Performance evaluation of a cabinet solar dryer for drying red pepper in Bangladesh

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Abstract

A cabinet type solar dryer was designed and fabricated over a collector and dryer area of 4.00 m^2 and 7.5 m^2 respectively for the geographical condition of Bangladesh. Red pepper was used to test the performance of the dryer. The upper tray and lower tray pepper drying needed 36 and 41 h to reduce moisture from 73% (wet basis) to 10% (wet basis) respectively and found 9 kg dried pepper from 30 kg fresh red ripe pepper. In contrast, open sun drying needed 85 h to reduce moisture from 73% (wet basis) to 11% (wet basis) and produced 2.43 kg dried pepper from 8 kg red ripe pepper. The average global radiation was about 133 W/m^2 while the flux incidence and flux absorbed on collector was about 128 W/m^2 and 103 W/m^2 respectively. The average collector and dryer efficiency was about 48% and 34% respectively. The average exergy efficiency was obtained 63%. The average rate of top, bottom and side collector loss was 37 W/m^2, 20 W/m^2 and 3 W/m^2 respectively. The upper tray, lower tray and open sun pepper seed germination was 76%, 81% and 85% respectively ($P \geq 0.01$). The redness value of lower tray pepper ($a^*=27.1$) was higher followed by upper tray ($a^*=24.7$) and open sun pepper powder ($a^*=21.1$), which means direct exposure of sunlight diminishes the quality of pepper colour. The redness value of fabricated solar drying was significantly ($P \leq 0.01$) higher than that of open sun drying.

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Introduction

Solar energy is a cheap, clean and safe renewable energy source, which has been used in agricultural product drying since the dawn of civilisation. Solar drying is the oldest preservation technique of agricultural products using several types of solar crop dryers based mostly on solar energy, which is abundant, renewable and sustainable (Azaizia *et al*., 2017). With the development of modern science and technology, scientists all over the world augmented many research works to facilitate efficient use of solar energy for crop drying. Many assumptions were made for designing of collector, dryer chamber, number of trays and fan power *etc*. for different crop in different geographical location. All are purposed for maximising dryer efficiency, judicial use of energy and minimising energy loss especially in developing world where energy is a crisis and mechanical drying is not possible due to excessive initial investment (Muhlbauer *et al*., 1993).

Bangladesh (lat. 20.57°-26.63° N and long. 88.02°-92.68° E) is a developing country, lies in a semi-tropical region, having annual solar radiation of 1700 kWh/m². It has about 7.6 h of average bright day length in the dry season, while in monsoon it is nearly 5 h (Shakir *et al*., 2012). The amount of solar radiation and day length demonstrates potentiality of solar energy use for agricultural product drying in this territory. Nevertheless, the high amount of rainfall (average yearly 208 mm) is a matter of concern especially in monsoon, as it becomes problem in drying, reducing quality of dried product, especially for open sun drying (World Bank, 2016).

Open sun drying is an ancient practice, which exhibits slow draying rate, dirt or fungal contamination in product, birds and rodents' attack and deterioration of quality, especially colour or flavour degradation (Hossain, 2003). But, still more than 90% of people practice this traditional sun drying method in Bangladesh. The main reason for such tendency is assumed as, lack of suitable dryer technology which can be adopted in this region and lack of quality concern among the farmers and consumers, which is believed to be replaced soon, as people are being conscious about food safety day by day.

Pepper is an important spice in Bangladesh, used at everyday meals either fresh or powdery. In consuming fresh pepper, no extra care is needed for processing *etc*. while, preparing pepper powder needs proper drying and crushing. Dried pepper is more popular in the subcontinent than other region of the world and the production is also higher in this region. Due to lack of proper dryer, farmer tends to sell green pepper in the local market although they get a very few profit. The main reason for such tendency is traditional sun drying practice is labour intensive and time consuming. Moreover if the dried product does not look attractive, they do not get the proper value of their product. In this case a suitable dryer is needed for the farmers so that they can produce quality-dried product, which will help them to be benefited economically, fulfilling national and international demand.

Hossain and Bala (2006) developed a mixed mode type forced convection solar tunnel dryer under the weather conditions of Bangladesh. The dryer consisted of transparent plastic covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using two fans operated by a photovoltaic module. The dryer had a loading capacity of 80 kg of fresh peppers. Moisture content of red pepper was reduced from 2.85 to 0.05 kg/kg (db) in 20 h in solar tunnel dryer and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg/kg (db) in improved and conventional sun drying methods, respectively. Chowdhury *et al*. (2011) presented an energy and exergy analysis of solar drying of jackfruit leather in a solar tunnel dryer. Jackfruit leather was dried from initial moisture content of about 76% (w.b.) to 12% moisture content (w.b.) in the solar tunnel dryer within 2 days of drying while at the same drying time the moisture content of similar sample reached 14% (w.b.) in the open sun drying method. Pangavhane *et al*. (2002) developed a natural convection solar dryer consisting of a solar air heater and a drying chamber for drying various agricultural products like fruits and vegetables and reported that shade drying and open sun drying required 15 and 7 days, respectively, while the natural convection solar dryer took only 4 days and produced better quality raisins. An indirect forced convection solar dryer integrated with different sensible heat storage maternal was developed and tested by Mohanraj and Chandrasekar (2009) for its performance for drying pepper under the metrological conditions of Pollachi, India. The system consists of a flat plate solar air heater with heat storage unit, a drying chamber and a centrifugal blower. Drying experiments was performed at an air flow rate of 0.25 kg/s. Drying of pepper in a forced convection solar dryer reduced the moisture content from around 72.8% (wet basis) to the final moisture content about 9.1% in 24 h. The average dryer efficiency was estimated as about 21%.

Though a significant amount of research was conducted on solar dryer at all over the world but a very few work was accomplished in the geographical condition of Bangladesh. Hossain and Bala (2006) developed a solar tunnel dryer at Bangladesh Agricultural University, Mymensingh and found technically suitable for drying red and green peppers. Hossain (2011) also developed a hybrid dryer at Bangladesh Agricultural Research Institute, Gazipur, which is run by solar energy as well as by electrical heater as a supplement energy source and found good for seed drying. Cabinet type solar dryer can be another option to be adopted in this region, thus the research was undertaken. The paper focuses on design, fabrication and energy utilisation character of cabinet solar dryer for the geographical condition of Bangladesh, especially Shibganj, Bogra (25.1° N, 89.19° E) to dry red pepper.

