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A Greenhouse Solar Dryer for Tomato Paste Production in Iraqi Rural Region

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ABSTRACT

Tomato fruit is a source of many important nutrients. It is difficult to store it for a long time because it contains a high percentage of moisture. The moisture content could be reduced in different ways to restrict the high growth of fungi. This study mainly aims to manufacture a simple and easy-to-use solar dryer for drying tomato fruits with solar cell-based fans. This method can be adapted to dry a wide range of Vegetables and fruits. The measured factors in this study are solar radiation, ambient temperature, relative humidity, and drying time. Solar drying is an affordable method to soothe the negative impact of post harvest losses on cultivators in Iraq. A greenhouse dryer (1 × 0.5 × 0.5 m) was constructed using glass of (τ = 0.9 for 0.4 μm < λ< 0.7 μm and τ = 0.01 for λ > 0.7 μm). Two fans are used to force an airstream with an average velocity of 0.025 m/s at the tray section. A selected quantity of tomato was washed and ground, making 1 kg of puree to check the effectiveness of the dryer. An experiment conducted on 10-11 March 2023 showed that 14 drying hours are needed to bring the paste to an acceptable quality of 0.25 brix. The efficiency of the greenhouse has not exceeded 25% on average, accompanied by an average drying rate of 60 g/hr. It was found that converting the perishable tomato crop into paste is profitable for cultivators in Iraqi conditions. Using a solar dryer is particularly profitable for local farmers by reducing crop losses, as per 1 m^2 land area, a production of 6 kg of tomatoes is expected with losses of about 1 kg, and a profit of 6 thousand IQD and losses of 1 thousand IQD. A land area of 1 m^2 with a dryer produces 3.6 kg of tomatoes converted into 1.008 kg tomato paste producing 15 thousand IQD without losses.

1. INTRODUCTION

Vegetables and their products have a high nutritional value due to their content of antioxidants, vitamins, fiber, and polyphenols, which help get rid of harmful free radicals. Increasing the profitability for the farmer plays an important role in raising the economic efficiency of using the production elements [1]. Tiris et al. [2] stated that there are two ways to avoid spoilage of nutrients, especially in tomatoes. The first method is cold storage, storing food in a refrigerated room and thus providing it at any time to farmers to meet sudden and many requests, though it is expensive. The second method is more appropriate which reduces spoilage, results in longer shelf life, and helps small farmers economically.

To make a profitable drying, Patel and Kar [3] used a heat pump in the drying of grapes, adopting a drying mechanism, with different speed and temperature rates. The ratio of drying time was approximately 50% with the heat pump assisted system. Tiwari and Tiwari [4] pointed out the importance of using energy more productively. Using free energy sources such as solar energy may significantly reduce drying costs. Mkhize et al. [5] studied the effects of air relative humidity and temperature on drying kinetics using a convection dryer for pumpkin, watermelon, and quince.

Tomatoes are an essential ingredient of Iraqi cuisine due to their nutritional value. Farmers in Iraq produce about 750,000 tonnes per year, of which about 10-20% are damaged in post-harvest operations [6]. Poor technologies, infrastructure, and improper policies are the main factors and causes of losses [7, 8]. Drying reduces these losses, but new techniques and technology can be difficult for most farmers in developing and electricity-poor countries, including Iraq. When it comes to rural areas, the problem is even greater [9-11] and this is the case for many countries in Asia and Africa because the electricity grid is not affordable for farmers [12]. Hyder et al. [13] designed a solar dryer to dry fruits and vegetables. It works on transferring solar energy to thermal energy in the Islamabad area. The temperature is maintained between 45-50°C by controlling feedback. The design is based on solar radiation for December, and it was found that the energy required to dry a kilogram of bananas and apples is 220 watts and 245 watts respectively. Venkateswarlu and Reddy [14] studied the energy efficiency of solar dryers for proper storage through the regular nature of solar energy to increase the quality of materials as they dried. They studied solar dryers to enhance energy efficiency.

