Journal of Engineering Science and Technology
Vol. 4, No. 3 (2009) 251 - 263

STUDY OF PENETRATION CURVES OF SOLAR HEAT INTO DATE FRUITS AS A MEAN TO CONTROL INSECTS

ALHUSSEIN M. ASSIRY

Department of Agricultural Engineering / King Saud University
P. BOX 2460, Riyadh, 11451, Saudi Arabia
Email: assiry@ksu.edu.sa

Abstract

The annual palm date production in Saudi Arabia approached 970 thousands tons in 2006. One of the most important processes in the date industry is fumigation which is based on chemical treatment to destroy insects. Previous studies indicate that insects are very sensitive to temperature rise and can be destroyed instantly if exposed to 64ºC. The harvesting period of date fruits in the Riyadh region of Saudi Arabia extends from June till the end of September. During the summer months, the standard day temperature in the Riyadh area ranges from 35 to 45ºC. Therefore, this study is an attempt to develop a procedure to utilize the solar energy to destroy date insects as an alternative method to the fumigation process. Thus, the goal of this research was to study the heat penetration curves of solar energy into five varieties of date fruits (Kholas, Khudari, Seri, Sefri and Sukari) using lab size flat solar collector. Temperatures of three locations were recorded during solar exposure (inside the date fruits, inside the solar collector and the surrounding atmosphere temperature). Mathematical models were developed for the heating curves. Fruit color and moisture content before and after solar heating were determined as quality parameters. The heat penetration rates depend mainly on the size of the date fruit. The time to approach the lethal temperature ranges from 33-37 minutes of exposure to solar radiation inside the collector. Little change was observed in the color differences which was less than 9%. No significant changes occurred in the moisture content of the date before and after exposure. The results indicate that solar energy can be used to destroy the insects with little change of date quality.

Keywords: Solar energy, Heat penetration, Palm date, Insect control

1. Introduction

Date palm trees (*Phoenix datylifera*) are the most extensively grown fruit in the Kingdom of Saudi Arabia with an annual production exceeding 970,000 tons of

Nomenclatures

Ave	Average
*a**	Greenness - redness color component.
*b**	Blueness - yellowness color component .
count	Number of samples
co95	95% Confidence
E	Total color
ΔE	Color difference
f_h	Time factor, min.
*L**	Lightness - darkness color component
MC	Moisture content in wet basis, %
ML	Moisture loss, %
max	Maximum value
min	Minimum value
stdev	Standard deviation
T_C	Central temperature, ˚C
T_{in}	Temperature of the air inside the solar collector, ˚C
T_o	Initial temperature, ˚C
T_{out}	Temperature of the air outside the solar collector, ˚C
t	Time, min.

dates from 400 different cultivars [1]. The final stage of fruit maturation is the "Tamr" stage when the fruit is left on the tree if climatic conditions are favorable. This stage is the brown color, universally known "date" dried fruit, where the moisture content is a self-preserving maximum of 25%. The harvesting period of date fruits in the Riyadh region of Saudi Arabia starts in June and continues till the end of September. The average daily maximum temperature is approximately 40ºC from May to September, reaching maximum average highs of 43ºC in July. The low average humidity is approximately 10% to 14% during June to September indicating low humidity during hot-dry periods [2]. It has been reported that the total solar radiation on Riyadh throughout the year to range between 1085-1233 W/m^2 [3].

The date processing industry has been growing steadily during the past few years. Mainly these factories process 70,000 tons of dates annually. The first step after harvesting is a fumigation process which is made by exposure of dates to methyl bromide for 4 to 6 hours to kill insects at all stages. Methyl bromide (MeBr) is an odorless, colorless gas that has been used as an agricultural soil and structural fumigant to control a wide variety of pests. However, because MeBr depletes the stratospheric ozone layer and is classified as a Class I ozone-depleting substance [4], there is a great interest to seek an alternative method of insect control which is suitable for palm date producers - especially farmers in remote areas.