Materials and methods

Design consideration

The cabinet solar dryer is consisted of two main parts namely dryer and collector. The dryer area is composed of drying chamber, four numbers of drying trays, exhaust pipe, exhaust fan and solar panel *etc*. The outer cover of the dryer is made by insulating materials such as poly-vinyl-chloride (PVC) sheet, which is also water resistive. The trays are placed in two columns where two trays are placed in each column. The trays are made from poly-coated iron net for better perforation and resistance to weather. To ensure easy movement, four number of bearing over a diameter of 10 mm was attached at the bottom of the each tray. The exhaust fan is attached to the end of the exhaust pipe placed vertically attached at the top end part of the dryer. The solar panel is attached just above the man height and beside of the dryer concerning that the panel shade does not fall on the top of the dryer. The main part of the collector is the absorber plate. The absorber plate is a corrugated iron sheet, which is painted by black colour for absorbing more solar energy. The collector and the solar panel are placed at a tilt angle of 23.5°, which is recommended for maximum exposure of solar radiation in the research location (Bala, 1998). The collector inlet and exhaust area is kept similar for smooth entry of air. For easy handling and movement 10 number of wheel over a diameter of 10 cm was fixed at he bottom of the dryer frame. The engineering drawing and prototype picture of the dryer is shown in Figure 1A-C.

The dryer was designed following the design parameter shown in Table 1 and equation 1 to 12 (Joshua, 2008):

Amount of moisture removed from product;

$$M_r = \frac{W_p(M_i - M_f)}{(100 - M_f)} = 21.85 \text{ kg} \quad (1)$$

Calculation of Energy; $E = M_r \times L = 52434.78$ kJ (2)

Collector area; $A_c = \frac{E}{S_r \times \eta} = 4.00 \text{ m}^2$ (3)

Length of the collector; $L_c = \frac{A_c}{w} = 2.67$ m (4)

Drying rate; $D_r = \frac{M_r}{t} = 0.91$ kg/h (5)

Mass flow rate; $m_f = \frac{D_r}{(W_{a2} - W_{a1}) \times 3600} = 0.13$ kg/s (6)

Volumetric air flow rate; $V_a = \frac{m_f}{\rho_a} = 0.11 \text{ m}^3/\text{s}$ (7)

Outlet area; $O_a = \frac{V_a}{V_w} = 0.03 \text{ m}^2$ (8)

Outlet diameter; $D_o = \sqrt{\{\pi \times O_a(\text{cm}^2)\}/4} = 15.86$ cm (9)

Drying area; $A_d = \frac{W_p}{\rho_s} = 7.5 \text{ m}^2$ (10)

Considering number of tray, $N_t = 4$:

Area of each tray; $A_t = \frac{A_d}{N_t} = 1.875 \text{ m}^2$ (11)

Width of each tray; $W_t = \frac{A_t}{L_t} = 1.25$ m (12)

Drawing of dryer in SolidWorks 2014

SolidWorks is a computer aided drawing and simulation tool that supports users in creating precise drawing, solid models and many more. The SolidWorks part mode allows users to create parts, whereas its assembly mode supports the assembling of parts to create an assembly (Anonymous, 2016a). The solar dryer was drawn in SolidWorks 2014. The dimension unit was in millimetre. The value was inserted per calculation of the equation, from 8 to 12.

Dryer fabrication materials

The specification of the dryer is shown in the Table 2.

Drying of pepper

About 30 kg and 8 kg of fresh harvested red ripe pepper of same variety (line CO517) was collected from the research field of Spices Research Centre, Shibgonj, Bogra for drying in the dryer and open sun respectively. The initial weight of pepper was weighed by an electric balance (MATP-31, China). The data of solar radiation, airflow rate, temperature, and relative humidity was recorded by solar meter (UVA 18573, USA), anemometer (TA 430, England), digital thermometer (K202, Germany) and hygrometer (GM 1360, China) respectively from 8:00 am to 5:00 p.m. at one-hour interval. Six samples were placed at different part of the top and bottom tray. These samples were weighed at one-hour interval by an electric balance (FA2004B, China) in order to calculate drying rate. Similarly, six samples were placed on the open sun and they were also weighed for every one-hour interval. The final weight of the pepper was recorded by the electric balance.

Energy balance

An energy balance on the absorber plate yields the following equation tor a steady state (Sukhatme, 1997):

$$q_u = A_p S - q_l \tag{13}$$

Energy and exergy analysis

The thermal efficiency of a solar collector is the ratio of useful heat gained to the solar radiation incident on the plane of the collector. This thermal efficiency is expressed as (Fudholi *et al.*, 2013):

$$\eta_c = \frac{m_f C(T_o - T_i)}{A_c I_g} \times 100\% \tag{14}$$

Moreover, system-drying efficiency is defined as the ratio of the energy required evaporating moisture to the heat supplied to the dryer. The system drying efficiency can be obtained using the

