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Design and performance evaluation of portable folding type solar dryer for drying of amla candy

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■ **ABSTRACT :** The research was conducted to design and evaluate the performance of portable folding type solar dryer for drying of amla candy. The developed dryer consist of chimney, chimney stand, drying chamber, polyethylene sheet with mosquito net as dome and perforated try. The dryer had capacity of 2 kg per batch of amla candy of thickness 6 to 7 mm. The dimensions of dryer were 0.9 m length, 0.6 m width and 0.6 m height. The collector area was 0.539 m^2 with drying cabinet size of 0.9 x 0.6 m. The total cost of construction of dryer was Rs. 1349. Wet amla pieces with and without sugar were selected as drying material. The dryer was tested for its performance at without load and with load. During no load test maximum temperature achieved in dryer was 61.6 ^{0}C. The moisture content of 6 mm thick amla pieces treated with sugar was reduced from 281.67 % (db) to 29.93 % (db) in 600 minutes. While moisture content of amla pieces without sugar was reduced from 718.33 % (db) to 58.56 % (db) in 600 minutes. The drying rate of amla pieces with sugar and without sugar had peak value of 1.4126 and 1.6777 g water per gram dry matter per hour, respectively during drying time interval of 8.30 am to 9.30 am of the day. The temperature reached in the dryer was 15 to 20 ^{0}C higher than atmospheric temperature.

■ **KEY WORDS :** Amla, Amla candy, Foldable, Portable, Solar dryer

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India is an agricultural country. Its products ranges from food grains to various vegetables and fruits. These products need some kind of preservation to enhance their shelf-life. India receives solar energy equivalent to over 5000 Trillion kWh per year (Rai, 1988). The daily average solar energy incident over India varies from 4-7 kWh per square meter depending upon the location (Anonymous, 2007). Solar energy is abundantly available in Konkan region for 8 to 9 months in year with average sunshine hours 6.5 to 8 hours per day (Sengar *et al*., 2009).

Aonla or Amla (*Emblica officinalis*) is a medicinally and nutritionally important fruit of Indian origin, which is richest source of vitamin C (Ascorbic acid). Every 100 g of amlacontains nearly 700-750 mg of vitamin C. Many Ayurvedic preparations use amla as a major constituent as it rejuvenates all the organ system of the body and promotes health and wellness (Pragati and Dhawan, 2003). It also has antibacterial and anti-aging properties.

There is good opportunity to increase percentage of amla products like amla candy by using various means of drying. Drying increases shelf-life of product. Natural sun drying has many disadvantages like uncontrolled drying, contamination by birds, insects, dust etc. (Sajith and Muraleedharan, 2013 and Sundari *et al.*, 2013). Solar dryers can be considered to replace open sun drying, where higher quality product is desired. Various types of solar dryers are developed by many scientists. Many of them have disadvantage that they are not easy to handle because they are not portable and foldable (Ekechukwu and Norton, 1999). They occupy lot of space during idle period.The present study was undertaken to design and develop a portable folding type solar dryer. The performance of dryer was evaluated by drying of amla candy.

■ METHODOLOGY

The present study was carried out at Energy Park, Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dr. BalasahebSawant Konkan KrishiVidyapeeth, Dapoli (M.S.). In direct type of solar dryer the heated air in drying chamber was passed through bed of wet amla pieces and at the same time top surface of amla pieces absorbs solar energy directly through transparent cover. The essential components of dryer are air inlet, drying chamber, dome and chimney discharging air at upper elevation. Collector area was painted black to absorb more and more solar radiations.

When ambient air enters in drying chamber got heated and heated air expands and become relatively light. The light air then impelled upwards by buoyancy force (Hossain *et al.*, 2005). Amla candy was dried simultaneously by both convection and conduction principle. The design considerations taken from Sajith and Muraleedharan (2013) and Anand (2012)for design and development of portable folding type solar dryer are as follows. The dryer was fabricated with 16 mm plywood and 200 gauge polyethylene sheets was used as covering material on baby mosquito net frame as a dome. The chimney was consisted of thin metallic plate with 0.04 m diameter and 0.3 m in length.