Tomato is considered an essential constituent of Iraqi cuisine, besides its nutritional value. Cultivators in Iraq produce around 750k tonnes annually, in which about 10-20% spoiled in post harvest processes [6]. Lack of technologies, poor infrastructure, improper policies among other factors are the main causes of these losses [7, 8]. Drying could reduce such losses, however; most cultivators might not afford to acquaint themselves with such expensive technology [9, 10]. Developing countries in general suffer from electricity shortages and Iraq is no exception. When it comes to rural areas the problem is even worse [11], that's the case for many countries in Asia and Africa, since grid electricity is not affordable for cultivators [12]. Many new creative innovations have been introduced in this industry through the past few years such as elevated pressure processing, pulsed electric fields, as well as radiofrequency and others. All these technologies are intended to reduce production cost, energy consumption and maintain sustainability as well [15]. However, these alternative dryers come with large capital and running costs for small farmers [9, 10]. This is attributed to the fact that drying is an energy intensive process, as such adopting [16] solar or any other clean energy sources is mandatory [17]. Besides, the outcome of many conferences like COP27 strongly recommend adopting renewable energy sources. Thus frequently farmers resort to solar dryers as an effective environment-friendly alternative to increase their income [12] and maybe compete with the imports. Iraq has high potential for solar energy utilization because of its high solar radiation intensity, long daylight hours and relatively low humidity around the year [18]. Drying crops is crucial for the inhabitants of rural areas since they rely on dried products in non harvest seasons when there are no crops to live [19]. However; there are no documented projects of solar dryer utilization due to the lack of awareness in the farmers community and in decision makers. Nevertheless, there are a lot of encouraging research works in this field [10, 20, 21]. Drying of crops is crucial for the rural areas inhabitants since they rely on dried products in non harvest seasons where there are no crops for living [19]. Among many crops in Iraq, tomato has special importance since its paste is an essential ingredient in Iraqi cuisine and all over the world because of its highly nutritional value [22]. No wonder why there are thousands of research work, conferences and workshop proceedings per year published relating to post harvest management of tomatoes [23]. Tomatoes are composed of 95% water and 5% solids and sugar making it very perishable due to microorganisms effects [24, 25], and for its high metabolism (ripening) [8] during the after harvest period [26]. There are new technologies like microorganism eradication or genetic manipulation but they come with some health risks and elevated costs [27]. Low temperature treatment also has some demerits such as cost and chilling injury. Processing tomatoes into concentrated paste is common practice [28] which is then used in many end products. The solid material quantity in the paste should not exceed the 28% limit, sometimes called the “Brix” [29, 30]. Tomato paste could be either produced by any of “Hot Break” or “Cold break” methods depending on the temperature of the process [31]. The quality of the paste depends eminently on the production processes [32]. With the conditions in the greenhouse, only the cold break could be attained which results in a better color and flavor paste, though it is not as efficient as the hot break [32]. Greenhouse effectiveness could be improved by the use of PCM’s [33], desiccants [8], reflector plate, nanofluids [34], or shape modifications [35]. All methods enhance either solar energy collection, drying air conditions, or energy management. In fact by improving the greenhouse we try to counter some negative impact of unfavorable weather conditions. Low solar intensity increases drying time and may perish the product. High air humidity also increases drying time likewise air temperature. The objective of this work is to develop and test a scaled down autonomous greenhouse dryer to produce tomato paste, although there are quality differences between vacuum produced paste and that produced under atmospheric conditions [36]. Assess the possibility of reducing postharvest tomato crop losses by greenhouse dryers utilization in Iraqi environment and life circumstances.

2. MATERIALS AND METHODS

The weather conditions have a great influence on the drying speed and capacity. Crops are seasonal possessing out of hand harvesting time which may occur in unfavorable weather seasons featuring high humidity and/or low solar radiation [37]. Iraqi weather in January and February might not be suitable for efficient solar drying due to their high relative humidity (Figure 1) and low solar radiation (Figure 2) while March has more encouraging conditions. The total solar radiation received during January, February and March are 61 kWh/m^2, 80 kWh/m^2 and 106 kWh/m^2 respectively. Thus; it is decided to conduct the drying experiment in March. A (1m × 0.5m × 0.5m) greenhouse model was constructed from horticultural glass to facilitate the experiment. The pertinent properties of this glass is shown in Table 1. Greenhouse effectiveness greatly affected by the characteristics of this glass, safety is also considered as a factor. Traditionally, horticultural glass (3 mm thickness) is a standard glazing for greenhouses due to its low cost, in spite of the safety concerns caused by its weakness. Shattered horticultural glass forms sharp shards which may harm any nearby pets or children. Cleaning is also a problem since it cannot be cleaned thoroughly due to accumulated dirt and algae [38]. A glass sheet was cut to dimensions and pieces glued together to construct the greenhouse. Holes are drilled in the two side walls to facilitate the air stream inlet and outlet. The greenhouse was equipped with a PV solar panel to power the attached two fans (Figure 3). Also, sensors of temperature, humidity and insolation intensity were added to the dryer. A sample of ripe tomato was selected, washed and pretreated to make 1 kg of puree placed in a tray (15 × 11) cm ready for drying. The site of experiment was at 33°18′55″N latitude.