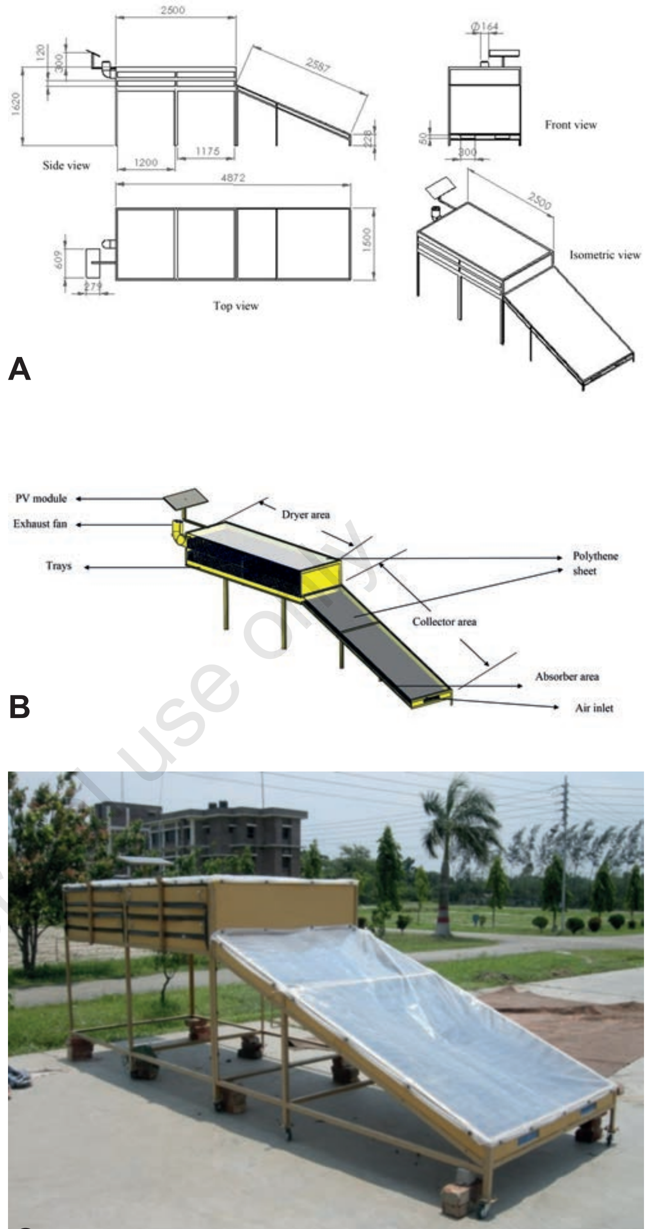

Figure 1. A) Engineering 2D drawing of the dryer in SolidWorks 2014 (values are in millimeter); B) cross-sectional 3D view of different parts of the dryer in SolidWorks 2014; C) prototype of the cabinet solar dryer.

Table 1. Design parameter of the dryer.

Sample weight (W_p)	30 kg	Air density on average 40°C drying temperature (ρ_a)	1.127 kg/m^3
Initial moisture (M_i)	75%	Wind speed (V_w)	3.5 m/s
Final moisture (M_f)	8%	Ambient temperature (T_a)	30°C
Latent heat (L)	2400 kJ/kg	Dryer temperature (T_d)	50°C
Solar insolation for three days drying (S_r)	52,380 kJ/m^2	Drying time (t)	24 h
Dryer efficiency (η)	25%	Spreading density (ρ_s)	4 kg/m^2
Width of dryer (w)	1.5 m	Humidity ratio before drying (W_{a1})	0.019 kg/kg water
		Humidity ratio after drying (W_{a2})	0.021 kg/kg water

following equation:

$$\eta_d = \frac{M_r L}{A_c G + P_f + P_h} \times 100\% \qquad (15)$$

The exergy values are calculated from the first-law energy balance using the characteristics of the working medium. The general form of the exergy equation applicable for a steady flow system can be expressed as (Akbulut and Durmus, 2010):

For exergy inflow of drying chamber which can be written as follows:

$$Ex_{dci} = m_f C\left[\left(T_{dci} - T_a\right) - T_a \ln\left(\frac{T_{dci}}{T_a}\right)\right] \qquad (16)$$

Similarly, for exergy outflow of drying chamber following relation can be expressed as:

$$Ex_{dco} = m_f C\left[\left(T_{dco} - T_a\right) - T_a \ln\left(\frac{T_{dco}}{T_a}\right)\right] \qquad (17)$$

The exergy efficiency can be defined as the ratio of energy use in the drying of the product to exergy of the drying air supplied to the system. The exergy efficiency can be thus written as (Akpinar, 2010; Akbulut and Durmus, 2010):

$$\eta_{Ex} = \frac{Ex_{dco}}{Ex_{dci}} \times 100 \qquad (18)$$

Overall heat loss from the collector

It is convenient from the point of view of analysis to express the heat lost from the collector in terms of an overall loss coefficient defined by the equation (Sukhatme, 1997):

$$\frac{q_l}{A_p} = U_l\left(T_{pm} - T_a\right) \qquad (19)$$

The heat lost from the collector is the sum of the heat lost from the top, the bottom and the sides. Thus we can write:

$$q_l = q_t + q_b + q_s \qquad (20)$$

Each of these losses is also expressed in terms of coefficients called the top loss coefficient, the bottom loss coefficient and the side loss coefficient and defined by the equations:

$$q_{t,b,s} = U_{t,b,s} A_p \left(T_{pm} - T_a\right) \qquad (21)$$

Top loss coefficient

The top loss coefficient can be obtained by the following relation (Sukhatme, 1997):

$$U_t = \left[\frac{M}{\left(\frac{c}{T_{pm}}\right)\left(\frac{T_{pm}-T_a}{M+f}\right)^{0.33}} + \frac{1}{h_w}\right]^{-1} + \left[\frac{\sigma\left(T_{pm}^2 + T_a^2\right)\left(T_{pm}+T_a\right)}{\frac{1}{\varepsilon_p + 0.05M(1-\varepsilon_p)} + \frac{(2M+f-1)}{\varepsilon_c} - M}\right] \qquad (22)$$

where:

$$f = \left(1 - 0.04\, h_w + 0.005 h_w^2\right)\left(1 + 0.091\, M\right) \qquad (23)$$

$$c = 365.9\left(1 - 0.00883\beta + 0.0001298\beta^2\right) \qquad (24)$$

Convective heat transfer coefficient at the top cover has been generally calculated so far, from the following empirical correlation as (Sukhatme, 1997):

$$h_w = 5.7 + 3.8\, V_w \qquad (25)$$

The bottom heat loss coefficient

The bottom loss coefficient U_b is evaluated by considering conduction and convection losses from the absorber plate in the downward direction through the bottom of the collector. (Sukhatme, 1997):

$$U_b = \frac{K_i}{X_i} \qquad (26)$$

Side loss coefficient

If the dimensions of the absorber plate are $L_1 \times L_2$ and the height of the collector casing is L_3, then the area across which heat flows sideways in $2(L_1+L_2)L_3$. The temperature drop across which the heat flow occurs varies from $(T_{pm}-T_a)$ at the absorber plate level to zero both at the top and bottom. Assuming, therefore, that the average temperature drop across the side insulation is $(T_{pm}-T_a)/2$ and that the thickness of this insulation is δ_s, we have (Sukhatme, 1997):

$$q_s = 2L_3(L_1 + L_2)k_i \frac{(T_{pm} - T_a)}{2\delta_s} \qquad (27)$$

Again, $q_s = U_s\ A_p\ (T_{pm} - T_a)$

Thus,

$$U_s = \frac{(L_1 + L_2)L_3 k_i}{L_1 L_2 \delta_s} \qquad (28)$$

Table 2. Specification of materials.

