 50 and 41 N, respectively, for ambient air system at the middle layer of grain of airflow rte of 3.2 m^3/ min. Mg. The grain hardness decreased by 26.8 % when the drying process was delayed from 1-15 October to 1-15 November.

5.3.4. Germination rate:

For all the drying systems and periods, increasing the airflow rates tended to increase the germination rate of grain. The germination rate increased by 13.4 % when the airflow rate increased from 3.2 to 4.8 m^3/ min. Mg for solar heated air at the bottom layer of grain during the first drying period. The percentages of germination rate were 93 , 90 and 89 % for drying periods of 1-15, 16-31 October and 1-15 November, respectively, for solar heated air system and for airflow rate of 4.8 m^3/ min. Mg at the bottom layer of grain.

5.3.5. Transparency, grain whiteness and milling degree:

Increasing the airflow rate tended to increase both transparency, grain whiteness and milling degree for both the drying systems and periods. The transparency, grain whiteness and milling degree increased by 30.4, 7.3 and 12.7 % when the airflow rate increased from 3.2 to 4.8 m^3/ min. Mg, for ambient air system at the bottom layer of grain during the third drying period.

The solar heated air system showed the higher values of transparency and grain milling degree compared with the ambient air system for all airflow rates and drying periods. While, the ambient system showed higher values of grain whiteness degrees than that of the solar heated air system. The values of transparency, grain whiteness and milling degrees were higher during the first drying period compared with the second and third drying periods. The grain whiteness degrees were 41.6, 40.5 and 39.8 units during drying periods of 1-15, 16-31 October and 1-15 November, respectively.

The transparency increased by 11.1 % and 18.5 % for the grain at the middle and the bottom layers compared with the top layer of grain for solar heated air system for airflow rate of 3.2 m^3/ min. Mg during the first drying period. However, the grain milling degrees were 92.6 , 91.0 and 89.0 % at the bottom, the middle and the top layer of grain, respectively, for solar heated air system and for airflow rate of 4.8 m^3/ min. Mg during the third drying period.

5.3.6. Fungal growth:

The airflow rates of 3.2, 4.0 and 4.8 m^3/ min. Mg indicated values for fungal growth percentages of 3.7 , 3.3 and 2.3 %, respectively for the solar heated air system and the top layer of grain during the first drying period. The maximum and minimum values of fungal growth were 9.3 and 1.6 % for sun and shade drying methods, respectively during the second drying period. The ambient air system indicated less values of fungal growth percentages than that of the solar heated air system for all the airflow rates and drying periods. The bottom, the middle and the top layer of grain indicated values of fungal growth percentages of 1.9, 2.1 and 2.3 %, respectively, for solar heated air system at 4.8 m^3/ min. Mg airflow rate and during the first drying period. The fungal growth increased by 10.5 and 21.1 % in the middle and the top layer of grain, respectively, compared with the bottom layer of grain.

5.4. Energy and cost analysis:

5.4.1. Energy consumption for the operation of the drying systems:

For solar heated air and ambient air drying systems and periods, increasing the airflow rate tended to increase the energy required for the operating the drying systems. The energy values were 12.23, 13.36 and 17.35 kWh/Mg at airflow rates of 3.2, 4.0 and 4.8 m^3/ min. Mg, respectively, for the ambient air system during the first drying period. The energy values increased by 41.9 % when the airflow rate increased from 3.2 to 4.8 m^3/ min. Mg. The solar heated air system consumed less energy than that of ambient air system for all the treatments. The energy values required for fan operation decreased by 38.3 % when the solar heated air was used instead of ambient air system at airflow rate of 4.8 m^3/ min. Mg during the first drying period.

