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Research Article

Application of ANN and prediction of drying behavior of mushroom drying in side hybrid greenhouse solar dryer: an experimental validation

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ABSTRACT

The newly developed Heat Exchanger Evacuated Tube Assisted Drying System (HE-ETADS) is fabricated in roof of campus of MITS, Gwalior, India. Heat transfer analysis of developed drying system is carried out by drying mushroom inside it. The heat transfer coefficient plays a significant role in drying method. The study emphasizes on determining the convective as well as evaporative heat transfer coefficients (CHTC & EHTC) and the determination of best drying rate model fit for mushroom drying inside novel drying system. The artificial neural network is developed for predicting the CHTC & EHTC. Value of CHTC & EHTC varies from 2.10 to 3.43 and 25.68 to 49.85 W/m^2°C respectively. The developed ANN model helps in predicting the heat transfer coefficient once trained using input factors like solar radiation, relative humidity, environmental temperature and time. The value of R^2 for the developed ANN model is 0.99, which shows that model predicts the value very close to the calculated value of heat transfer coefficients. Drying kinetics of mushroom is tried to fit in nine drying rate models. The Midili-Kucuk model shows the better fit among the other models.

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INTRODUCTION

Using suns power for preservation of foodstuff and other agriculture products have been in preparation for centuries. Traditionally, crops are dried direct exposure of solar radiation in open sky. It is also known as open sun drying (OSD), is common as well as cost-effective technique of crops conservation, as compare to dehydrating using heating effect generated through conventional sources of energy, and is normally being used in a large numbers of the developing countries. Limitation of this process is that food and

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agriculture products are exposed to direct contact of dust, dirt, incest, animals as well as open environmental influences and necessity of protection during the adversative climatic conditions such as in rainy season. Apart from these limitations, drying results are dependent on good weather conditions. The recent drying method and system has more efficiency, provides hygiene, and is capable of keeping the crops innocuous from loss. Dehydration of food products conducted inside the drying system using thermal energy. These drying system control and manage the drying cabin temperature, as well as other affecting ambient parameters (room temperature, relative humidity, air speed). Adequate dehydration helps in preserving flavor, texture as well as quality assessment in term of color index of dried product [1], [2], [3].

To lead an energetic as well as hearty life, human beings want adequate food and a balanced nutritious diet. Vegetables and fruits contain various types of vitamins, minerals, and fiber. Vegetables and fruits also provide antioxidants that safeguard us from many chronic diseases. But the maximum of the vegetables and fruits are seasonal. Seasonal excess and small shelf-life makes this crop decease [4]. Around 30 % of overall production gets spoiled at different post-harvest phases. Mostly the product gets spoiled caused by microbial action by bacteria, enzymes, yeast, and molds [5]. Food product preservation can decrease decomposition of seasonal excess, and can return high market value in term of profit through requirement [6].

Drying is one of methods for preserving the crop for a long time and makes it available throughout the year [7]. OSD is the old-style method that is mostly adopted in various tropical as well as subtropical regions of the country [8]. Therefore, the quality assessment of dehydrated products play a significant role in human beings life, and it is affected caused by environmental influences [9],[10]. Abandoned drying rate, fluctuations in climate conditions i.e. rain and dew, necessity of large floor area, more drying period, maximum labour cost are also some of limitations of OSD [11]. Various efforts have been made in developing mechanical to overcome the driers in recent year's disadvantages of natural or open sun drying. Most of this mechanical drying system needs conventional sources for their operation. As energy assets of fossil fuel are reducing at a fast rate and also these system causes pollution. Mechanical driers or drying system using the power of sun as a source of energy, and can overcome these problems [12]. Solar energy is richly available and is pollution-free. Hence solar driers are nearly attractive and sustainable. Different kinds of drying system are present for the dehydration of foodstuffs. [13], [14], [15].

After gone the literature survey, it is found that a large number of researches are done on solar dryer under free and forced mode and very few researches assisted with FPC. Also no one has reported the performance of solar dryer assisted with ETSC. The paper presents an experimental validation of drying kinetics. The ANN model is also trained and evaluated to predict the CHTC and EHTC for OSD and HGSD respectively. The error analysis shows the deviation between the experimental, calculated and ANN predicted values.

PREVIOUS STUDIES ON SOLAR DRYER

Previous study indicates that a large number of solar drying systems coupled with Flat plate collector (FPC) [16], [17], and [18]. ETSC can be the right choice for FPC solar isolation trap; ETSC is consisting of two same type glass tubes – inside as well as outside. Inside tube is glazed through selective glaze and room b/w these both tubes is evacuated. Due to the room b/w both tubes, no heat loss occur by convection as well as conduction. This phenomena increase the efficiency of this types of collectors [19], [20], [21], and therefore performance of drying system would be higher assisted with ETSC as compared to FPC in term of efficiency. A few numbers of researchers conducted investigation on drying system assisted with ETSC [22], [23]. A number of experiment have been carried out on drying behavior of different foodstuff product for example rice [1], cassava [2] ginger [24],[25] pork strips [26], prickly pear cladode [27], tomato [28], onion [29], and grapes [30], [31],[32],[33].Further, literature has also stated that no study has been conducted on the drying of mushroom in solar drying with ETC. Table1 shows the outcomes of previous research.