Name of materials	Amount
PVC sheet	2058×2058×12 mm^3
MS Bar — Angle bar Square bar	66,400×318 mm^2 96,300×8 mm^2
Wheel	8 no. (101.6 mm diameter)
Poly coated wire net	4087×4087 mm^2
Bearing	16 no. (10 mm dia.)
Polythene	2700×2700×1.5 mm^3
Nut and bolt diameter)	100 pcs (12.7 mm diameter), 20 pcs (25.4 mm
Corrugated iron sheet	1500×2700×1 mm^3
Paint	2 L black and 2 L yellow
Solar panel	609.6×304.8×25.4 mm^3 (24 W, mono-crystalline)
Fan	1 no. (150 mm die), 12 W DC

Germination test

The pepper was soaked in clean water for one hour. After draining water the seeds were placed on the surface of soaked blotter papers in the petri dishes. Twenty numbers of petri dish were used for seed germination test while 10 numbers for each drying system. About 100 numbers of seed were placed in each petri dish. The average room temperature and relative humidity was 20°C and 76% respectively. The germination was counted up to 6 days. (Sultana, 2001).

Colour test

The colour of dried red peppers was quantified by using a Minolta (CR-400) Chromameter (Osaka, Japan). L*, a* and b* values were measured to describe three dimensional colour space and interpreted as follows: L* is the brightness/lightness or whiteness ranging from no reflection for black (L=0) to perfect diffuse reflection for white (L=100). The value a* is the redness ranging from negative values for green to positive values for red. The value b* is the yellowness ranging from negative values for blue and positive values for yellow. The data were presented as means of nine independent measurements for each treatment (Hossain and Bala, 2006).

Results and discussion

The cabinet type solar dryer was designed and fabricated to dry red pepper over a collector and dryer area of 4.00 m² and 7.5 m²

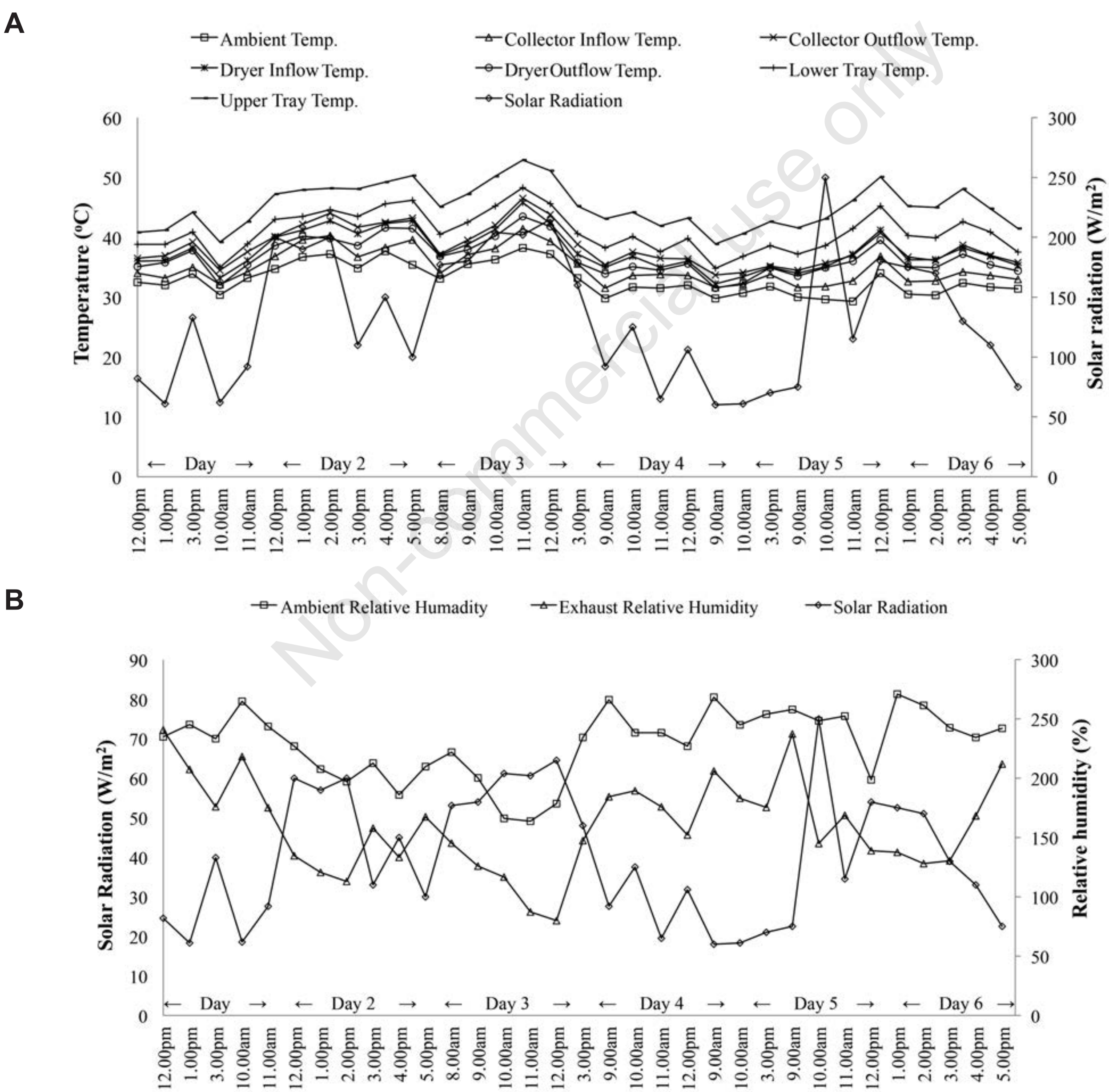

Figure 2. A) Temperature variation on different solar radiation; B) relative humidity variation on different solar radiation.

respectively. The prototype of the cabinet type solar dryer was fabricated in the workshop of Spices Research Centre, Bogra, Bangladesh. The dryer was fabricated by angle bar, square bar, PVC sheet, polythene sheet, wheel, nut and bolt, poly coated wire net, corrugated iron sheet, paint, solar panel and exhaust fan. Hossain and Bala (2006) designed, fabricated and installed a Hohenheim type solar tunnel dryer in Bangladesh Agricultural University, Mymensingh where the area of the dryer unit was same as that of the collector. In case of our cabinet dryer, two trays, namely upper and lower are placed in column and reduce the area significantly, which is not possible in case of tunnel dryer.