After gathering the required primitive data, the output parameters were calculated as follows:

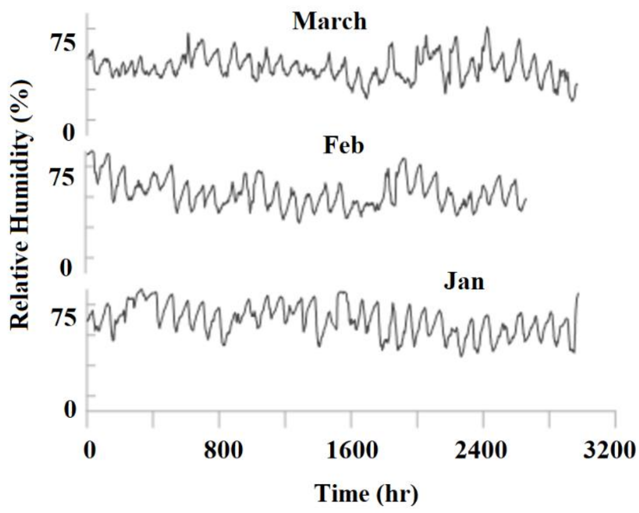

Figure 1. Ambient relative humidity [39]

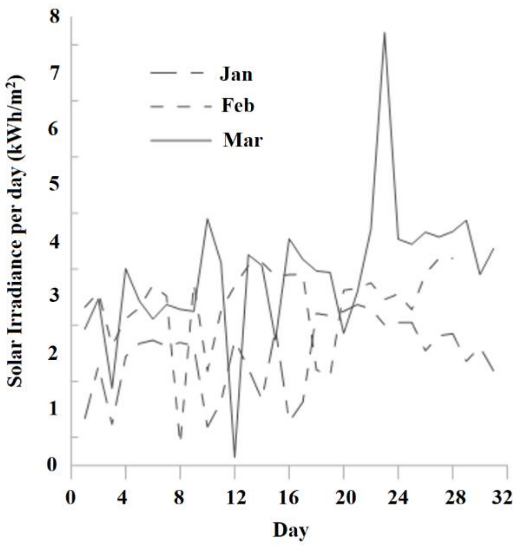

Figure 2. Solar radiation in Iraq [39]

Table 1. Horticultural glass properties [40]

Thickness (mm)	3
Transmittance at wavelength (0.4m<<0.7m)	0.9
Transmittance at wavelength (>0.7m)	0.01

Figure 3. The greenhouse

Air inlet and outlet moisture content (humidity ratio W in kg/kg) was calculated from [41]:

$$W = 0.622 \frac{p_w}{P - p_w} \quad (1)$$

where, the water vapor saturation pressure (p_s in Pa) could be calculated from Magnus formula [42]:

$$p_s = 610.94 \exp\left(\frac{17.625t}{t + 243.04}\right) \quad (2)$$

Then from the measured relative humidity $\boldsymbol{\phi}$, p_w would be [43]:

$$p_w = \phi \cdot p_s \quad (3)$$

t is the measured air temperature at inlet or outlet in °C. P in Eq. (1) stands for the ambient pressure. Accordingly, air enthalpies are:

$$h = (1.005 + 1.88W)t + L \cdot W \quad (4)$$

L is the latent heat of water evaporation in (J/kg) which is calculated by [44]:

$$L = 1.91846 \times 10^6 \left(\frac{T}{T - 33.91}\right)^2 \quad (5)$$

In which T is in (K).

Airstream heat gain Q_{air} is:

$$Q_{air} = \dot{m}\left(h_o - h_i\right) \quad (6)$$

h_i and ho are the inlet and outlet enthalpies respectively and is the air flow rate.

Heat gain from the solar irradiation Q_r is:

$$Q_r = I \cdot A \quad (7)$$

where, A is the projected area and I is the insolation.