Date fruits are subject to insect attack, and one of the most common insects that infect dates *is Oryzaephilus surinamensis: Silvanidae*. The effect of conventional and electrical thermal stresses on the destruction of *Oryzaephilus surinamensis: Silvanidae* inside the fruits of some date varieties has been studied [5]. The results indicate that the destruction rate order of the insect can be described successfully by applying zero order kinetics models in both heating mechanisms: conventional and electrical. In addition, the destruction of the adult insects insures the destruction of all other stages of the insect in the Sefri, Seri and Khudari varieties. Kinetic study indicates that the insect is very sensitive to temperature and can be destroyed instantaneously by heat exposure to 64 ºC [6].

Solar radiation has been used to satisfactorily disinfect seeds. Grain temperature from 60-65ºC for a few seconds or minutes is necessary to kill all stored grain insects. The species, stage of development and moisture content of food will influence the response to temperature. The lethal effect of temperature on the stored-product insects has been reported where raising grain temperature above 62ºC causes insects death in less than one minute, temperature 50-62ºC causes death in less than one hour, and temperature 45-50ºC causes death in less than one day [7 , 8].

Therefore, this study is an attempt to develop a procedure to utilize solar energy to destroy date insects as an alternative method to the fumigation process and to serve the farmers in remote areas. The specific objective of this research was to study the heat penetration curves of solar energy into five varieties of date fruits (Kholas, Khudari, Seri, Sefri, Sukari) by using a flat solar collector.

2. Materials and Methods

Flat solar collector was constructed in rectangular shape (40 cm×40 cm inside space) consisted of wood, thermal insulation (Styrofoam) and single glass cover as shown in Fig.1.

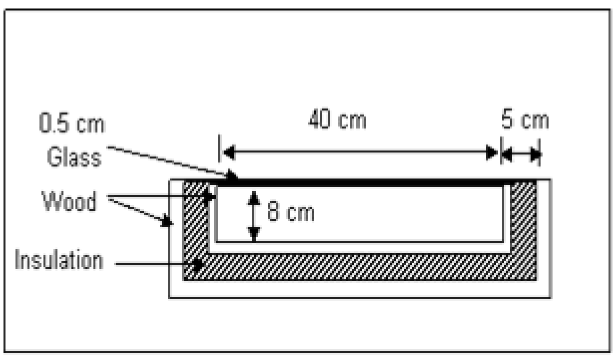

Fig. 1. Geometry and Dimensions of the Solar Collector.

Five common varieties (Kholas, Khudari, Seri, Sefri, Sukari) of palm date fruits in the Tamer stages were supplied by local date factory in Riyadh region. Samples of ten fruits from each variety were randomly selected to measure their volume. Three samples of date were selected randomly for moisture content measurement before and after exposure to solar heating using a Halogen Moisture Analyzer (HR73 Halogen, Switzerland). In each experimental run, the color of 20 samples was measured before and after solar heating using Color Flex (Model No.45/0, USA) at room temperature.

An amount of 500 gm of date fruits was placed inside the solar collector (Fig. 2). Three fruits selected randomly to measure the temperature (T_c) in the preferred space for insect to live, which is between the flesh and the seed of the fruits, thus three thin thermocouples (0.5 mm thick thermocouple points) were inserted carefully inside the fruit toward its center. These three fruits were distributed evenly among the 500 gm of dates inside the solar collector. Other three thermocouples were evenly placed inside the solar collector to measure the temperature (T_{in}) of the air surrounding the date fruits. These thermocouple points were shielded in a way to avoid radiation effect. All the temperatures inside the fruits and the surrounding air inside the solar collector were recorded each minute using data loggers.

Fig. 2. Photo of the Date Fruits inside the Flat Solar Collector.

The standard air temperature outside the solar collector (T_{out}) and the solar radiation were recorded each minute by data loggers and the thermal performance of the solar collector was tested in Riyadh city (N: 24-44-11.9, E: 46-37-14.9, 649 m above sea level). Table 1 shows the experimental data at the test location during the solar exposure of the five varieties of date fruits.

3. Results and Discussions

Figure 3 indicates an example of the air temperature and the solar radiation of the data collected in the test location. It should be noticed that the solar radiation was more than 500 [W/m^2] for more than 6 hours of the day of 9th of Oct. This reflects the possible working hours of the solar treatment unit with high effectiveness of heating during and after the harvesting period of date.