The upper tray and lower tray pepper drying needed 36 and 41 h to reduce moisture from 73% (wet basis) to 10% (wet basis) respectively and found 9 kg dried pepper from 30 kg fresh red ripe pepper. In contrast, open sun drying took 85 h reducing moisture from 73% (wet basis) to 11% (wet basis) and produced 2.43 kg dried pepper from 8 kg red ripe pepper. The drying character demonstrates that cabinet solar drying is quicker than that of conventional sun drying method. The average ambient temperature, upper tray temperature, lower tray temperature, ambient relative humidity, exhaust relative humidity and solar radiation during experiment was 33°C, 45°C, 41°C, 69%, 48% and 133 W/m^2 respectively shown in Figure 2A and B. Fudholi *et al*. (2013) studied performance of solar drying system for red pepper. Red chili was dried to final moisture content of 10% w.b from 80% w.b in 33 h using this system. In his study the average solar radiation was 420 W/m^2 while in our study the average solar radiation was 133 W/m^2. This represent that even though the sun intensity is low, our designed solar dryer is capable in reducing moisture with no significant time differences.

The average upper tray temperature (45°C) and drying rate (1.26 kg/h) was higher than that of average lower tray temperature (41°C) and drying rate (1.13 kg/h). In contrast, open sun drying represented poor drying rate (0.65 kg/h). The average mass flow rate in the dryer was 0.07 kg/s over the vent area, average air speed and air density of 0.04 m^2, 2.18 m/s and 1.13 kg/m^3 respectively. The drying characteristics curve for upper tray, lower tray and open sun pepper is shown as in Figure 3.

The average global radiation was measured as about 133 W/m^2 ranged from 60 W/m^2 to 250 W/m^2. Similarly, the flux incidence on collector was calculated as about 128 W/m^2 ranged from 58 W/m^2 to 241 W/m^2. Moreover, the flux absorbed on the collector was calculated as about 103 W/m^2 ranged from 58 W/m^2 to 193 W/m^2. The declination angle was achieved 11.23° for experiment period of 20th April while the hour angle was considered for 09:30 a.m., about 37.5°. To calculate clearness index the value a,b was assumed about 0.28 and 0.42, considering location of Calcutta, India as there is no available data for Bogra, Bangladesh and both the city are adjacent to each other and weather condition is almost same. The refractive angle was calculated over a refractive index of 1.53. The extinction coefficient and emissivity was considered 20 m^{-1} and 0.95 respectively (Sukhatme, 1997). The relationship among global radiation, flux incidence and flux absorbed on the collector is shown in the Figure 4.

The average collector efficiency was approximately 48%, which was maximum (73%) on 3rd day of drying, at 11:00 a.m., over a solar radiation of 202 W/m^2, at a mass flow rate of 0.11 kg/s. However, minimum (20%) was obtained on 5th day of drying, at 03.00 p.m., over a solar radiation of 70 W/m^2, at a mass flow rate of 0.04 kg/s. However, it is noticeable that, collector efficiency increased with the increase of solar radiation and vice versa shown in Figure 5.

System drying efficiency was obtained, 34%, to reduce 22 kg water from 30 kg pepper, over a latent heat L=2400 kJ/kg (666.06 W h/kg), average drying time (38.5 h), average solar radiation, I_g=133 W/m^2, over a fan power of 43.2 kWh. Fuller *et al*. (2005) studied on feasibility study on solar dryer for pepper and found average collector and system drying efficiency of 30% and 14.5% respectively.

Lingayat *et al*. (2017) designed a solar collector area of 2 m^2 for drying banana. The size of the drying cabinet is 1×0.4×1 m (width, depth, and height). The moisture content of banana was reduced from initial value of 356% (db) to final moisture content of 16%, 19%, 21%, 31%, and 42% (db) for Tray1, Tray2, Tray3, Tray4, and open sun drying respectively. The average thermal efficiency of the collector was found to be 32% and that of drying chamber was 22%.

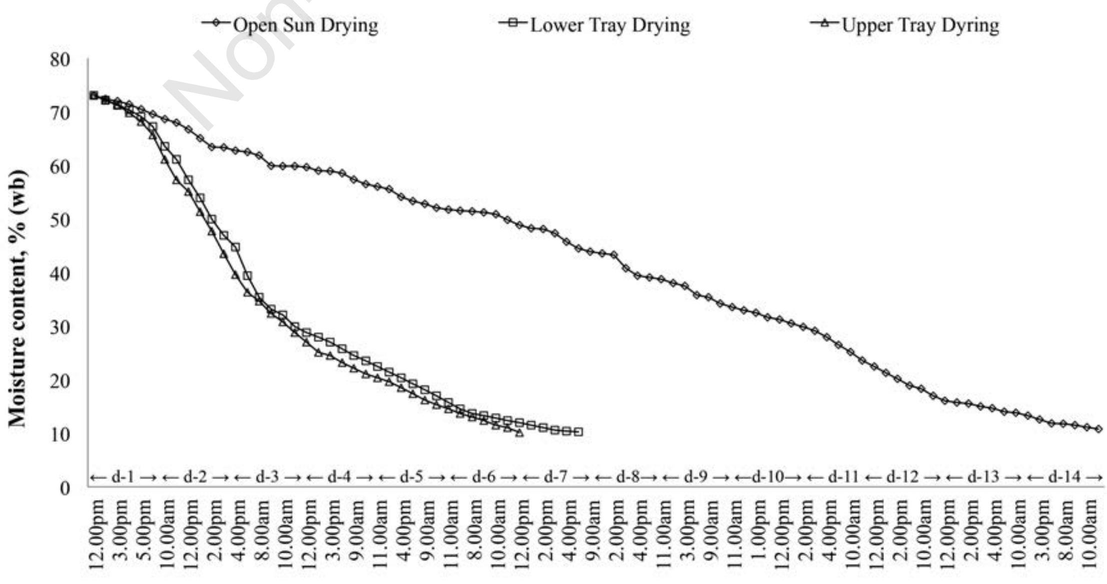

Figure 3. Drying curve of pepper.

