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Performance Evaluation and Cost Economics of a Low Cost Solar Dryer for Ber (*Zizyphus mauritiana)* Fruit

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ABSTRACT

Increasing population and high cost of fuels have created opportunities for using alternate energies for post-harvest processing of foods. Solar food processing is an emerging technology that provides good quality foods at low or no additional fuel cost. A number of solar dryers, collectors and concentrators are currently being used for various steps in food processing and value addition. Keeping in mind this future requirement, a reliable, efficient and low cost box type solar dryer was designed and developed at ICAR-Central Arid Zone Research Institute, Jodhpur to dry perishable arid agricultural produce. In this paper, the performance of box type solar dryer was evaluated with ber (Zizyphus mauritiana) fruit because it is one of the popular seasonal fruit in India but highly perishable in nature. During the performance evaluation, the maximum stagnation temperature inside the drying chamber was observed to be 63°C and on loading with 3 kg ber it reduced to 49°C, while outside ambient temperature was 27°C on a clear sky condition (from 10:00 h to 17:00 h) in the month of January, 2016. During the drying process, moisture content of ber fruits reduced from 80% (wet basis) to about 26% within 7 days. As compared with open sun drying, the duration of drying was reduced by about more than 50% of the time.The efficieny of this dryer was found to be 12.1%. The cost-benefit ratio was 3.84, which shows the potential of using solar dryers in place of conventional dryers. The developed dryer was also used to dry spinach and grated aonla and beetroot. Appearance, taste and flavour of ber in this dryer was superior to that of open sun drying. The use of solar dryer will be a great boon for farmers of arid region of Rajasthan.

Keywords: *Low cost solar dryer, Solar collector, Drying chamber, Ziziphus mauritiana (ber)*

INTRODUCTION

Drying is practiced to enhance the storage life, to minimize losses during storage and to reduce transportation costs of agricultural produce (Leon *et al.,* 2002). India is the second largest producer of fruits and vegetables in the world, contributing 12.6% and 14.0% of the total world production respectively. Out of the total production of fruits and vegetables, nearly 76 percent is consumed in fresh form, while wastage and losses account for 20 to 22%. Only 2-4 % of vegetable and fruit productions are being processed and preserved by industries. It has been observed that food crisis in most parts of the developing countries are due to inability to preserve food surplus rather than solely due to low production. In India, still 70% people are depending on agricultural practices and of this most farmers are subsistence farmers and affording hi-tech facilities and equipment is a major problem. Direct sun drying method has been practised since ancient time and it is still being widely used in developing countries. Although this method of drying is cheap, yet it is associated with the problems like contamination by foreign materials such as, dirt, dust and wind blown debris and insect infestation as well as uneven drying. During rainy season, the material cannot be dried to the desired safe storage moisture and the material also may get wet. In this sense, proper utilization of solar energy for crop drying can easily be made possible by choosing a proper solar dryer. A major barrier to the use of solar drying technology and equipment is their cost. Purohit *et al.,* (2006) analyzed the economy of solar dryers compared to open sun drying and found that solar drying of agricultural produce was financially attractive for cash crops and it may even be possible to justify the use of high cost solar drying systems. However, for drying highly perishable products, it is extremely important to develop low cost system (Purohit *et al.,* 2006). Today it is possible to develop low cost solar dryers from local materials. Sharma *et al*., (2009) reviewed some easy-to-fabricate and easy-to-operate low cost dryers that can be suitably employed at small-scale factories or at rural farming villages while Fudholi *et al*., (2010) gave examples of several solar driers and their possible prices for local manufacture. Properly designed solar dryers may provide a much-needed appropriate alternative for drying of some of the agricultural produce in developing countries (Mahapatra and Imre, 1990; Sodha and Chandra, 1994; Ekechukwu and Norton, 1999; Hossain *et al.,* 2005). Fortunately India is blessed with abundant solar energy. The arid parts of India receive maximum radiation i.e. 7600 – 8000 MJm^{-2} per annum, followed by semi arid parts 7200 – 7600 MJm^{-2} per annum and least on hilly areas where solar radiation is still appreciable i.e. 6000 MJm^{-2} per annum. Therefore, solar dryers seem to be good substitute for mechanical dryers.