Amount of moisture to be removed, W_w (kg) :

$$W_w = W_g \times \frac{M_i - M_f}{100 - M_f}$$

where,

W_g = Initial mass of wet amla pieces, kg

M_i= Initial moisture content of amla pieces, % wet basis

M_f= Final moisture content of amla pieces, % wet basis

Average drying rate, W_{dr} (kg/hr) :

$$W_{dr} = \frac{W_w}{t_d}$$

where,

t_d= Total drying time required for removingthe W_w from wet amlapieces, hours

Quantity of air required for drying, W_a(kg) :

$$W_a = \frac{(W_w \times L)}{C_a \rho_a (T_i - T_f)}$$

where,

W_a= Quantity of air required for drying, kg

W_w= Quantity of water evaporated, kg

L = Specific latent heat of vaporization ofwater, kJ/kg

C_a = Specific heat capacity of air at constant pressure, kJ/kg °C

ρ_a = Density of drying air, kg/m^3

T_i= Initial temperature of drying air, °C

T_f= Final temperature of drying air, °C

Volume flow rate of air required, Q_a (m^3/hr) :

$$Q_a = \frac{W_a}{t_d}$$

Useful heat energy required, E_u (kJ) :

$$E_u = Q_a C_a \rho_a (T_i - T_f) t_d$$

where Q_a = Volume flow rate of air required, m^3/hr

Total collector area, A_c (m^2) :

$$A_C = \frac{E_u}{I_n}$$

where,

I = Total global radiation on the horizontal surface during the drying period, kJ/m^2

n = Collector efficiency, 30 to 50 % (Basunia and Abe, 2001)

Dryer dimensions :

Area = D x L

where,

Area = Collector area, m^2
D = Width of dryer, m
L = Length of dryer, m

Number of tray :

No. of tray = Actual drying area/total collector area

Air vent dimensions :

$$A_v = \frac{Q_a}{V_w}$$

where,
A_v = Area of air vent, m^2
V_w = Wind speed, m/hr

Dimensions of chimney :

$P = 0.000308\, g\, (T_i - T_f)\, H$

where,

P = Pressure difference between outside cold air and inside hot air, Pa

g = Acceleration due to gravity, 9.81 m/s^2

H = Height of chimney, m

A cost of proto type portable folding type solar dryer for drying of amla candy was calculated (as shown in Table B) by considering the cost of material required for fabrication and fabrication cost of dryer.

Sample preparation :

Samples were prepared from fresh amlas. A 2.5 kg

Table A : Assumptions made for dryer design and parameter recorded during performance evaluation of dryer

Sr. No.	Assumptions made for design of dryer: Items	Assumptions	Parameters recorded during performance evaluation: Parameters	Values
1.	Mode of drying	Natural convection	Mass of water to be evaporated	1.32 kg
2.	Material to be dried	Amla candy	Average drying rate	0.3771 kg/hr
3.	Drying period	Oct. to Nov.	Length of dryer	0.9 m
4.	Quantity of material per batch	2 kg	Width of dryer	0.6 m
5.	Initial moisture content	74 % (wb)	No. of tray	1
6.	Final moisture content	20 % (wb)	Area of air vent	0.001256 m^2
7.	Drying time	12 hrs	Pressure difference between outside and inside air	0.041 Pa
8.	Ambient air temperature	28.5 ^oC	Actual draft	0.031 Pa
9.	Ambient humidity	70 %	Final temperature of drying air	41.5 ^oC
10.	Wind speed	2 m/s	Velocity of exit air	0.2385 m/s
11.	Initial temperature of drying air	58-60 ^oC	Volume of exit air	148.59 m^3
12.	Collector efficiency	35 %	Rate of exit air	14.15 m^3/hr
13.	Latent heat of vaporization of water	2260 kJ/kg	Solar collector area	0.54 m^2
14.	Specific heat of air	1.005 kJ/kg^{o}C	Quantity of air required for drying	156.6 kg
15.	Density of air	1.115 kg/m^3	Volumetric air flow rate	13.37 m^3/hr
16.	Density of exit air	1.0539 kg/m^3	Total energy required for drying	2674.87 kJ
17.	Location	Dapoli	Diameter of chimney	0.04 m
18.			Height of chimney	0.3 m