The average exergy inflow was 27 W, where the maximum (77 W) was in 3rd day of drying, at 11:00 a.m. over a solar radiation of 202 W/m^2, while the lowest (3 W) was on 5th day, at 09:00 a.m. over a solar radiation of 60 W/m^2. Similarly, average exergy outflow is 17 W, where the maximum and minimum was 59 W and 2 W at 6th day of drying, at 10:00 a.m., for 250 W/m^2 and at 5th day of drying, at 10:00 a.m., for 61 W/m^2 respectively. However, average exergy efficiency was obtained 63%, whereas maximum and minimum was 93 %, 6th day, at 10:00 a.m., for 250 W/m^2 and 23%, at 2nd day, 10:00 a.m., for 200 W/m^2 respectively. Our designed dryer demonstrated better exergy efficiency in comparison to the study conducted by Fudholi *et al*. (2014) who obtained values for drying red pepper varied between 43% and 97% with an average of 57%. Exergy inflow, outflow, and loss follow similar patterns as similarly reported by Chowdhury *et al*. (2011) and Akpinar (2010) shown in Figure 6. Rabha *et al*. (2017) developed a forced convection solar tunnel dryer integrated with a shell and tube based latent heat storage module was designed and fabricated. Ghost pepper pepper and sliced ginger were successfully dried in the dryer in 42 h and 33 h in the drying air temperature range of 42-61°C and 37-57°C, respectively. Energy and exergy analyses of the drying processes of the two products were performed. The results showed

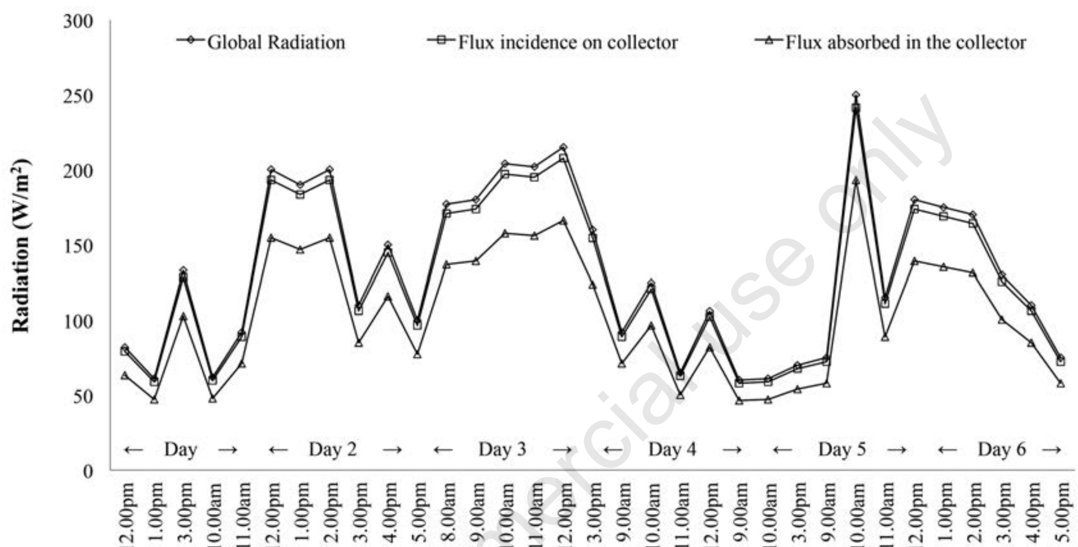

Figure 4. Flux characteristics on different period of drying time.

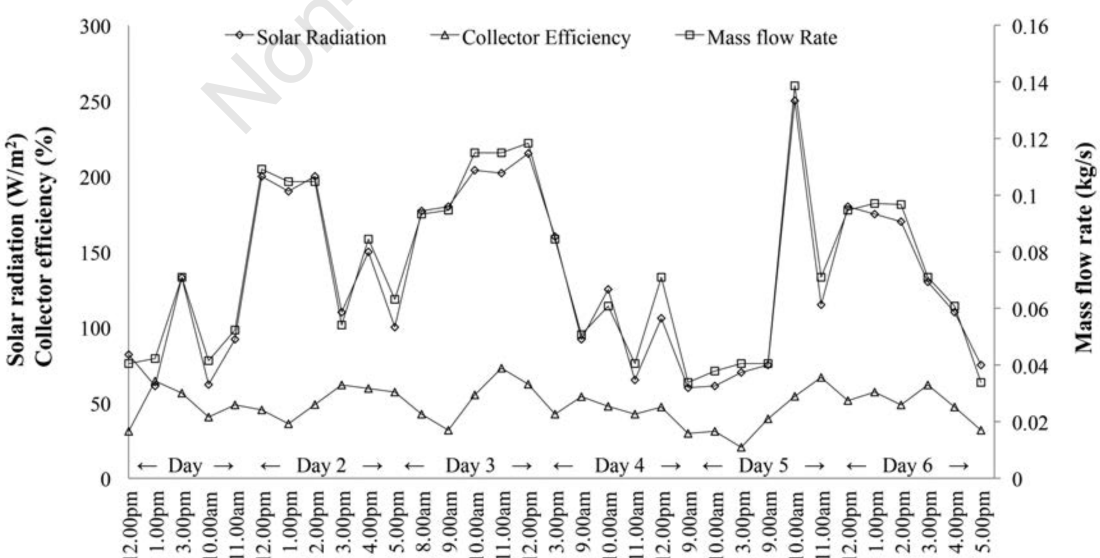

Figure 5. Variation of collector efficiency.

that the thermal efficiencies of the first and the second solar air heaters varied between 22% and 40% and 10% and 20%, respectively. The average overall thermal efficiency of the air heaters array varied between 23% and 23%. When the ghost pepper was dried, the exergy efficiency of the drying chamber was in the range of 21%-98% with an average of 63%, and it was 4%-96% with an average of 47%, while the ginger was dried. The exegetic efficiency increased with advancing in drying time, and high exergetic efficiency was recorded in the last few hours of the drying operation of the consecutive drying days.