The drying rate is calculated using [45]:

$$\gamma = \frac{dM}{dt} = \left(W_o - W_i\right)\dot{m} \quad (8)$$

W_i and W_o are the air humidity ratio at inlet and outlet respectively. Energy needed to remove moisture from the product is normally higher than latent heat of evaporation, nevertheless; it was assumed that they are equal in this work [46]. Thus; the heat required for moisture removal Q_d is:

$$Q_d = \gamma \times L \quad (9)$$

Hence, the efficiency of the drying process is:

$$\eta = \frac{Q_d}{Q_r} \quad (10)$$

The weight of the puree was measured hourly to obtain the remaining wet basis moisture content:

$$M_w = \frac{m - m_s}{m} \quad (11)$$

where, m_s is the mass of solids in the puree.

3. RESULTS

The results of all measurements and calculations are presented in the following figures.

The drying process started on 10 March 2023 at 12:30 pm with a slightly cold puree from the preprocessing preparation. First day drying continued up to 5:30 pm and continued throughout the sunset time until all stored heat in walls, ground, etc. is depleted (Figure 4). Subsequent day drying (11 March 2023) started at 8:30 am and continued up to 1:30 pm when the product was almost brought to the recommended moisture content. Figure 4 shows data points labels which are the timestamp at which the drying process occurs.

At the beginning, there is the transient adjustment period accompanied by a falling solar radiation which results in a decrease in drying rate (Figure 5). Also, the solid particles are still dispersed throughout the mixture, but after the overnight period it was sedimented leaving a surface of free water in contact with drying air. In the subsequent day the rate of drying falls due to depletion of the free water in the product.