Table B : Material and fabrication cost of portable folding type solar dryer for drying of amla candy

Sr. No.	Material required	Quantity of material	Total cost (Rs.)
1.	Plywood (16 mm)	0.9 x 1.2 m	645
2.	Aluminium wire frame	0.6 m^2	340
3.	Fevicol	0.1 kg	38
4.	Tekus	0.1 kg	14
5.	Polyethylene sheet (200 gauge)	2 m	110
6.	Black board paint	0.5 lit	90
7.	Screws	1 dozen	12
8.	Velcro	7 m	100
	Total cost (Rs.)		1349

amlas were washed and boiled in water for 5 min. They were cut and separated into slices of 6 to 7 mm thickness (Malviya and Gupta, 1985). Thickness was measured by Vernier caliper. Then 1 kg amla pieces were treated with sugar and 1 kg were kept as such. For sugar treatment amla pieces were kept in pot and 750 g was sugar added. After one day amla pieces begin to float in sugar solution. The pieces were kept in this condition for one more day and then drawn out. These samples were used for drying under portable solar dryer. Remaining 0.5 kg amla pieces were kept as a sample for open sun drying.

Performance evaluation of portable solar dryer:

It was carried out by conducting no load test for testing designed parameters and loaded test in comparison with open sun drying. Different parameters like temperature at various places, relative humidity, solar intensity and wind speed were measured at an interval of half an hour in a clear sunny day (Mukherjee, 1985).

A 2.5 kg amlas were taken and samples were prepared as discussed in sample preparation section for each trial. A 2 kg of amla pieces (sugar treated and untreated) were loaded in tray of portable solar dryer and 0.5 kg were kept for open sun drying. Ten samples were selected randomly from tray and weighed before and every 30 min (from 8 am to 9 am) and 1 h (from 9 am to 6 pm) interval after loading by using weighing balances to determine the moisture content. Initial and final moisture contents of amla samples were calculated using standard hot air oven method.

Moisture content :

$$\text{M.C. (w.b.) \%} = \frac{(W_1 - W_2)}{W_1} \times 100$$

$$\text{M.C. (d.b.) \%} = \frac{(W_1 - W_2)}{W_2} \times 100$$

where,

W_1 = Weight of sample before drying, g

W_2 = Weight of bone dried sample, g

Drying rate :

$$\text{Drying rate (D.R.)} = \frac{\Delta W}{\Delta T}$$

where,

ΔW = Weight loss in half hour interval (g/100 g of bone dry weight)

ΔT = Difference in time reading (hr)

Moisture ratio :

$$\text{Moisture ratio} = \frac{(M - M_e)}{(M_0 - M_e)}$$

where,

M = Moisture content (d.b.), %

M_e = Equilibrium moisture content (d.b.), %

M_0 = Initial moisture content (d.b.), %

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Performance evaluation of portable solar dryer :

Dryer was tested with no load test for thermal profile, which could be suitable for dying of amla candy. The purpose of load test was to calculate the time required for drying the commodities as well as to find out the system drying efficiency and pick up efficiency of dryer.

No load test:

The dryer was tested without loading sample in it and different atmospheric parameters *viz*., temperature, relative humidity, solar insolation etc. were measured. The changes in temperature and relative humidity with respect to solar insolation and time during no load test are depicted in Fig. 1 and 2.