5.4.2. Energy cost:

Increasing the airflow rate tended to increase the cost required for the operation of the fan for both the drying systems. The airflow rates of 3.2, 4.0 and 4.8 m^3/ min. Mg indicated values of energy costs of 1.48, 1.68 and 1.93 LE/Mg, respectively, for solar heated air system during the first drying period. The energy costs of the solar heated air system was less than that of the ambient air system for all the treatments. They were 2.86 and 3.92 LE/Mg for solar heated air and ambient air systems, respectively, at airflow rate of 4.8 m^3/ min. Mg during the third drying period. The energy cost increased by 30.4 and 60.8 % when the drying operation was carried out in the two periods of 16-31 October and 1-15 November instead of the period of 1-15 October.

5.5. The prediction equations of water removed from rough rice grains:

The prediction equations of water removed, W_r, during in-bin drying of rough rice grains for a wide range of airflow rate, A_f,(from 3.2 to 4.8 m^3/ min. Mg of grains) drying air temperature, T ,(from 290 °K to 306 °K) and drying time, t , (from 0 to 60 hours, drying time per day equal 10 hours) and for three drying periods (1-15 October, 16-31 October and 1-15 November) and two systems (solar heated air and ambient air system) were found to be presented as follows:

-The predictin equations for solar heated air system:

$$W_r = 43.65 + 0.93\ A_f + 0.34\ T - 1.32\ t. \quad \ldots\ 5.1.$$

(r^2 = 0.91, › 1-15 Oct.).

$$W_r = 12.23 + 1.18\ A_f + 1.09\ T - 0.89\ t. \quad \ldots\ 5.2.$$

(r^2 = 0.92, › 16-31 Oct.).

$$W_r = -21.70 + 3.56\ A_f + 2.12\ T - 0.75\ t \quad \ldots\ 5.3.$$

(r^2 = 0.94, › 1-15 Nov.).

Where:

W_r = water removed from grains, kg_w / Mg_{gr}.

A_f = airflow rate for drying the grains, m^3 / min. Mg.

T = air temperature for drying the grains, ° C.

t = drying time, h.

- The predictin equations for ambient air system:

$$W_r = 25.22 + 1.07\ A_f + 0.30\ T - 0.62\ t. \quad \ldots\ 5.4.$$

(r^2 = 0.91, › 1-15 Oct.).

$$W_r = -1.40 + 2.58\ A_f + 0.90\ T - 0.46\ t \quad \ldots\ 5.5.$$

(r^2 = 0.95, › 16-31 Oct.).

$$W_r = -14.20 + 3.42\ A_f + 1.04\ T - 0.21\ t. \quad \ldots\ 5.6.$$

(r^2 = 0.84, › 1-15 Nov.).

Where:

W_r = water removed from grains, kg_w / $Mg_{gr.}$

A_f = airflow rate for drying the grains, m^3 / min. Mg.

T = air temperature for drying the grains, $^\circ$ C.

t = drying time, h.

Two general prediction equations described the relationship between the water removed and other drying variables for solar heated air system and ambient air system are presented as follows:

$$W_r = 22.94 + 1.89\ A_f + 0.65\ T - 0.98\ t. \qquad 5.7.$$

(r^2 = 0.85, for solar heated air).

$$W_r = 11.46 + 2.36\ A_f + 0.40\ T - 0.45\ t. \qquad 5.8.$$

(r^2 = 0.82, for ambient air).

Recommendations:

Analysis of the data and the results obtained from the experiments indicated that, the plastic greenhouse is suitable as a solar collector for heating the air to decrease the initial moisture content of harvested paddy rice to the safe moisture content suitable for storage the grains. It is recommended for the engineers and the operators of the drying systems which utilize the solar heated air or ambient to consider the following engineering and the drying information:

1-The plastic greenhouse is effective and economic for collecting the solar radiation which can be utilize in the drying process as clean and renewable energy.

2-The use of the solar heated air system increased the drying rate and consequently, increases the drying capacity and decreases the operating hours of the fan and hence the drying cost in addition to the improvement of the grains quality.

3-The drying process during the harvested period of rice grain which started from 1 to 15 October by using the solar heated air system with airflow rate of 4.8 m^3/ min.Mg of rough rice grains is the optimum conditions for drying the high moisture rough rice in storage bins.