The average rate of top collector loss was 37 W/m^2, ranged from 13 W/m^2 to 62 W/m^2. Similarly, the average rate of bottom and side energy loss was 20 W/m^2 and 3 W/m^2 ranged from 9 W/m^2 to 30 W/m^2 and 2 W/m^2 to 5 W/m^2 respectively. To calculate top loss coefficient, the convective heat transfer coefficient was calculated over different air speed for collector tilt of 23.5^o and assuming one number of plastic cover. In this case, collector (ε_c) and absorber (ε_p) emissivity was considered 0.88 and 0.95 (Sukhatme, 1997). Similarly, in calculating bottom loss, the thermal conductivity of PVC sheet is 0.12 W/m–K (Anonymous, 2016b) over a thickness of 0.04 m. Likewise, the side loss coefficient was calculated for a given length, width and depth of the col-

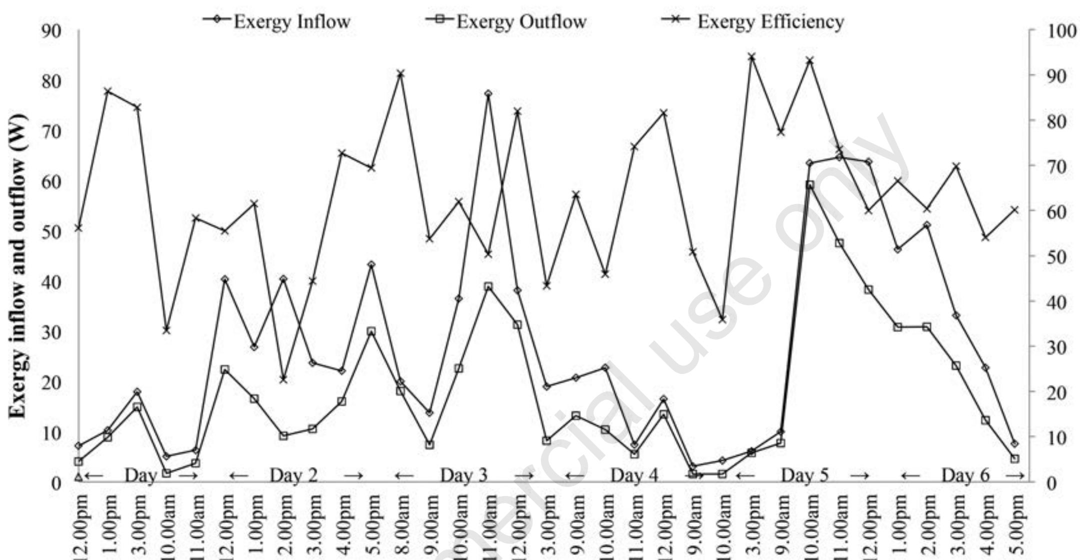

Figure 6. Exergy at different period of drying time.

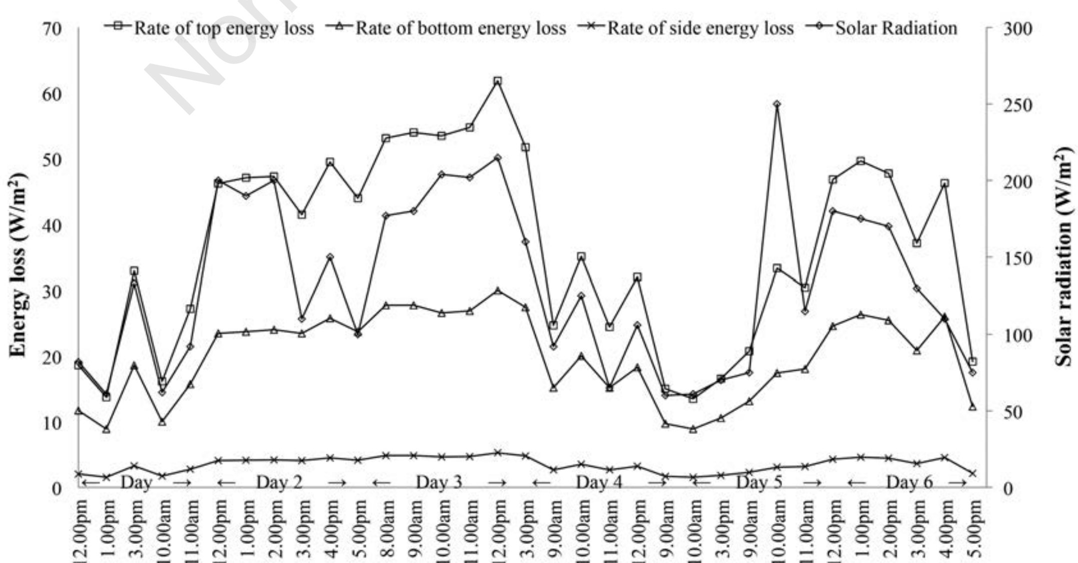

Figure 7. Energy loss through collector at different solar radiation.

lector. The energy loss phenomenon is shown in the following Figure 7. The upper tray, lower tray and open sun drying pepper seed germination were 76%, 81% and 85% respectively. However, the seed germination between dryer and open sun drying shows no significant statistical difference (P≥0.01). Krishnamurthy (1995) observed that higher seed quality in sun drying among traditional methods (sun and shade), whereas, in mechanical drying at different air temperatures, seeds dried under 40°C temperature showed higher germination. As the temperature in the dryer was higher about 45°C and 41°C for upper and lower tray respectively, which is believed to be responsible for diminishing seed germination in case of cabinat drying compared to open sun drying. Christinal and Tholkkappian (2012) also mentioned that pepper dried by sun and mechanical dryer at 37°C gave higher germination.

The average values of three chromatic scales (L*, a*, b*) measured on lower tray pepper were L*=42.28, a*=27.1 and b*=54.69, upper tray pepper were L*=43.6, a*=24.7 and b*=56.6 and open sun pepper were L*=49.5, a*=21.1 and b*=62.5, The redness (a*) value of lower tray pepper was higher than that of the upper tray and open sun pepper powder, while the darkness (L*) and yellowness (b*) was higher in case of open sun and upper tray pepper power which means direct exposure of sunlight diminishes the quality of colour. The redness value of solar drying was significantly (P≤0.01) higher than that of open sun drying. Similar result was also found by Hossain (2006) that colour values obtained from conventional sun dried green pepper was significantly lower than those obtained from solar tunnel and improved sun dried green pepper.

Conclusions

A cabinet type solar dryer was designed and fabricated by angle bar, square bar, PVC sheet, polythene sheet, wheel, nut and bolt, poly coated wire net, corrugated iron sheet, paint, solar panel and exhaust fan over a collector and dryer area of 4.00 m^2 and 7.5 m^2 respectively in Spices Research Centre, Shibganj, Bogra, Bangladesh.