The temperature inside portable and folding type solar dryer increased with solar insolation and time of day and attained peak value 61.6 °C at 12:30 pm, whereas

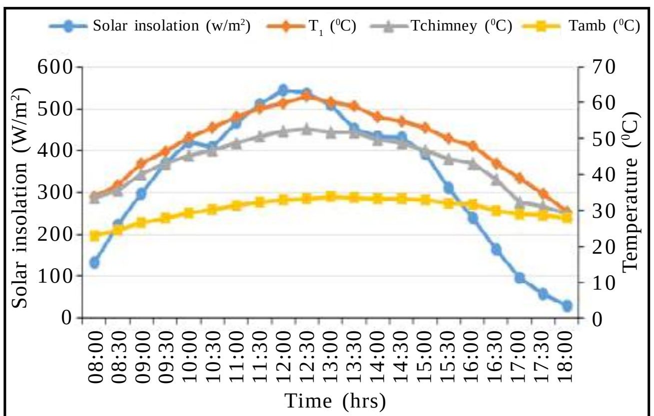

Fig. 1 : Temperature variation with solar insolation during no load test

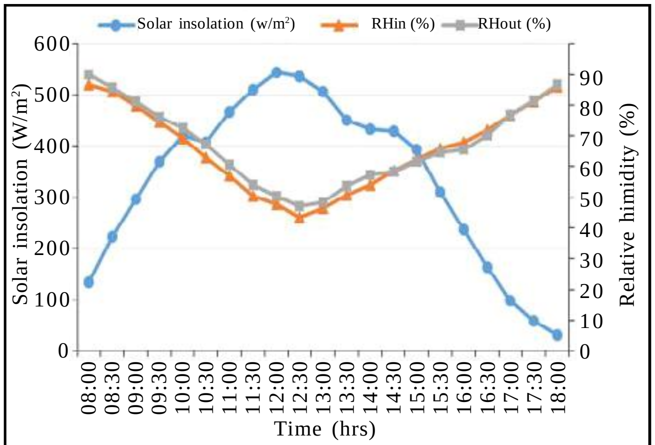

Fig. 2 : Relative humidity variation with solar in solation during no load test

peak atmospheric temperature value also attained at the same time. Solar insolation also varied according to time of day reaching its peak value as 545 W/m^2 at 12:00 pm (Fig. 1). The atmospheric humidity varied from 48.5 per cent to 86.9 per cent at 12:30 pm and 18:00 pm, respectively. Relative humidity inside dryer varied from 43.2 per cent to 86.0 per cent at 12:20 pm and 18:00 pm, respectively (Fig. 2).

The temperature inside portable and folding type solar dryer increased with solar insolation and time of day and attained peak value 61.6 ºC at 12:30 pm, whereas peak atmospheric temperature value also attained at the same time. Solar insolation also varied according to time of day reaching its peak value as 545 W/m^2 at 12:00 pm (Fig.1). The atmospheric humidity varied from 48.5 per cent to 86.9 per cent at 12:30 pm and 18:00 pm, respectively. Relative humidity inside dryer varied from 43.2 per cent to 86.0 per cent at 12:20 pm and 18:00 pm, respectively (Fig. 2).

In no load test, temperature inside dryer increased from bottom to top due to decreasing air density as it passed through hottest zone (Lal *et al.*, 1998). Bottom of dryer had minimum temperature because of just below the tray there was opening of fresh air entrance in dryer where the density of air was higher as compared to that above trays. As temperature increases humidity decreases, as per this phenomenon, humidity inside dryer was minimum as compared to outside conditions (Mujaffar and Sanket, 2004). Optimum collection efficiency was found inside portable and folding type solar dryer due to exposure to sun as well as it was perfectly airlock so given better hot air draft (Aliyu *et al.*, 2013). Overall collection efficiency was found to be 62.45 per cent.

Load test:

Moisture reduction study during load test :

Solar insolation increased from morning to afternoon and attained peak value 514 W/m^2 at 12:00 pm and again decreased from afternoon to evening. The corresponding value of ambient temperature with peak solar insolation was 34.5 ºC and that inside dryer was 52.3 ºC at 12:30 pm (Fig. 3).