EXPERIMENTATION

Experimental Setup

Important component of newly developed drying system are the ETSC, greenhouse drying chamber, pump, and heat exchanger. The line diagram and pictorial view of novel dryer are shown in Figure 1, Figure 2 correspondingly. The drying system was fabricated for metrological conditions of Gwalior region Madhya Pradesh, India (26°.2183N and 78°.1828E). Dimension of the drying cabin is selected in such a manner that design aspect ratio is 3 in term of floor area to volume. Greenhouse (hut type) is higher than the drying chamber which is made up of 2.51 m 2.61 m, 1.81 m central height & elevation of sidewalls towards 1.05 m from the ground and 30-degree roof is covered by canopy cover. The new thing is in this drying system that, it is coupled with 02 ETSC in series. Ten numbers of tubes are connected in one solar collector. The space b/w inside and outside tubes to create the vacuum, and to reduce the conduction and convection heat loss The entire drying setup is installed in solar energy lab of MITS Gwalior. Facing of system in south direction to get maximum solar radiation during the whole day of experimentation. To connect the outlet of ETSC to the drying cabin, a rubber hose is used. That is made of Ethylene Propylene Diene Monomer (EPDM).

Table 1. Summary of previous studies

Sr.no.	Authors	Year	Product	Findings of Investigation
1.	Etim, Ben Eke, and Simonyan [34].	2020	Banana	Examined influence of air inlet shape as well as size on drying kinetics.
2.	Bhardwaj, Kumar, and Chauhan [35].	2019	Valerina Jatamansi	The energy efficiency of the collector increases by16.12% after using sensible heat storage material with a solar collector attached to the dryer.
3.	Sansaniwal, Kumar, and Rajneesh [36].	2017	Ginger rhizomes	Find out the drying performance of solar dryer in the terms of CHTC and Efficiency of collector under active and passive mode.
4	Kumar et al. [37].	2016	Ginger	Computed h_c and h_e for indirect dryer in active mode. h_c and h_e was calculated 3.95 and 160.97 W/m2°C respectively.
5.	Sundari et al. [38].	2014	Grapes	Experimental studies on Muscat grape kinetic drying in a solar drying with ETC.
6.	N Rajeshwari et al. [33].	2012	Grapes	Find out the low-cost material effective box-type used for the manufacture of the drying system.
7.	Wiriyaumpaiwong et al. [26]	2012	Pork strips	The experiment conducted on mathematical modeling of pork strips
8.	Zomorodian et al.[30]	2009	Grapes	Experimental study done on different drying kinetics models.
9.	Ezekoye et al. [11]	2006	Rice	Improvement as well as execution the assessment of changed incorporated passive solar grain dryer.
10.	Alakali et al. [25]	2005	Cassava	Evaluated the drying kinetics and heat transfer coefficient.

A wire and tube types of heat exchanger (2m × 0.66m) is placed inside drying cabin, and hot water is circulated in this tubes comes from the ETSC. This concept is taken in consideration to enhance the drying cabin temperature. A 12volt DC pump also used to circulate hot water from ETSC to heat exchanger in a closed loop [39].

Mass flow rate of water can be varying by using regulator valve. Two air vents also provide on the top of drying system to remove or escape the moisture from inside the drying cabin.

Measuring Instruments and Devices

A fully automatic data logger is used for measuring the data such relative humidity (Rh), ambient temperature, drying cabin temperature, solar isolation. A number of equipment (Listed in Table 2) is connected to the data logger to record the above environmental parameters. Instead of these instrument other portable measuring instrument such as weighing m/c, anemometer, and IR temperature gun also used.

Sample Preparation

Mushrooms bought from the nearby market of Morar Gwalior .These were cleaned carefully to remove floor dirt.

Experimental Method

Experimentation was conducted in month of March 2018 from 11:00 am -04:00 Pm. Data was recorded at every 1 hour interval. Mushroom samples were kept on a set of rectangular sized wire mesh tray inside the drying cabin. These trays were stored at electronic balance gadget to decide moisture content (MC) cloth elimination for each drying length. A numbers of thermocouples were placed at different locations to observe the data i.e. drying cabin temperature, crop surface temperature, floor temperature, and inlet and outlet temperature of hot water in side heat exchanger. A anemometer (least count 0.1 m/s) is used to degree air goes along with the waft simply above the product floor. Sun isolation statistics of drying days are recorded with the aid of the use of a virtual solar electricity meter. Before and after drying mushroom samples are shown in Figure 3.

Convective Heat Transfer Coefficient (CHTC)