The performance of the solar collector in terms of the temperature changes with time can be illustrated by typical example as shown in Fig. 4. It indicates the outside standard temperature (T_{out}), the average temperature inside the solar collector (T_{in}), and the average temperature inside the date fruits (T_C) when the solar collector was exposed to the solar radiation for 60 minutes and then unexposed by placing it in room temperature for about 30 minutes. It should be noticed that air temperature inside the solar collector increased from room temperature gradually up to 90˚C, in the same time the temperature inside the fruits increased up to 85˚C.

Table 1. The Experimental Data at the Test Site during the Solar Exposure of the Five Varieties of Date Fruits.

Variety	Experiment Date	Starting Time	Statistical Parameter	T_{out} [°C]	Solar Radiation [W/m^2]
Kholas	10-Oct-05	11:00 AM	*count*	46	46
			max	39.4	862
			min	34.1	827
			Ave	37.5	847
			stdev	1.17	8.74
			co95	0.34	2.53
Khudari	9-Oct-05	11:50 AM	*count*	45	45
			max	36.1	860
			min	31.7	834
			Ave	34.8	849
			stdev	0.71	8.08
			co95	0.21	2.36
Seri	19-Oct-05	10:30 AM	*count*	45	45
			max	39.1	825
			min	34.5	780
			Ave	36.95	803
			stdev	1.29	16.66
			co95	0.38	4.87
Sefri	21-Sep-05	10:30 AM	*count*	48	48
			max	36.4	909
			min	34.7	803
			Ave	35.15	844
			stdev	0.25	20.67
			co95	0.07	5.85
Sukari	1-Oct-05	11:40 AM	*count*	46	46
			max	38.6	859
			min	33.2	825
			Ave	33.14	810
			stdev	1.24	10.00
			co95	0.36	2.89

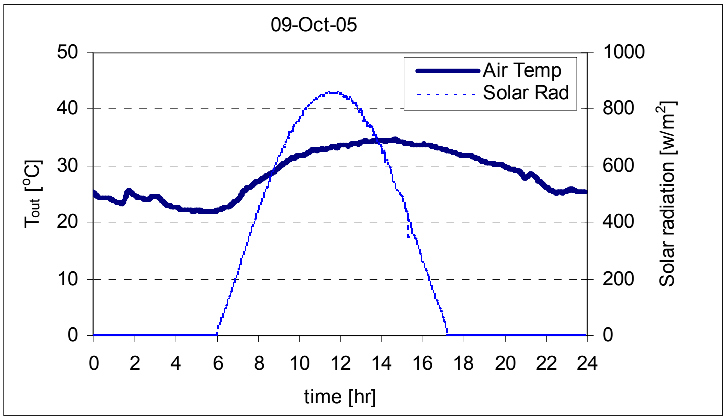

Fig. 3. Example of Air Temperature and Solar Radiation during the Day in Riyadh.

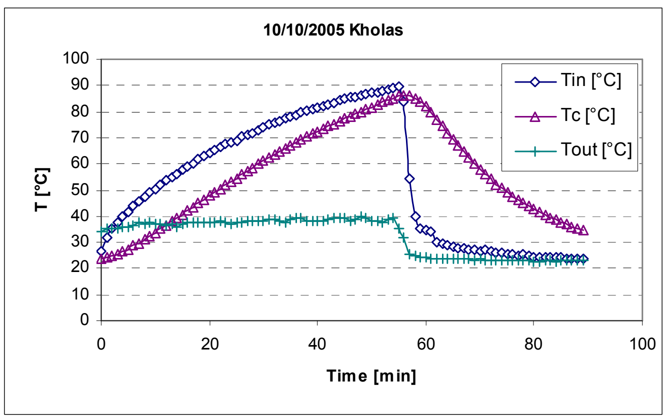

Fig. 4. Change of the Average Temperatures of Air Inside and Outside the Solar Collector, and Central Temperature of the Fruit.

All date varieties followed the same pattern of heat penetration curves. Figure 5 illustrates the penetration curves by applying the common heating equation [9]:

$$\frac{T_{in} - T_C}{T_{in} - T_o} = e^{\frac{t}{f_h}} \tag{1}$$

where T_o is the initial temperature inside the date fruits, and f_h is a time factor representing the rate of heating which can be obtained by the determination of the slopes (f_h =1/slope) in Fig 5.