With this in view, several types of solar dryers have been designed and developed at the ICAR-Central Arid Zone Research Institute, Jodhpur in the last three decades (Pande, 1980; Pande and Thanvi, 1982; 1991 and Thanvi and Pande, 1987 and 1989). However, the cost of these appliances is still high. In order to make it more economical we have designed and developed a simple and low cost box type solar dryer at ICAR- Central Arid Zone Research Institute, Jodhpur. The dryer that was developed is a simple box type solar dryer where the combined action of solar radiation incident on the material to be dried and the air heated in the solar collector provide the heat required for the drying operations. Here the atmospheric air enters through inlet portion of the solar collector at the bottom end and the moist air gets exhausted through the outlet portion. The objective of the dryer is mainly for the welfare of the marginalized and small farmers who can not afford hi-tech facilities and equipment to preserve their agricultural produce and eliminate the unwanted and unpredictable food spoilage due to lack of facilities in the arid region.

MATERIALS AND METHODS

Design of solar dryer: The main principle of this low cost solar dryer is based on greenhouse effect where the solar radiations enter into the chamber through glass sheet and thermal radiations are trapped inside the drying chamber and thus increase the temperature. The experimental solar dryer comprised of a drying tray (0.75m ´ 0.53 m) made of wooden frame and stainless steel wire mesh. A glass roof was made of clear window glass (4mm thick) fitted on a wooden frame and a couple of hinges with opening and closing arrangements. Suitable openings for entry of ambient air and exit of water vapour have also been provided. The drying material can be put on the perforated stainless steelwire mesh by opening the top wooden frame fitted with glass. The drying tray serves the twin purpose of solar collector and drying chamber (Fig. 1). The cost of the dryer is about Rs.1000/-.

Thermal efficiency (η): The efficiency of utilization

Fig.1: Solar dryer in *Ziziphus mauritiana* (ber) loaded condition

of solar energy in solar dryer (ratio of heat used in evaporation of moisture from ber to the incident total solar radiation on horizontal plane) has been worked out by using the relation (Leon *et al.,* 2002):

$$\eta = \frac{\mathrm{ML}}{A\int_0^{\theta} H_T d\theta} \quad ...(1)$$

Where A = Absorber area (m^2); H_T = Solar radiation on horizontal plane (J m^{-2} hr^{-1}); L = Latent heat of vaporisation (J kg^{-1}); M = Mass of moisture evaporated from the product (kg); θ = Period of test (hr) and η = Efficiency of the solar dryer.

Drying rate: Drying rate is one of the most important characteristics, which helps to estimate the performance of any solar drying system. Drying rate is porportional to the difference in moisture content between the material to be dried and its equilibrium moisture content (Shanmugam and Natarajan, 2006). The initial moisture content of ber on wet basis was calculated using the relation:

$$M_i = \left(\frac{W_i - W_f}{W_i}\right) \times 100 \quad ...(2)$$

Where M_i is the initial moisture content of ber on wet basis expressed in %, W_i is the initial weight of ber in g and W_f is the final weight of ber in g.

Moisture ratio: Amount of water to be removed from ber while drying to reach required final moisture content was calculated using the relation:

$$m_w = \frac{W_i\ (M_i - M_f)}{100 - M_f} \quad ...(3)$$

where m_w is the mass of water to be removed from ber in g, W_i is the initial weight of ber in g, M_i is the initial moisture content of ber in % and M_f is the initial moisture content of ber in %.

The instantaneous value of moisture content in ber fruit at any time t was calculated using the following expression (Shanmugam and Natarajan, 2006):

$$M_t = \left[\frac{(M_i + 1) \times W_t}{W_i}\right] - 1 \quad ...(4)$$

Where M_t is the moisture content in ber at any instant of time t, M_i is the initial moisture content of ber in %, W_t is the weight of ber at any instant of time t in g and W_i is the initial weight of ber in g. The moisture ratio was calculated using the relation,

$$\mathrm{MR} = \frac{M_t}{M_i} \quad ...(5)$$

The drying trial for dehydrating *ber* (*Zizyphus mauritiana)* in this dryer was conducted in the month of January, 2016 and performance was compared with open-courtyard sun drying. Equal quantities (3 kg) of ber fruits were kept inside as well as outside the dryer. The exposure surface areas were the same in both cases. Hourly total solar radiation received on the horizontal plane was measured by pyranometer coupled with integrator. Air temperature inside the dryer and ambient temperature were measured hourly from 10 h to 17 h during the drying trials. Moisture content of the ber fruits during each day were computed from difference in these weigths.