Nusselt Number (N_u) play a vital role in the calculation of CHTC (h_c) as,

$$h_c = \left(\frac{K_v}{L_c}\right) \times N_u \tag{1}$$

Where,

$$L_c = \frac{l \times b}{2}$$

Rate of heat-absorbing,

$$q_e = 0.016 \times h_c[P(T_p) - \gamma_e P(T_e)] \tag{2}$$

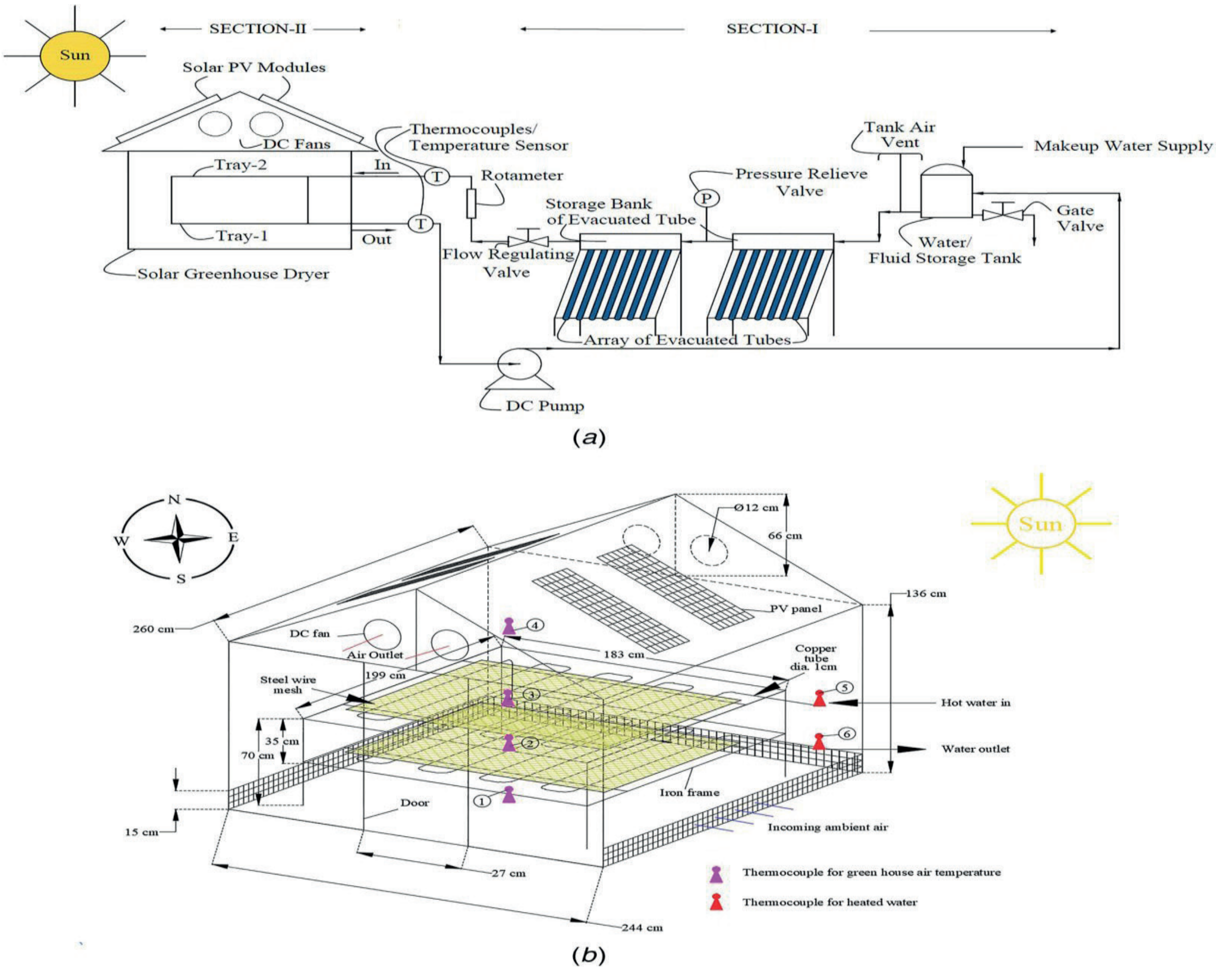

Figure 1. Schematic of HGSD systems with ETSC (Patent Application No:201921001878) [40].

Figure 2. Actual picture of novel drying system.

Table 2. Uncertainty and accuracy of different instruments

Instruments	Accuracy	Range	Uncertainty
Thermocouple	±0.1°C	−10 to 95 °C	±0.22 °C
Hygrometer (model HT-315)	0.1 %	10 % to 95 % R.H.	0.058
Weight machine		0.0001 to 20Kg	0.00055
Pyranometer (version WACO-206, least clarity ± 10 W/m²)	±10 W/m²	0–24 hours	1.41
Data logger (Make:-DataTaker; dEx Software interface)			

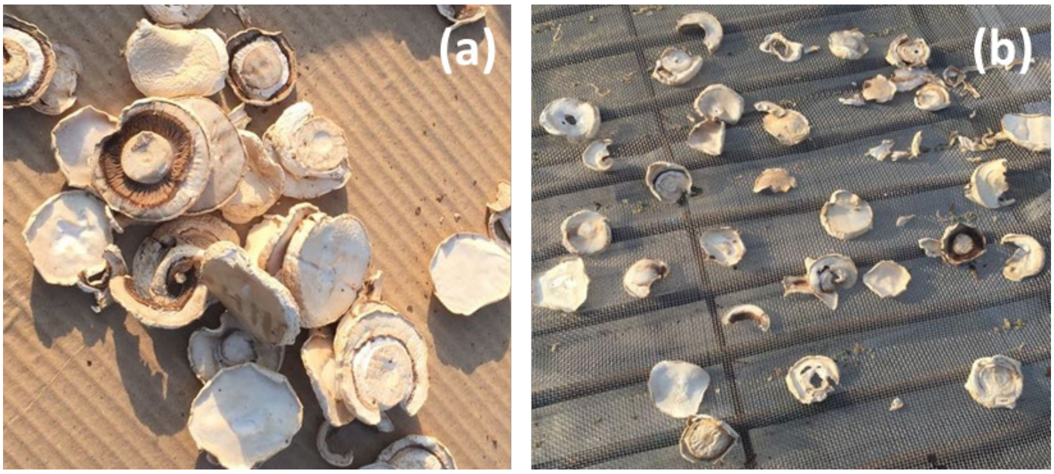

Figure 3. (a) Fresh Mushroom (b) Dried Mushroom.