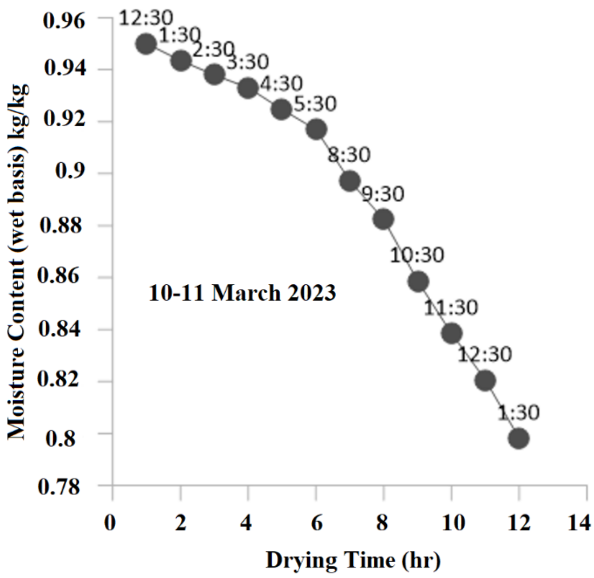

Figure 4. Wet basis moisture content

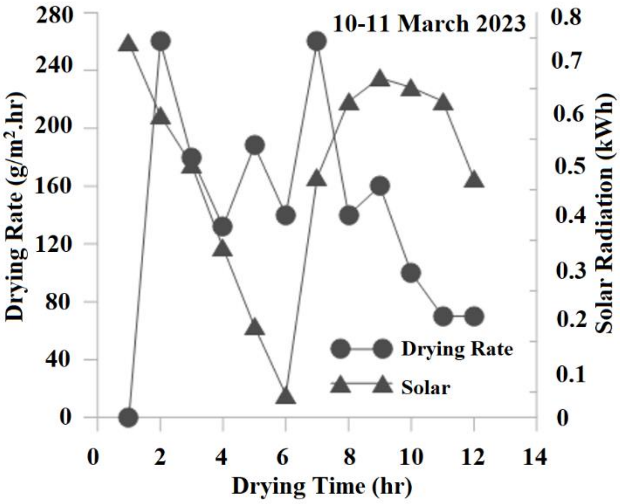

Figure 5. Drying rate and solar radiation

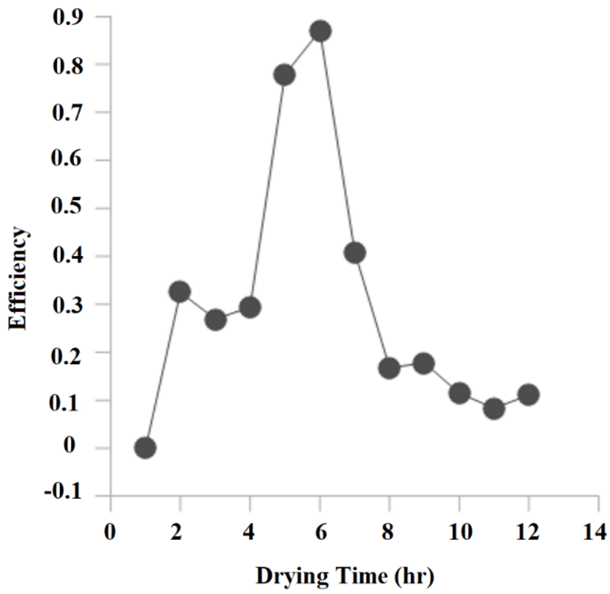

Figure 6. Drying efficiency

During the adjustment period, product temperature rises gradually by absorbing solar energy thus only part of the input energy was involved in evaporating water. Some solar energy is stored in the ground and glass cover as well. Therefore; the greenhouse efficiency gradually increased in this period (Figure 6). The apparent high efficiency in the hours 5-6 are misleading. When the solar radiation falls the stored energy continues to drive moisture out of the product with negligible external input energy resulting in apparent high efficiency. After most of the moisture was removed, the efficiency dropped since a larger amount of input energy is now used to raise product temperature instead of water evaporating.

Although the air stream is necessary to remove the evaporated water from the product, it also causes some energy losses by taking out heat with the outflow (Figure 7). However, higher air stream temperatures improve the efficiency of the drying process by increasing the saturation pressure of water vapor in the stream and hence increasing the driving force of moisture removal.

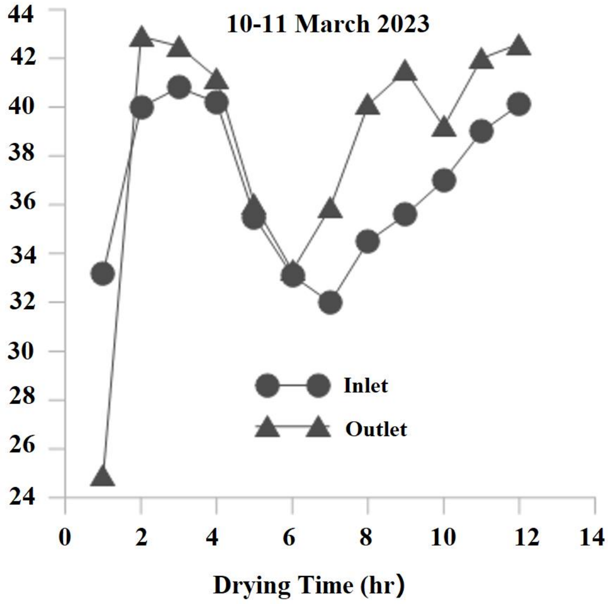

Figure 7. Air temperature

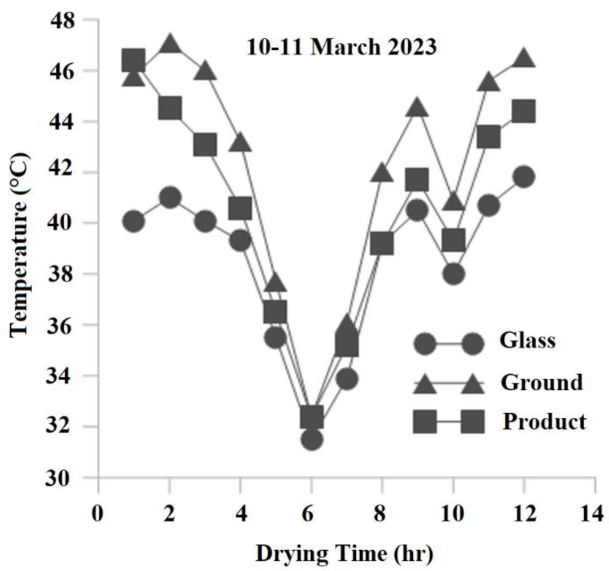

Figure 8. Greenhouse temperatures

The glass and the ground store part of the received solar energy as sensible energy appeared as a temperature rise. However, the glass cover also loses part of this energy by convection to ambient, thus its temperature is lower than that of the ground (Figure 8). The product absorbs solar energy as well but most of it goes to evaporate water thus its temperature is lower than the ground. Some of this stored energy can be reused when solar radiation falls to extend the drying time. Figure 9 depicts the energy distribution and losses throughout the whole drying process. Sensible heating cannot be considered as a total loss since some of it can be reutilized for drying when solar radiation falls.