The atmospheric relative humidity varied from 61.3 per cent to 87.7 per cent at 12:30 pm and 18:00 pm, respectively. Relative humidity inside dryer varied from

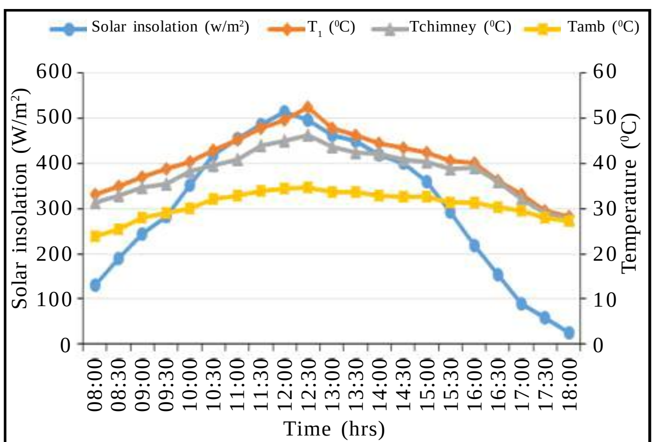

Fig. 3 : Temperature variation with solar in solation during load test

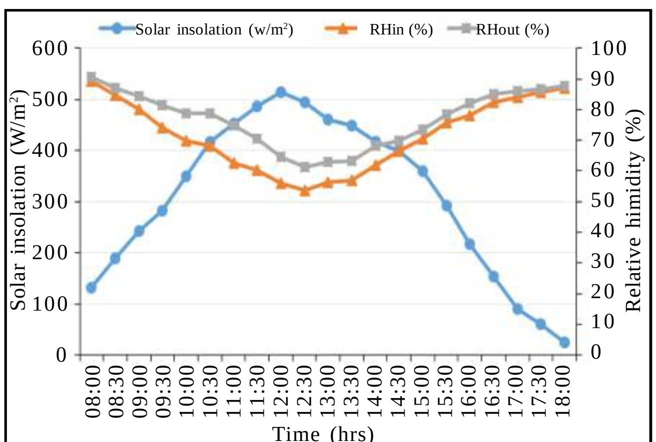

Fig. 4 : Relative humidity variation with solar in solation during load test

53.8 per cent to 87.1 per cent at 12:30 pm and 18:00 pm, respectively (Fig. 4).

Initial moisture content of sugar treated amla pieces was 281.67 per cent (db) and that of amla pieces without sugar was 718.33 per cent (db). Sugar treated amla pieces had less moisture content than amla pieces without sugar because of osmosis process, in which water in amla pieces moved towards higher concentration sugar solution (Bhattacherjee, 2013).

The moisture content of amla pieces treated with sugar reduced from 281.67 per cent (db) to 29.9311 per cent (db) in 600 minutes. The moisture content of amla pieces without sugar reduced from 718.33 per cent (db) to 58.5599 per cent (db) in 600 minutes (Fig. 6). Similar results were obtained by Wankhade *et al.* (2013).The drying rate of amla pieces which were with and without sugar had its peak value 1.4126 and 1.6777 g water/ g dry matter/ hr, respectively during drying time interval of 8:30 am to 9:30 am of the day *i.e.* within 1 to 2 hrs from the period of starting of the drying (Fig. 5). Moisture ratio variation with time is as shown in Fig. 7. Similar results were obtained by Leon *et al.* (2002).