Using Eq. 1 and Eq. 2,

$$q_e = 0.016 \times \left(\frac{K_v}{L_c}\right) \times \left[P(T_P) - \gamma_e P(T_e)\right] \times N_u \quad (3)$$

m_{ev} can be determined by $m_{ev} = \frac{q_e}{\lambda} \times A_t \times t$

$$m_{ev} = \left[\frac{0.016 \times \left[P(T_P) - \gamma_e P(T_e)\right] \times K_v \times A_t \times t}{L_c \times \lambda}\right] \times N_u$$

Now, in active mode Nusselt Number can be computed as:

$$\mathrm{Nu} = \frac{m_{ev}}{R} = C' \,(\mathrm{Re} \times \mathrm{Pr}) n' \quad (4)$$

Appling Log on both sides,

$$\ln[\mathrm{Nu}] = \ln C' + n' \ln(\mathrm{Re} \times \mathrm{Pr})$$

$$Y = mX + c$$

$Y = \ln[\mathrm{Nu}]$, $m = n'$, $X = \ln[\mathrm{Re} \times \mathrm{Pr}]$, $c = \ln C'$ and $C' = e^c$

Hence, constant can be computed using following relations.

$$n = \frac{N_0 \sum XY - \sum X \sum Y}{N_0 \sum X^2 - \left(\sum X\right)^2} \quad (5)$$

$$C = \frac{\sum X^2 \sum Y - \sum X \sum XY}{N_0 \sum X^2 - \left(\sum X\right)^2} \quad (6)$$

Characteristic of Air

Thermal characteristic of air could be estimated following Jain and Tiwari Model [41].

$$C_V = 999.2 + 0.143 T_i + 1.101 \times 10^{-4} T_i^2 - 6.7581 \times 10^{-8} T_i^3 \quad (7)$$

$$K_V = 0.0244 + 0.7673 \times 10^{-4} T_i \quad (8)$$

$$\beta_V = \frac{353.44}{T_i + 273.15}$$

$$\mu_V = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} T_i \quad (9)$$

$$P(T) = \exp\left[25.317 - \frac{5144}{T_i + 273.15}\right] \quad (10)$$

$$T_i = \frac{T_p + T_e}{2}$$

By using the value of h_c, h_e can also be calculated from Eq. 11,

$$h_e = 16.273 \times 10^{-3} h_c \left(\frac{P(T_p) - \gamma P(T_e)}{T_p - T_e}\right) \quad (11)$$

Mathematical Model

Moisture ratio (MR) of mushroom can be computed as [42].

$$\text{MR} = \frac{M_t - M_e}{M_i - M_e} \quad (12)$$

Where M_e – equilibrium moisture is contented; M_t – moisture contented at any instant of time t, and M_i – moisture content in the product (Mushroom) before drying. Because of long drying period value of M_e is too small, hence, it is considered as neglected [42]. The MR value is evaluated following Eq. 12 from investigational drying value data of mushroom in Hybrid solar greenhouse drying cabin.

$$\text{MR} = \frac{M_t}{M_i} \quad (13)$$

If the graph is drawn b/w observe Moisture ratio value and drying period then it gives the experimented moisture ratio (MR_{exp}) drying graph. By using various thin-layers drying kinetics models (Table 3) predicted moisture ratio (MR_{pre}) can be calculated. There are different kind's techniques to equating MR_{exp} value with MR_{exp} value for obtaining the drying kinetic behavior of drying products such as mushroom dried under specific drying environments. Statically analysis done to calculate moisture ratio for various drying mathematical model. The chi-square (χ^2), coefficient of determination (R^2) and root means square error (RMSE) is calculated for all nine models. To find the good fit drying kinetics mathematical model as well as to evaluate drying curve equation for mushroom coefficient of determination is key factor. Good-fit drying kinetics model is nominated based on maximum R^2 and lowermost χ^2 as well as RMSE value should be tended to zero [43]. This can be estimated as

$$R^2 = \frac{\left(\sum_{i=1}^{N} \text{MR}_{\exp,i} \text{MR}_{pre,i}\right)^2}{\sum_{i=1}^{N} \text{MR}_{\exp,i^2} - \sum_{i=1}^{N} \text{MR}_{pre,i^2}} \quad (14)$$

Table 3. Thin- layers Kinetics mathematical models [42].