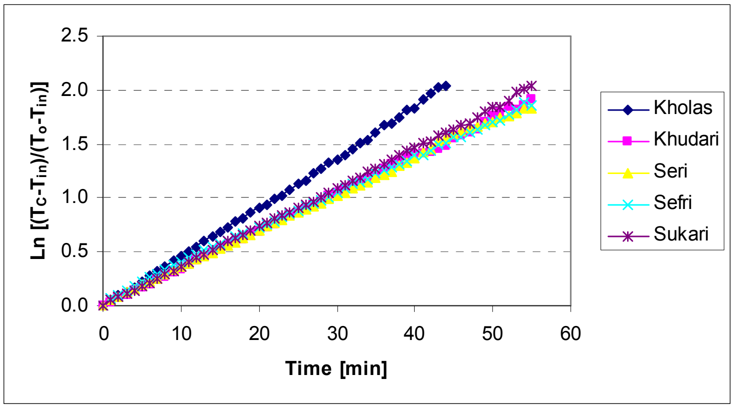

Fig. 5. Thermal Penetration Curves of Different Date Varieties.

The time factor ranges from 20.20 min to 30.30 min as indicated in Table 2. The higher is the time factor; the lower is the heating rate. It should be noticed that all varieties have negligible change in the time factor except the Kholas variety, which has a lower time factor because it has the smallest volume among the date varieties under investigation. The time factor has a significant dependence on the size of the fruits as indicated by Fig. 6.

Table 2. The Time Factor, Volume, the Time when the Temperature inside the Fruits Exceeded the Lethal Temperature 64˚C, the Average outside Temperature and the Average Solar Radiation.

Variety	f_h [min]	R^2	Volume [cm^3/fruit]	*t* at *T*>64˚C [min]	T_{out} [°C]	Average Solar Radiation [W/m^2]
Kholas	20.20 ±1.01	0.991	9.37±0.14	33	37.5±1.17	847±8.74
Khudari	28.84±1.44	0.999	10.52±0.23	37	34.8±0.71	849±8.08
Seri	29.51±1.48	0.999	12.50±0.11	36	36.95±1.29	803±16.66
Sefri	30.30±1.52	0.999	12.74±0.30	37	35.15±0.25	844±20.67
Sukari	27.32±1.37	1.000	11.14±0.17	37	33.14±1.24	810±10.00

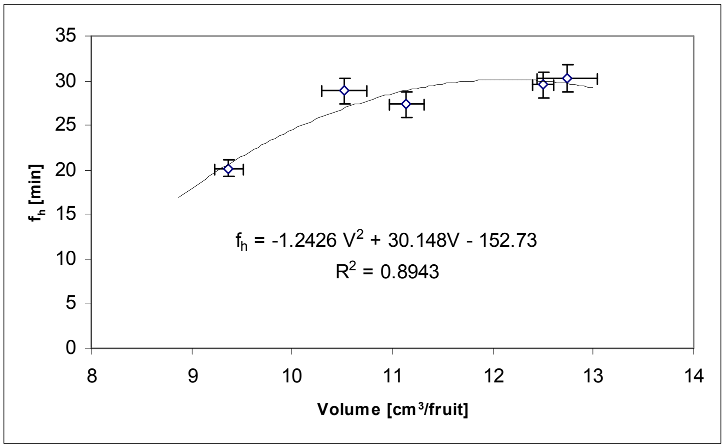

Fig. 6. The Relationship between the Time Factor and the Volume of the Date Fruits. Error Bars Represent the 95% Confidence Interval.

The required time to reach the lethal temperature ranges from 33 to 37 minutes as indicated in Table 2. In all experiments, the air temperature inside the solar collector approached about 80ºC after 40 minutes, and the solar radiation ranges from 803 to 849 W/m^2. Larger solar collector with 1 m^2 area can process about 6.2 kg of date fruits within 40 minutes. The capacity of such collector will be 9.3 kg/hr assuming that the solar radiation is above 800 W/m^2.

Date quality

As the date temperature increased due to solar exposure, it is important to determine some of the quality parameters that can be influenced by high temperature such as color change and moisture loss. Table 3 indicates the moisture content (*MC*% on wet bases), color components (L^*, a^* and b^*), total color (E), color difference (ΔE) and moisture loss (*ML* %) of all varieties of date before treatment.