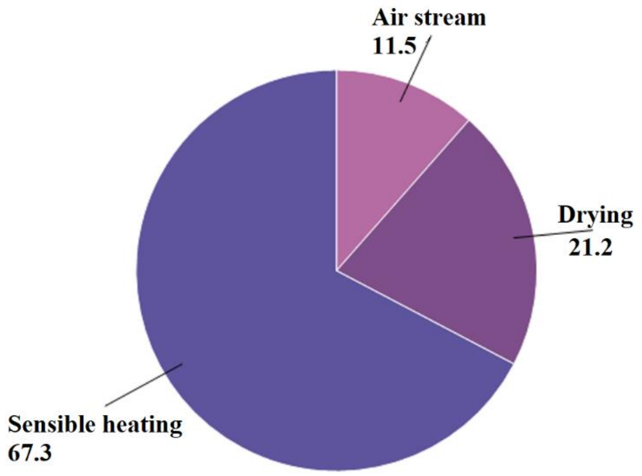

Figure 9. Energy distribution

Air moisture carrying potential (Figure 10) was calculated using known psychrometric relations [43, 47] and measured air properties. The air was assumed to exit with 80% relative humidity for the full potential. The actual performance of the drying process is way below the anticipated possibly because of the lack of sufficient heat to release water vapor from the product [48, 49] resulting in a waste in the available air potential.

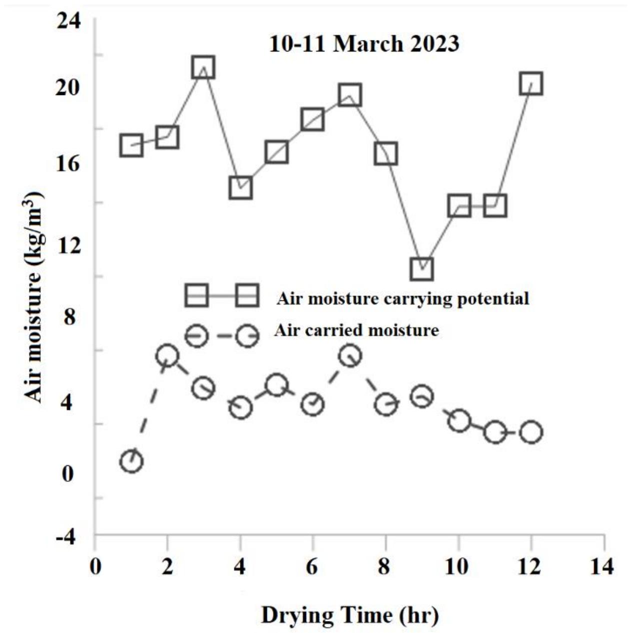

Figure 10. Air carried moisture

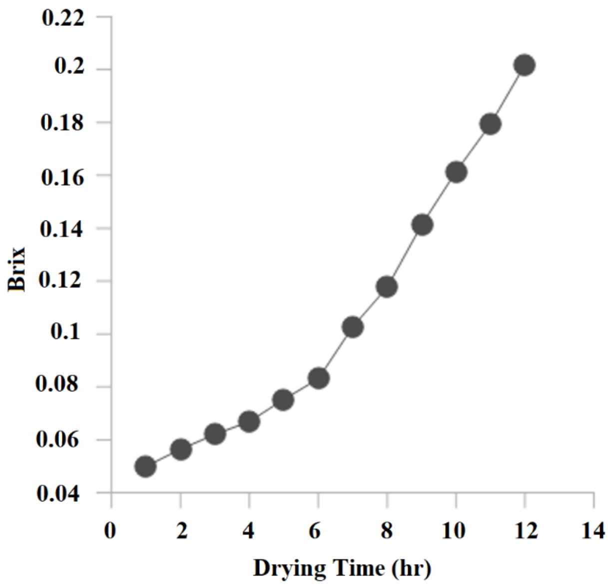

Figure 11. Product brix

It took 14 hours of drying time to attain the minimum acceptable brix for tomato paste to be used in any useful way (Figure 11).