Model Name	Equation
Lewis	M.R = exp(−kt)
Henderson and pabis	M.R = a exp(−kt)
Page	M.R = exp(−kt^n)
Modified page	M.R = a exp(−kt^n)
Logarithmic	M.R = exp(−kt) + c
Wang and Singh	M.R = 1 + at + bt^2
Two term	M.R = a exp(−k_0t) + c exp(−k_1t)
Approach of diffusion	M.R = a exp(−kt) + (1 − a) exp(−kbt)
Midili-Kucuk	M.R = a exp(−kt^n) + bt

$$\chi^2 = \frac{\sum_{i=1}^{N} (\text{MR}_{pre,i–}\text{MR}_{\exp,i})^2}{N - n'} \quad (15)$$

$$\text{RSME} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2} \quad (16)$$

Experimental Uncertainty Analysis

The experimental observation of open sun drying and hybrid greenhouse solar drying were measured using different equipment's. Uncertainty of relative humidity (Rh), solar radiation, air flow rate, ambient temperature, and MC has been taken in consideration during the designing of drying system.

Let various independent parameters x_1, x_2, x_3……….. x_n influences some output R, & w_R is elaborate uncertainty, hence w_1,w_2,w_3……….w_n be uncertainty in independent variables [44].

Where, $U(Y)$ is the uncertainty in the measured function and $u(x_1)$……$u(x_n)$ is the uncertainties in independent parameters (x_1……x_n), affecting function Y in Eq.17.

$$U(Y) = \left[\left(\frac{\partial Y}{\partial x_1}\right)^2 u^2(x_1) + \left(\frac{\partial Y}{\partial x_2}\right)^2 u^2(x_2) + \ldots\ldots\ldots + \left(\frac{\partial Y}{\partial x_n}\right)^2 u^2(x_n)\right]^{1/2} \quad (17)$$

The resultant uncertainty in the calculation of drying temperature can be evaluated as,

$$U_T = [(U_{\text{Thermocouple}})^2 + (U_{\text{connection point}})^2 + (U_{\text{reading}})^2]^{0.5}$$

$$U_T = [(0.25)^2 + (0.1)^2 + (0.1)^2]^{0.5} = 0.287$$

The resultant uncertainty in calculation of *Rh* (U_{Rh}) can be expressed as,

$$U_{Rh} = [(U_{\text{Hygrometer}})^2 + (U_{\text{reading}})^2]^{0.5}$$

$$U_{Rh} = [(0.20)^2 + (0.1)^2]^{0.5} = 0.223$$

The resultant uncertainty in calculation of air flow rate ($U_{\text{a.v}}$) can be written as

$$U_{\text{a.v}} = [(U_{\text{Anemometer}})^2 + (U_{\text{reading}})^2]^{0.5}$$

$$U_{\text{a.v}} = [(0.1)^2 + (0.1)^2]^{0.5} = 0.14$$

The resultant uncertainty in calculation of MC ($U_{\text{moisture content a.v}}$) can be described as

$$U_{\text{moisture content}} = [(U_{\text{Digital balance}})^2 + (U_{\text{reading}})^2]^{0.5}$$

$$U_{\text{moisture content}} = [(0.01)^2 + (0.1)^2]^{0.5} = 0.100$$

The resultant uncertainty in the calculation of Solar Radiation ($U_{\text{solar intensity}}$) can be evaluate as,

$$U_{\text{Solar Intensity}} = [(U_{\text{Pyranometer}})^2 + (U_{\text{reading}})^2]^{0.5}$$

$$U_{\text{Solar Intensity}} = [(1.0)^2 + (1.2)^2]^{0.5} = 1.41$$

Total uncertainty in experimentation is calculated as:

$$U_{\text{Exp}} = [(U_T)^2 + (U_{Rh})^2 + (U_{\text{a.v}})^2 + (U_{\text{moisture content}})^2 + (U_{\text{Solar Intensity}})^2]^{0.5}$$

$$U_{\text{Exp}} = [(0.287)^2 + (0.223)^2 + (0.14)^2 + (0.100)^2 + (1.41)^2]^{0.5} = \pm 1.46$$

RESULTS AND DISCUSSION

Throughout experimentation process, solar intensity varied from 100–800W/m^2. A little variation is occurred in solar radiation intensity due to sudden cloud cover. Inside greenhouse air temperature does not vary due to the use of ETSC. The atmospheric temperature fluctuated between 20.0 and 36.0°C and inside greenhouse air temperature maintained between 29 to 69.2°C. The relative humidity varied in the atmospheric condition ranged between 32% and 42.5% and in the drying chamber maintained between 30% and 42.2%. The mushrooms dried at the temperature of 15–25°C more than the air temperature. The preliminary moisture content in mushroom was 80.6 % on wb and dry up to it got absolute moisture content 2.9% on wb. The variation in Rh and solar intensity in open sun drying (OSD) and hybrid greenhouse solar dryer (HGSD) are shown in Figure 4. The mushroom mean surface temperature T_m and temperature above the mushroom T_c variation during drying is given in Figure 5.