Figure 7 illustrates the changes in the color component L^*, which represents the lightness or darkness of date fruits. At 95% confidence interval, it is clear that there was a significant darkness of the Kholas and Khudari, a significant increase in case of the Seri and no significant change fore the Sefri and the Sukari.

The color component a^* represents the color coordinates where -100 means greenness and +100 is redness. Figure 8 shows that there is a significant decrease in redness in Khudari, and an increase in the Sefri. However, there were no significant changes in the redness of the other varieties.

Table 3. The Quality Parameters of Different Date Varieties before and after Exposure to High Temperature inside the Solar Collector.

Variety	Statistical Parameter	MC%	Before Exposure				After Exposure				ΔE	ML%
			L*	a*	b*	E	L*	a*	b*	E		
Kholas	count	3	20	20	20	20	20	20	20	20	20	3
	Ave	8.61	31.07	12.09	14.50	36.43	29.22	13.38	15.50	35.77	4.36	0.38
	stdev	0.31	1.99	1.66	1.98	2.27	0.90	1.45	2.25	1.34	1.73	0.07
	co95	0.35	0.87	0.73	0.87	1.00	0.40	0.64	0.99	0.59	0.76	0.08
Khudari	count	3	20	20	20	20	20	20	0	20	20	3
	Ave	9.13	28.04	10.49	10.71	31.88	25.75	7.25	10.71	28.91	4.53	0.51
	stdev	0.45	1.71	2.44	2.55	3.11	1.41	0.78	2.16	1.19	3.07	0.09
	co95	0.51	0.75	1.07	1.12	1.36	0.62	0.34	0.95	0.52	1.35	0.11
Seri	count	3	20	20	20	20	20	20	20	20	20	3
	Ave	6.17	30.37	10.51	16.23	36.07	32.41	9.55	14.47	36.84	5.01	0.38
	stdev	0.68	2.32	1.74	2.00	2.69	1.41	1.86	2.16	1.94	2.44	0.03
	co95	0.77	1.02	0.76	0.88	1.18	0.62	0.82	0.95	0.85	1.07	0.03
Sefri	count	3	20	20	20	20	20	20	20	20	20	3
	Ave	13.44	25.74	9.71	8.00	28.74	24.95	12.04	9.86	29.52	5.16	0.60
	stdev	0.46	2.46	1.53	1.90	2.63	1.98	1.75	2.42	2.46	1.88	0.04
	co95	0.52	1.08	0.67	0.83	1.15	0.87	0.77	1.06	1.08	0.83	0.05
Sukari	count	3	20	20	20	20	20	20	20	20	20	3
	Ave	15.66	32.14	14.59	18.03	39.71	34.41	13.46	19.67	41.93	5.07	0.92
	stdev	0.81	2.55	1.44	3.15	3.40	3.15	1.13	3.35	3.99	2.62	0.08
	co95	0.91	1.12	0.63	1.38	1.49	1.38	0.50	1.47	1.75	1.15	0.09

The color component b^* represents the coordinate of color in which -100 is blueness and +100 is yellowness. There were no significant changes in all the varieties as indicated by Fig. 9. It should be mentioned that increasing b^* values toward yellowness is preverbal, where that happen in the case of Kholas, Sefri and Sukari varieties.

Changes in the color components were not sensibly recognizable by the human eyes, rather it is the combination of these components, therefore the total color (E) and color difference (ΔE) can be determined by Eqs. (2) and (3) respectively [10]:

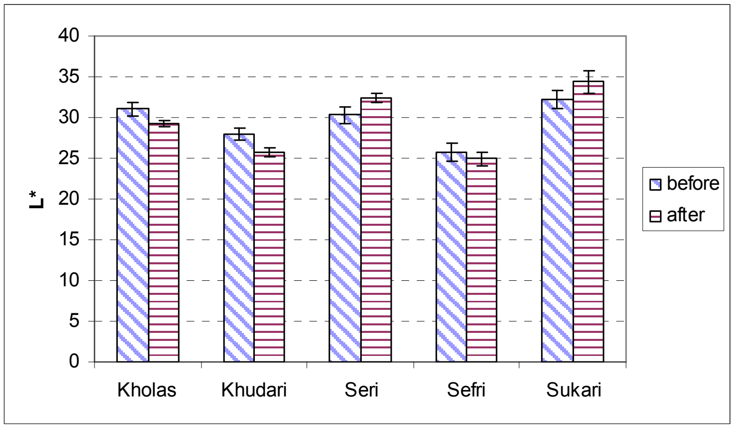

Fig. 7. The Value of *L of Different Date Varieties before and after Exposure to Solar Radiation inside the Solar Collector.**