RESULTS AND DISCUSSION

From Table1, it is clear that during the drying trials, the maximum stagnation temperature observed inside the drying chamber was 63°C and on loading 3 kg of ber the maximum temperature reduced to 49°C, when the outside ambient temperature was 27°C on a clear sky condition (from 10:00 h to 17:00 h) in the month of January, 2016. The variation of solar insolation, ambient temperature and temperature inside dryer, when ber fruit was loaded during the drying trails (Fig. 2).

The variation of measured moisture content (wet basis) of the ber fruits on each day of drying trials was shown in Fig. 3. It can be seen that the moisture content reduced from about 80% to 26% within 7 days by the solar drying method and on 10^{th} day it reached 20%. However after 7 days (26% moisture content) it could be safely stored for further use. In contrast, it took 20 days to dehydrate the same quantity of ber fruits by open drying. The drying rate in the solar dryer increased sharply when the moisture content fell below 66%. The higher moisture reduction during the initial stages of drying was observed due to evaporation of free moisture from the outer surface layers and then gets reduced

Table 1. Details of drying trials on *Ziziphus* (ber) in low cost solar dryer

Month January, 2016 Time (hrs)	Radiation on horizontal plane (W/m^2)	Temperature (in no load condition)		Radiation on horizontal plane (W/m^2)	Temperature (ber loaded condition)	
		Ambient (°C)	Inside dryer (°C)		Ambient (°C)	Inside dryer (°C)
10.00	680	20	36	640	21	34
11.00	820	23	58	880	23	40
12.00	920	25	62	980	25	44
13.00	980	27	63	960	27	49
14.00	900	26	59	920	26	47
15.00	720	26	57	640	26	44
16.00	490	25	49	390	24	40
17.00	210	22	40	220	25	35

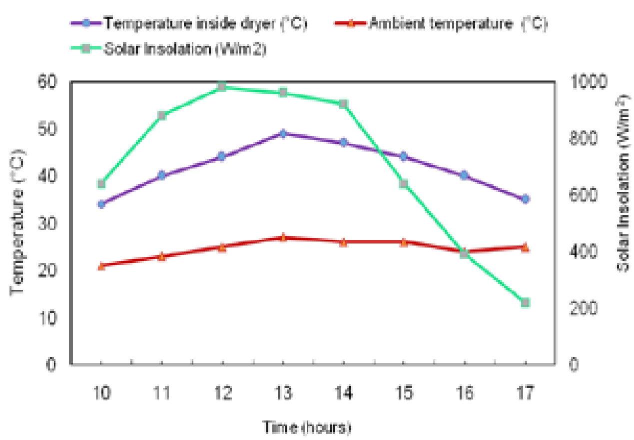

Fig. 2: Variation of solar intensity, ambient temperature and temperature inside dryer (with ber loaded)

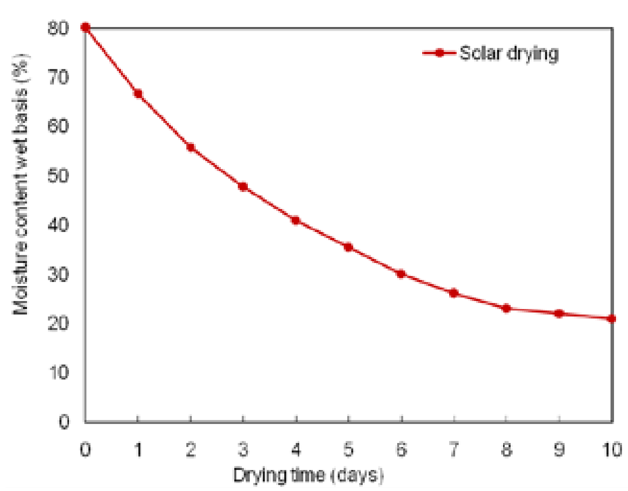

Fig. 3: Variation of moisture content in solar and open drying against drying time

due to internal moisture migration from inner layer to the surface, which results in a process of uniform dehydration. Temperature inside drier was higher than ambient temperature and corresponding relative humidity in the drier was lower than ambient relative humidity. As a result, drying rate of ber fruits in a box type solar dryer was found to be higher than that of open sun drying. High drying rate (of about 2.5 kg/kg of dry matter) was observed during the initial stages of drying and decreased with increase in drying time. Drying occurs in the falling rate period with steep fall in moisture content in initial stages of drying and becomes very low in the later stages. The reason for sudden increase in drying rate during second day is due to increase in collector out let temperature. Drying rate decreased due to decrease in collector outlet air temperature and increased due to increase in collector outlet air temperature.