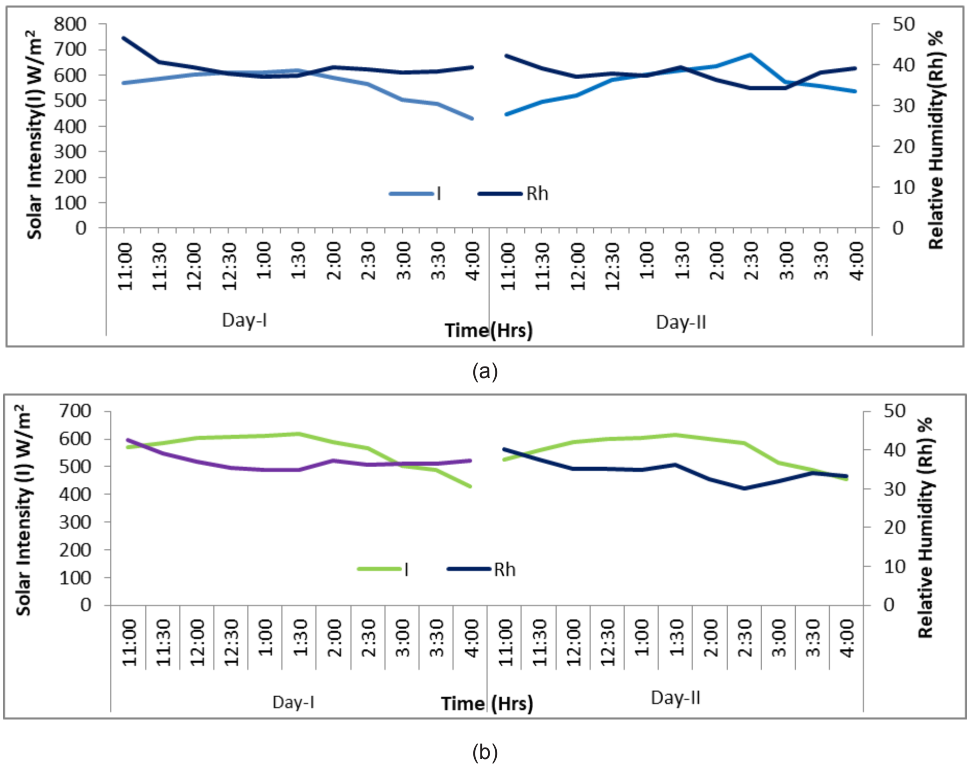

Figure 4. Experimental data of solar radiation intensity (I) and Relative humidity (Rh) in (a) OSD and (b) HGSD.

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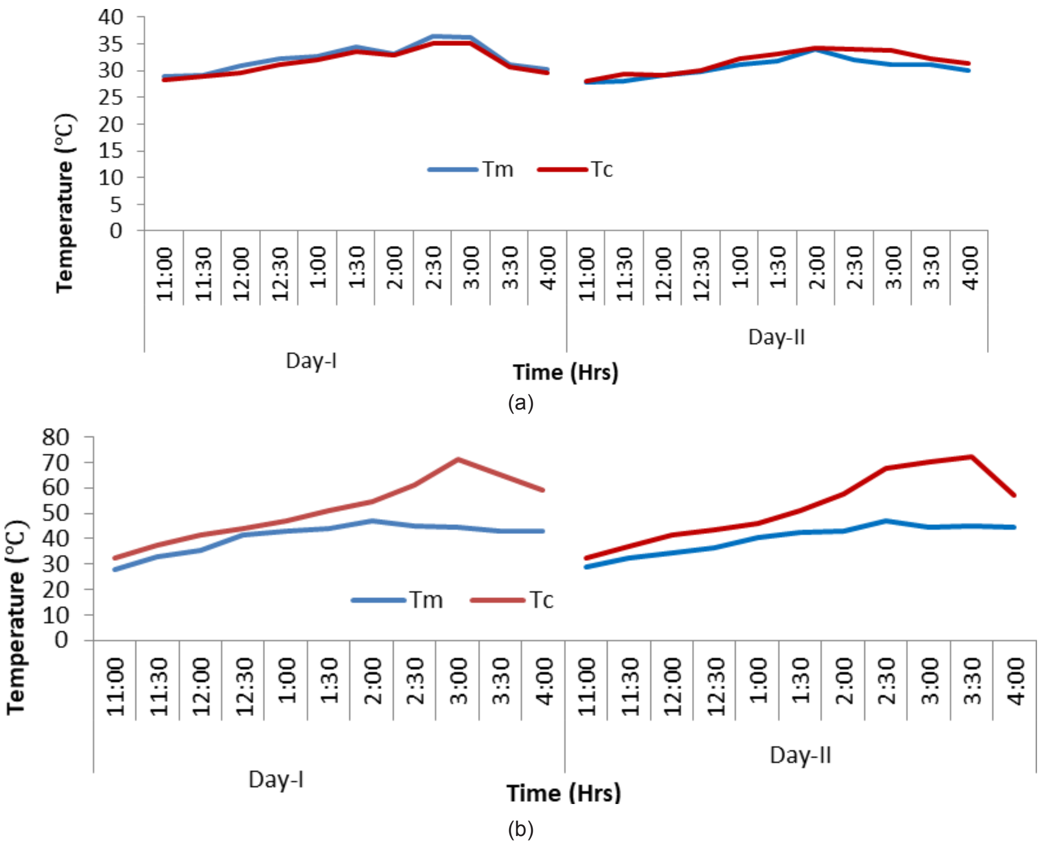


Figure 5. Variation of mean surface temperature T_m and temperature above the mushroom T_c during drying in (a) OSD and (b) HGSD.