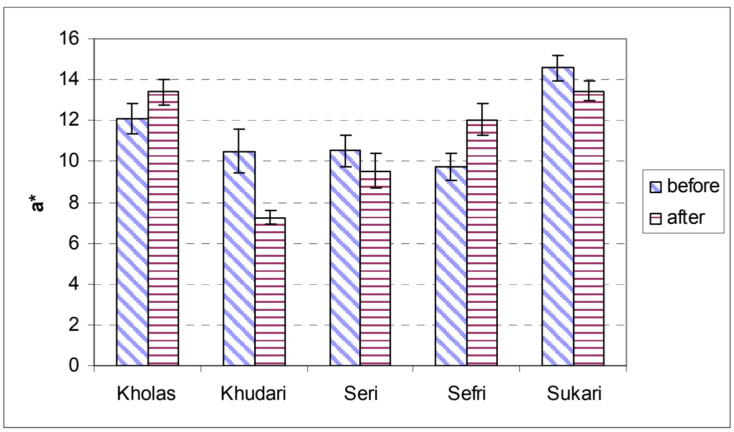

Fig. 8. The Value of *a of Different Date Varieties before and after Exposure to Solar Radiation inside the Solar Collector.**

$$E = \sqrt{L^{*2} + b^{*2} + a^{*2}} \qquad (2)$$

$$\Delta E = \sqrt{\left(\Delta L^{*}\right)^{2} + \left(\Delta b^{*}\right)^{2} + \left(\Delta a^{*}\right)^{2}} \qquad (3)$$

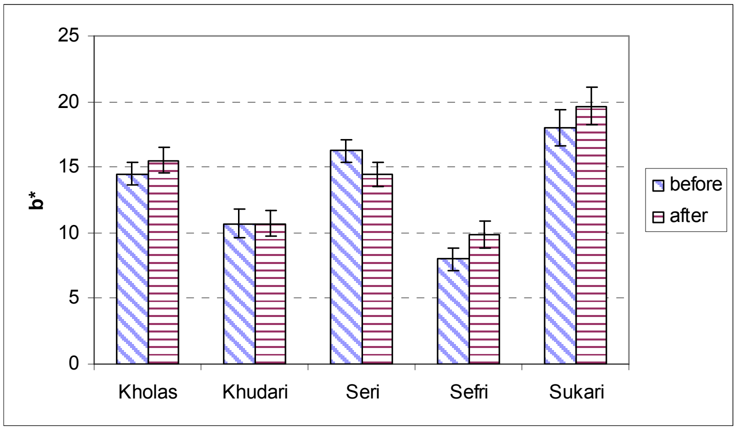

Fig. 9. The Value of *b of Different Date Varieties before and after Exposure to Solar Radiation inside the Solar Collector.**

Eq. (2) was used to calculate the total color before and after the treatment. The total color of the date fruits was not changed by solar exposure except for the Khudari variety were the total color reduced significantly at 95 % confidence interval as shown in Fig. 10. In general, the total color of Seri, Sefri and Sukari was improved by solar exposure that can be attributed to the diffusion of moisture toward the skin of the fruit which becomes soft and smooth.

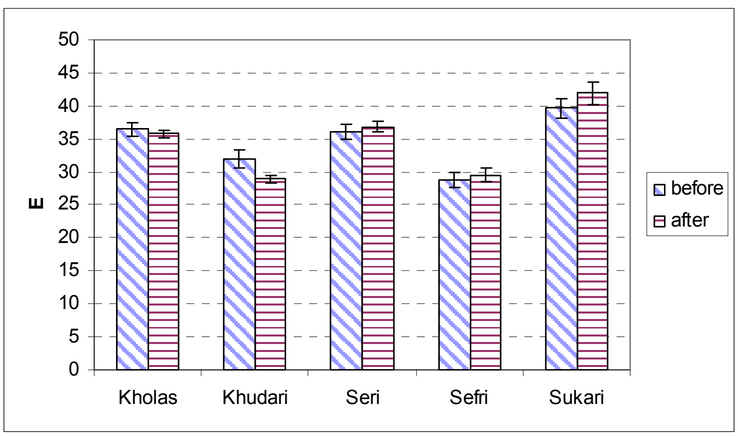

Fig. 10. The Value of the Total Color (*E*) of Different Date Varieties before and after Exposure to Solar Radiation inside the Solar Collector.