To dry pepper the upper tray and lower tray needed 36 and 41 h to reduce moisture from 73% (wet basis) to 10% (wet basis) respectively and found 9 kg dried pepper from 30 kg fresh red ripe pepper. In contrast, open sun drying took 85 h reducing moisture from 73% (wet basis) to 11% (wet basis) and produced 2.43 kg dried pepper from 8 kg red ripe pepper.

The average ambient temperature, upper tray temperature, lower tray temperature, ambient relative humidity and exhaust relative humidity during experiment was 33°C, 45°C, 41°C, 69% and 48% respectively.

The average mass flow rate in the dryer was 0.07 kg/s over the vent area, average air speed and air density of 0.04 m^2, 2.18 m/s and 1.127 kg/m^3 respectively.

The average global radiation was measured as about 133 W/m^2 ranged from 60 W/m^2 to 250 W/m^2. Similarly, the flux incidence on collector was calculated as about 128 W/m^2 ranged from 58 W/m^2 to 241 W/m^2. Moreover, the flux absorbed on the collector was calculated as about 103 W/m^2 ranged from 58 W/m^2 to 193 W/m^2.

The average collector efficiency was approximately 48%, ranged from 20%-73%. It is noticeable that, collector efficiency increases with the increase of solar radiation and vice versa. System drying efficiency was obtained, 34%.

The average exergy inflow was 27 W, where the maximum ranged from 3 W to 77 W Similarly, average exergy outflow is 17 W, ranged from 2 W to 59 W. Average exergy efficiency was obtained 63%, ranged from 23% to 93%.

The average rate of top collector loss was 37 W/m^2, ranged from 13 W/m^2 to 62 W/m^2. Similarly, the average rate of bottom and side energy loss was 20 W/m^2 and 3 W/m^2 ranged from 9 W/m^2 to 30 W/m^2 and 2 W/m^2 to 5 W/m^2 respectively.

The upper tray, lower tray and open sun drying pepper seed germination were 76%, 81% and 85% respectively. The seed germination between dryer and open sun drying shows no significant statistical difference (P≥0.01).

The redness value of lower tray pepper (a*=27.1) was higher followed by upper tray (a*=24.7) and open sun pepper powder (a*=21.1). The darkness (L*) and yellowness (b*) was higher in case of open sun were (L*=49.5 and b*=62.5) followed by upper tray pepper power (L*=43.6, and b*=56.6) and lower tray pepper (L*=42.28, a*=27.1 and b*=54.69) which means direct exposure of sunlight diminishes the quality of colour. The redness value of fabricated solar drying was significantly (P≤0.01) higher than that of open sun drying.

Nomenclature

a,b	Constants obtained by fitting data
A_c	Collector area (m^2)
A_d	Drying area (m^2)
A_p	Area of absorber (m^2)
A_t	Area of each tray (m^2)
C	Specific heat of air (kJ/kg–K)
D_o	Outlet diameter (cm)
D_r	Drying rate (kg/h)
E	Energy (kJ)
Ex_{dci}	Exergy in dryer chamber inflow (W)
Ex_{dco}	Exergy in dryer chamber outflow (W)
Ex_{loss}	Exergy loss (W)
h_w	Wind heat transfer coefficient (W/m^2-°C)
I_d	Diffuse radiation (W/m^2)
I_d	Beam radiation (W/m^2)
I_g	Global radiation (W/m^2)
I_T	Flux on tilted surface (W/m^2)
K	Extinction coefficient
K_i	Thermal conductivity (W/m–K)
K_T	clearness index
L	Latent heat (kJ/kg)
L_c	Length of collector (m)
L_t	Length of tray (m)
M	Number of glass cover
M_r	Moisture to be removed (kg)
M_i	Initial moisture content (%)
M_f	Final moisture content (%)
m_f	Mass flow rate (kg/s)
N_t	Number of tray
n	Day of the year
O_a	Outlet area (m^2)
P_f	Fan power (W)
P_h	Heater power (W)
q_u	Useful heat gain (W)
q_b	Rate of heat loss from bottom (W)
q_l	Rate of heat loss (W)
T_{dci}	Temperature in dryer chamber inflow (°C)
q_t	Rate of heat loss from top (W)
R_I	Reflective index
r_b	Tilt factor for beam radiation
r_d	Tilt factor for diffuse radiation
r_r	Tilt factor for reflected radiation
S	Heat absorbs in collector (W/m^2)
Ś	Monthly average sunshine hour per day (h)
$Ś_{max}$	Maximum possible day length per day (h)
ρ_s	Spreading density (kg/m^2)
S_r	Solar insolation (kJh/day)
t	Drying time (h)

T_a Ambient temperature (°C)
T_d Dryer temperature (°C)
T_{dco} Temperature in dryer chamber outflow (°C)
T_i Collector inflow temperature (°C)
T_o Collector outflow temperature (°C)
T_{pm} Mean absorber surface temperature (°C)
U_b Bottom loss coefficient (W/m^2–K)
U_l Overall loss coefficient (W/m^2–K)
U_s Side loss coefficient (W/m^2–K)
U_t Top loss coefficient (W/m^2–K)
w Width of dryer (m)
W Amount of water removed (kg)
W_p Sample weight (kg)
V_a Volumetric airflow rate (m^3/s)
V_w Wind speed (m/s)
W_{a1} Humidity ratio before drying, kg/kg water
W_{a2} Humidity ratio after drying, kg/kg water
W_t Width of each tray (m)
X_i Thickness of the insulation (m)
θ Angle of incidence (°)
θ_1 Angle of incidence on collector (°)
θ_2 Angle of refraction on collector (°)
θ_z Zenith angle (°)
Φ latitude (°)
δ Declination (°)
α Absorptivity
τ Transmissivity
$(\tau\alpha)_b$ Absorptivity-transmissivity for beam radiation
$(\tau\alpha)_d$ Absorptivity-transmissivity for diffuse radiation
ω Hour angle (°)
β Slope (°)
ρ Density (kg/m^3)
ρ_a Density of air (kg/m^3)
q_s Rate of heat loss from side (W)
ρ_I, ρ_I Reflectivity
η Efficiency (%)
η_c Collector efficiency (%)
η_d Dryer efficiency (%)
η_{Ex} Exergy efficiency (%)
ε_P Emissivity of absorber
ε_c Emissivity of cover
δ_c Thickness of bottom insulation (m)
δ_s Thickness of side insulation (m)

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