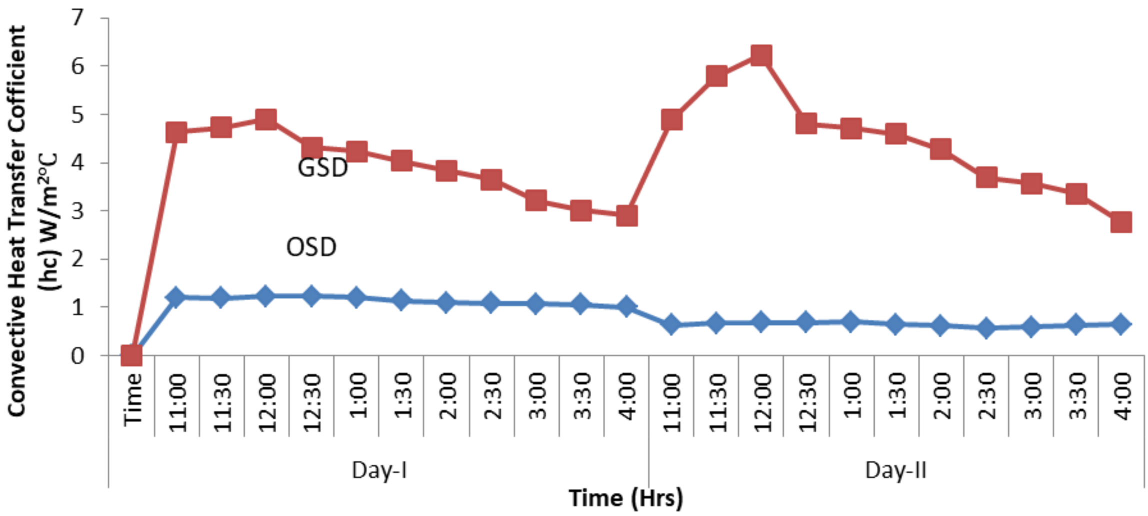


Figure 6. Variations of CHTC (h_c) in open sun drying (OSD) and HGSD.

The experimental observed value of mean surface temperature (T_m) of mushroom and air temperature (T_c) above the mushroom in the drying chamber of HGSD, and inside air relative humidity of dryer were used to find out thermal physical property of humid air inside HGSD by following Eq. (discussed in Table 2). These were data used to evaluate Reynolds number and Prandtl number (Pr). Then Prandtl number was calculated 0.696 within the limit of ambient temperature. By following the Nusselt No-(Nu) Correlations (Eq no.) value of CHTC (h_c) was calculated at

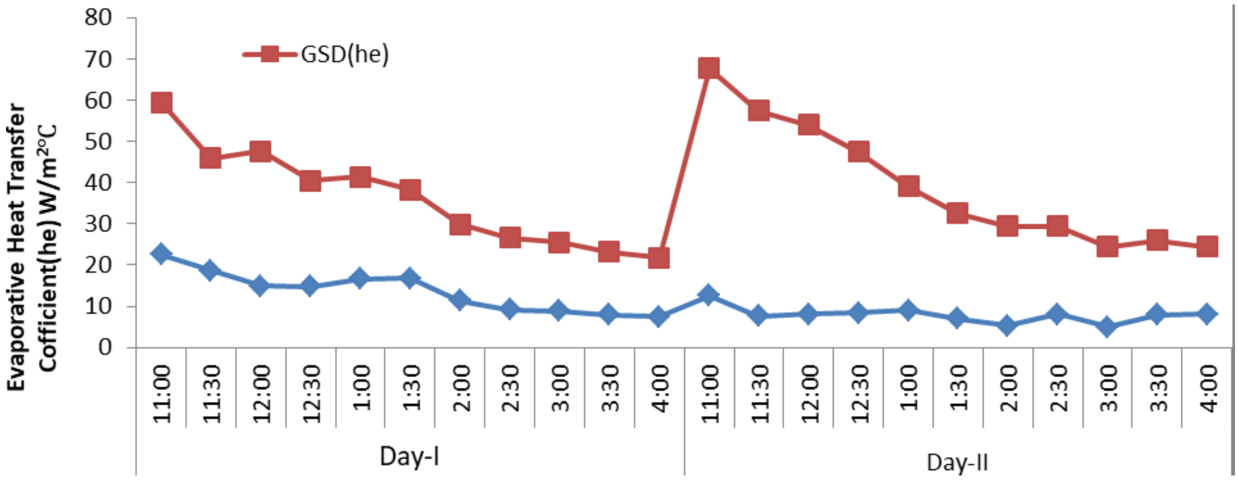


Figure 7. Variations of EHTC (h_e) in open sun drying (OSD) and HGSD.

Table 4. Summaries of h_c and h_e estimated from the experimental drying value of mushroom in HGSD

Product	C	n	CHTC (h_c) W/m² °C	EHTC (h_c) W/m² °C
Mushroom	0.21	0.32	3.43	49.85

half hours intervals. The constant *c* and *n* depend upon the thermal and geometry parameters of HGSD, and also vary with the orientation of HGSD. It may be evaluated from regression analysis. Variations of h_c in open sun drying (OSD) and HGSD is shown in Figure 6.