Color difference can be determined by Eq. (3). Figure 11 indicates that the over all color change was small in the range 4.6-5.16. In general, any increase in color components is preferable by consumer, where the general practice of consumer is to look for dates with more lightness, yellowness and redness.

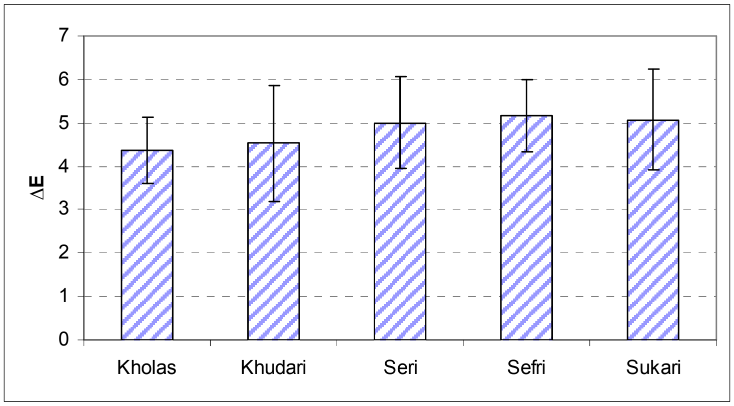

Fig. 11. The Color Difference (Δ*E*) of Different Date Varieties before and after Exposure to Solar Radiation inside the Solar Collector.

Moisture content

The average moisture contents of all the varieties of date range from 6.17% to 15.66% on wet bases. In all the varieties the moisture content after the solar exposure was reduced but this reduction was not significant at 95% significant interval as indicated in Fig. 11. Therefore, exposure to solar radiation fore a short period of time will not affect the moisture content of the date.

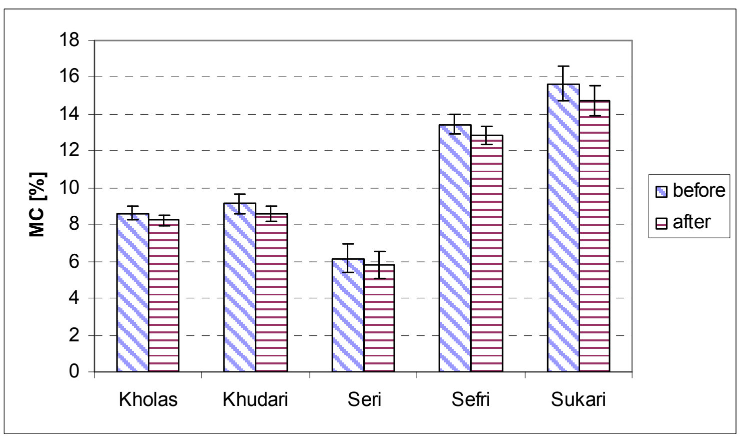

Fig. 12. The Change of Moisture Content of Different Date Varieties before and after Exposure to Solar Radiation inside the Solar Collector.

4. Conclusions

The results of this research indicate that the solar radiation can be utilized to control the date insects. Either batch or continuous solar treatment unit can be designed and used as alternative for the fumigation treatments of date. A batch unit will be suitable for small and remote date farms, while a continuous unit requires a moving conveyer. The expected capacity of solar unit is 9.4 kg/m^2hr under the Riyadh climate characteristics.

Also, the results indicate that using solar energy can be an effective method to control insects in date fruits with less than 9% of total color change and less than 0.92% of moisture loss. It is recommended to build a pilot scale solar unit to examine its performance by using infected date fruits. Also coast analysis should be made to optimize the design of a solar unit where its cost is in the hand of small farmers. The industrial application of such unit should be examined.

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