The average efficiency of utilization of solar energy in the solar dryer was calculated by equ(1) and it was found that about 12.1% solar energy was utilized in this solar dryer while it was only 4.6% in the open drying method. The quality of the final dried ber fruits was found better compared to open sun drying. The desiccant material is stable even after continuous operation for more than a year. The dryer can be used for drying various agricultural produce. It can reduce drying time and improve quality of the dried product. The farmers can dehydrate fruits and vegetables when these are available in plenty and at low cost. Dehydrated fruit and vegetables can be sold in the off season when prices of fruits and vegetables are high and farmers can generate more income.

Economic analysis of low cost solar dryer: The dryer was used for drying ber (*Zizyphus mauritiana)* fruits. The initial investment (P_i) of the dryer is Rs. 1000, interest rate *(i)* 15% per annum and useful life of solar dryer (*n*) is 10 years, R_m operational and maintenance expenses per year as 20% of the cost of dryer and S the salvage value as 10% of the cost of dryer at the end of the life. Annualized uniform first cost of dryer is defined as the product of net present value of the dryer and capital recovery factor (CRF) and can be written as (Tiwari, 2002):

Annual first cost of dryer=P_i × Capital recovery factor (CRF)

The Capital recovery factor (CRF) can be expressed as:

$$\text{CRF} = \frac{i\,(1+i)^n}{(1+i)^n - 1} = \frac{0.15\,(1+0.15)^{10}}{(1+0.15)^{10} - 1} = 0.199$$

Annual first cost of dryer, Rs = 199.25

(ii) Annual salvage value = Sinking fund factor x salvage value as 10% of the cost of dryer at the end of the life

$$\text{Sinking fund factor} = \frac{i}{(1+i)^n - 1} = 0.0492$$

Annual salvage value, Rs = 4.92

(iii) Annual maintenance cost, Rs = 20% of Annual first cost of dryer = 39.9

Hence annual cost of dryer = Annual first cost of dryer + annual maintenance cost - Annual salvage value

Total annual cost of dryer, Rs = 234.2

Benefit-Cost ratio: Benefit-cost ratio (B/C) was obtained when the present worth of the benefit stream was divided by the present worth of the cost stream. For an investment to be worthwhile, BCR should be greater than one to indicate that the investor is recovering every Rs. worth of his investment. Conversely, a BCR less than one implies that at the assumed interest rate, the investment being evaluated is not profitable. The benefit-cost ratio (BCR) can be expressed as:

$$\text{Net Benefit cost ratio (BCR)} = \frac{\text{Net Annual benefit}}{\text{Annual cost of dryer}}$$

During the season as many as 15 drying trials of ber are possible yielding about 15 kg of dried ber costing 1800/Rs @ 120 per kg. Cost of raw ber (45 kg) comes to about 900/Rs. @ 20 kg. Therefore, Net benefit, Rs = 1800-900 = 900. The Net Benefit cost ratio (BCR) is:

$$\text{Net Benefit cost ratio (BCR)} = \frac{900}{234.2} = 3.84$$

The cost-benefit ratio was also as high as 3.84 which show the potential of using solar dryers in place of conventional dryers. The B/C ratio of solar dryer was very high because of lower operating cost and nil fuel cost. Solar dryer is also superior viable than conventional drying system in terms of environmental benefits (lowered carbon emission) associated with the adoption of this technology.

CONCLUSIONS

The developed solar dryer could be very useful at the domestic level. Due to its low cost, it is very affordable. It can dry vegetable and fruits which can be packed for use in off season. It can be used to dry fruits such as, ber, aonla, beat root, leafy vegetables, spinach, coriander, chilies, fenugreek and other vegetables such as, onion, garlic, carrot etc. The use of such dryers at domestic level can go a long way in reducing post harvest losses as well as carbon emission.

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