3.1 Cost benefit analysis

According to the Iraqi ministry of agriculture [6], the Iraqi cultivators productivity of tomato is about 6 kg per m^2 of which the losses are about 1kg. The dryer capacity is 5 batches per week with each batch of 1.5kg/m^2 which produces 1.4 kg/m^2 wk of tomato paste. This generates 15k ID/m^2 wk while the whole tomato generates 6k ID/m^2 per season. In terms of land utilization 1 m^2 of dryer can serve 1.5 m^2 of crop land and make it more profitable. This totals to about 200k ID of annual benefits (AB) and resulted in a life cycle benefit (in present worth) [50, 51]:

$$\text{Life Cycle Benefit} = AB \cdot \frac{r \cdot \left(1-r^n\right)}{1-r} \tag{12}$$

$$r = \frac{1+inf}{1+i} \tag{13}$$

where, i is the current interest rate (8%), n is the number of years, and "inf" is the inflation rate (10%).

While the present worth of life cycle including the initial cost (IC =150k ID) and annual running cost (RC = 100k ID) subtracting the salvage value (SV = 10% 0f IC) would be [52]:

$$\text{Life Cycle Cost} = IC + RC \cdot \frac{r \cdot \left(1-r^n\right)}{1-r} - \frac{SV}{(1+i)^n} \tag{14}$$

By equating life cycle cost and benefit we can solve for n which is the payback period (about 1.5 years).

From an energy perspective, 5.5 kWh/m^2 is needed to operate the dryer for a week which is provided entirely from solar radiation. In effect, that means an equal amount of electricity was saved leading to an about 6 kg/m^2 reduction in Carbon emission per week of operation. There is no known direct effluent of CO_2 or any environmental harmful elements from drying chambers other than high moisture air. This may affect the nearby ecological system and the comfort of residents.

The current work was compared with the work of reference [53] as shown in Figure 12. The drying rate was divided by the received solar radiation for each kg of drying sample to eliminate the effect of differences in solar radiation and size of samples. The discrepancy may be attributed to the different configurations used and the types of samples since in this work a puree was used while in their work slices was used.

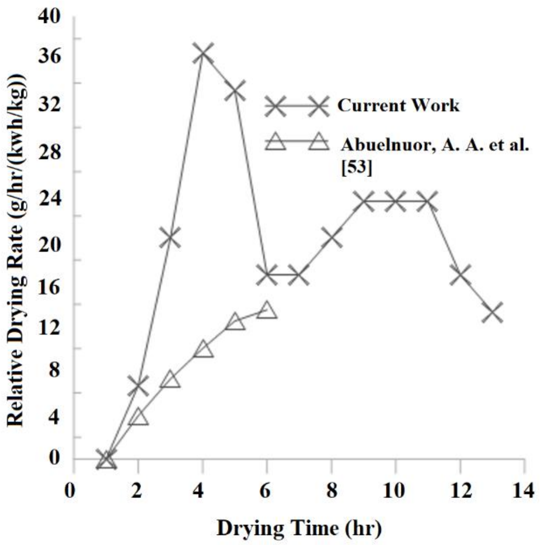

Figure 12. Comparison with Abuelnuor et al. [53]

4. CONCLUSION

Although the current study was limited to the conditions of the experiment mentioned above such as area of the dryer, type of tomato, month in which the experiment was conducted, etc., the following points could be concluded:

1- Solar dryers are easy to make, cheap, and can be adopted by farmers. In addition, the drying efficiency is good compared to other methods.

2- The adoption of solar cells as an electricity supply in the operation of fans helps in removing moisture and drying more quickly.

3- The use of solar energy to dry tomatoes in the current way has reduced drying costs as electricity is prepared from solar energy, reducing environmental impact and increasing product quality.

4- From an energy perspective, the cost of life cycle and benefit were found through the payback period (about 1.5 years). The dryer was operated for a week to obtain 5.5 kWh/m^2 which is supplied entirely from solar radiation.

5- There is no CO_2 effluent and low carbon emissions during operation. And there are no environmentally harmful elements from drying chambers other than high-humidity air.

6- Each 1 m^2 land produces 6 kg tomato with 1 kg losses, that generates 6 k ID profit and 1 k ID losses.

7- Each 1 m^2 land with a dryer produces 3.6 kg tomato converted to 1.008 kg tomato paste generating 15 k ID without losses.

8- Dryer utilization is specifically profitable to local farmers by reducing crop losses, increases income, and makes more food available for people.

This work was conducted on 10-11 March, other months may be more successful for their higher solar intensity, temperature and lower humidity.

An improvement in the design is required to enhance heat collection leading to an increase in the use of air moisture loading potential.

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