In load test of dryer, amla pieces required more time for drying in open conditions due to minimum temperature and maximum humidity and vice versa in solar drying conditions. Use of dryer for drying amla candy was helpful to remove moisture rapidly as compared to open sun drying and it also given better colour to amla candy (Prajapati *et al.*, 2011). Drying efficiency and collection efficiency were depended on removal of moisture from wet amla pieces and hence, maximum efficiencies were found as dryer was airlock

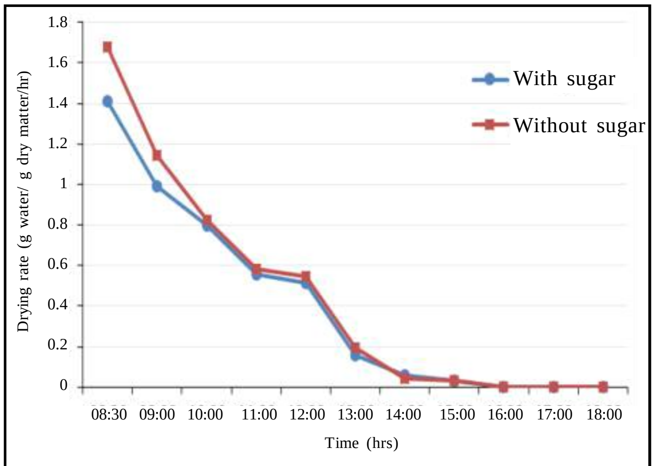

Fig. 5 : Drying rate of amla in dryer

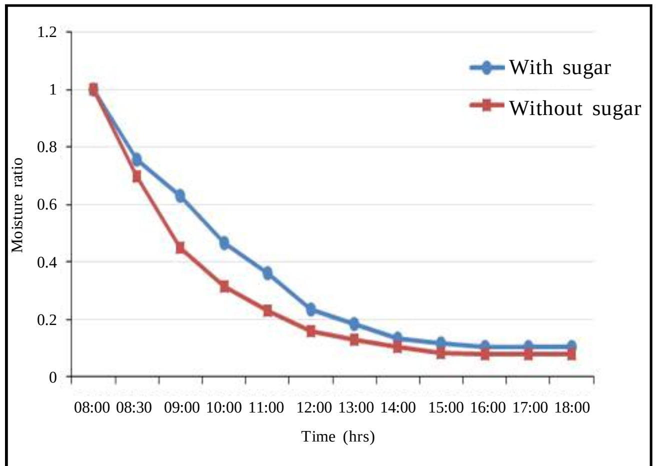

Fig. 7 : Moisture ratio variation during drying

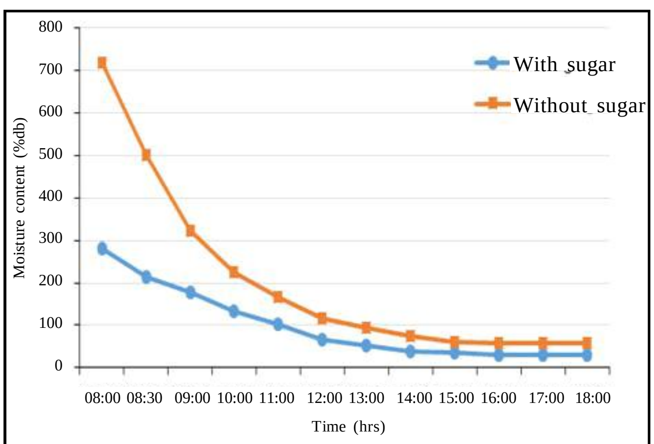

Fig. 6 : Moisture content reduction during drying of amla in dryer

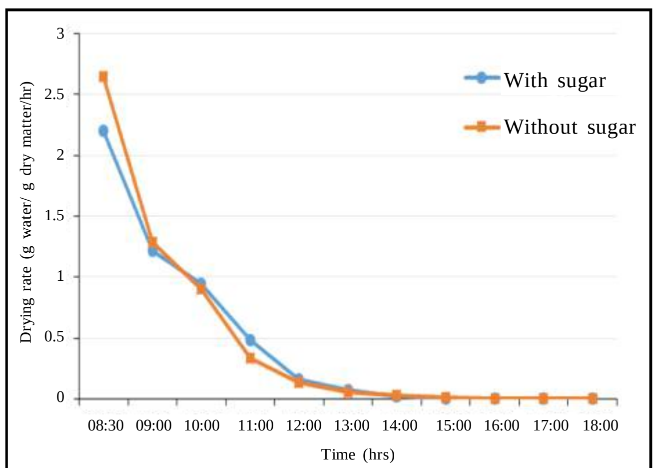

Fig. 8 : Drying rate during open sun drying

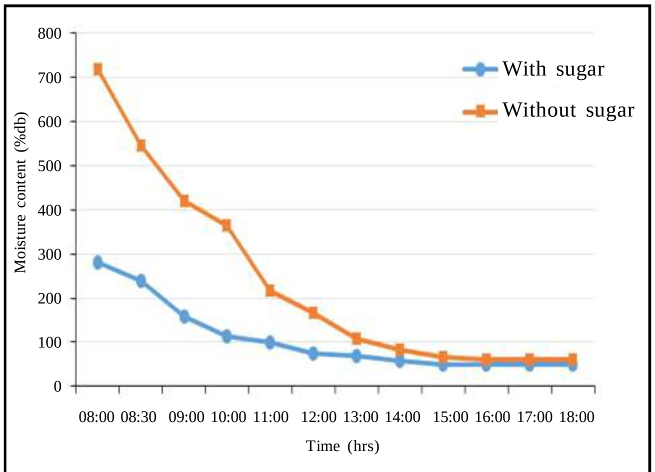

Fig. 9 : Moisture content reduction during open sun drying of amla

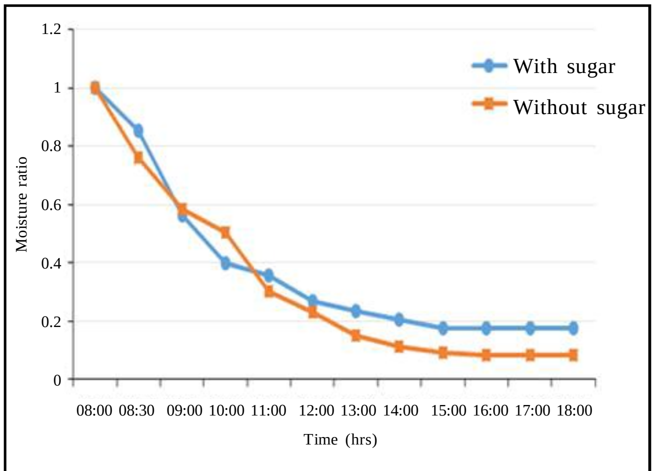

Fig. 10 : Moisture ratio variation during open sun drying

from all sides (Bala, 2005).

Moisture reduction study under open sun drying:

The moisture content of sugar treated amla pieces under open sun drying was reduced from 281.67 per cent (db) to 49.683 per cent (db) in 600 minutes. The moisture content of amla pieces not treated with sugar reduced from 718.33 per cent (db) to 60.6108 per cent (db) in 600 minutes (Fig. 9).

The peak drying rate observed for sugar treated amla pieces was 2.2034 g water/ g dry matter/ hr during drying time interval of 8:00 am to 9:30 am of the day and that of amla pieces without sugar was 2.6456 g water/ g dry matter/ hr during drying time interval of 8:00 am to 9:30 am of the day (Fig. 8). The moisture content showed decreasing trend as depicted in Fig. 9 and trend of variation of moisture ratio against drying time as shown in Fig. 10. It was also observed that drying time was reduced for portable dryer as temperature inside dryer was 10 to 15 ^{o}C higher than atmospheric temperature.

Conclusion :

The temperature attained inside portable folding type solar dryer was 15 ^{o}C and 30 ^{o}C higher than atmospheric temperature during load test and no load test, respectively. By visual analysis amla candy dried in solar dryer was good in colour and appearance. The drying rate under dryer was 4.5 per cent higher than that of open sun drying which was preferable for reducing drying time. Hence, in all cases the use of solar dryer leads to considerable reduction in drying time in comparison to open sun drying. The quality of solar dried product was far better than the open sun dried product (Stilling *et al.*, 2012). The portable folding type solar dryer required 19 per cent less time as compared to open sun drying of amla candy.

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