The value of CHTC (h_c) for mushroom fluctuate between 1.2 – 0.64 W/m²°C for OSD and 3.43 – 2.34 W/m²°C for HGSD. The quantity of H.E is necessary for moisture evaporation (Q_e) can be determined by Eq.3. The quantity of moisture evaporated plays a role in finding out the EHTC (h_e) from the surface of the mushroom. EHTC (h_e) lies between 8.16 – 22.54 W/m²°C and 49.85 – 16.32 W/m²°C. The variation in EHTC with respect to drying period was detected to be greater than CHTC as demonstrate in Figure 7. The maximum EHTC was achieve b/w 12:00 to 02:00 PM due to increasing in solar intensity during experimentation. Summary of h_c & h_e, estimated from the investigational drying value of mushroom in HGSD is discussed in Table 4.

Drying Performance

The drying performance of the HGSD in terms of mass reduction in comparison with OSD is shown in Figure 8.

The curve was plotted M.R vs. drying period is displayed in Figure 9 in which amount of M.R is removed from the mushroom dried. M.R is directly related to drying air temperature, that is also depend on the solar radiation as well as dimension (characteristic length) of dried product. Likewise, EHTC also related to the air flow rate

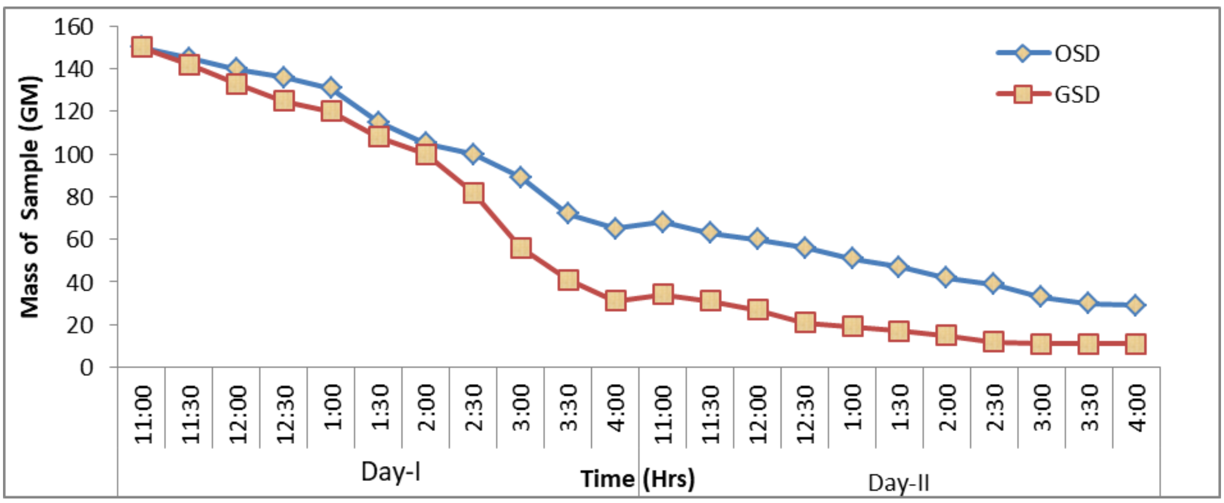


Figure 8. Drying performance of the HGSD in terms of mass reduction in comparison with OSD.

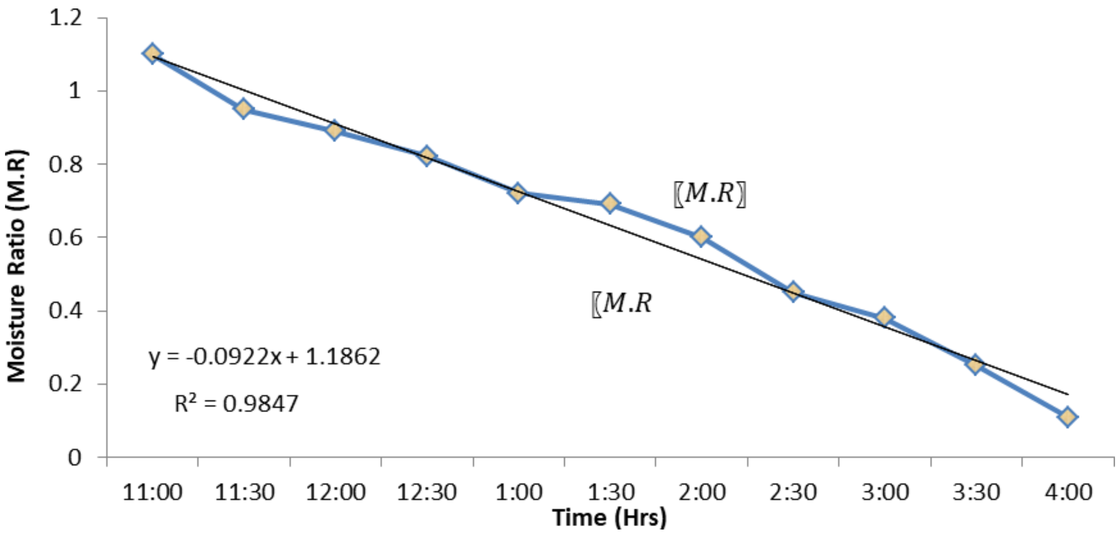


Figure 9. $M.R_{exp}$ equated with Midili-Kucuk model (MKM).

Table 5. Model Used to experimentally drying graph

Model Name	Equation	*a*	*b*	*K*	*n*
Midili-Kucuk Model (MKM)	$M.R = a\ \exp(-kt^n) + bt$	1.004	–.014	.84	.75

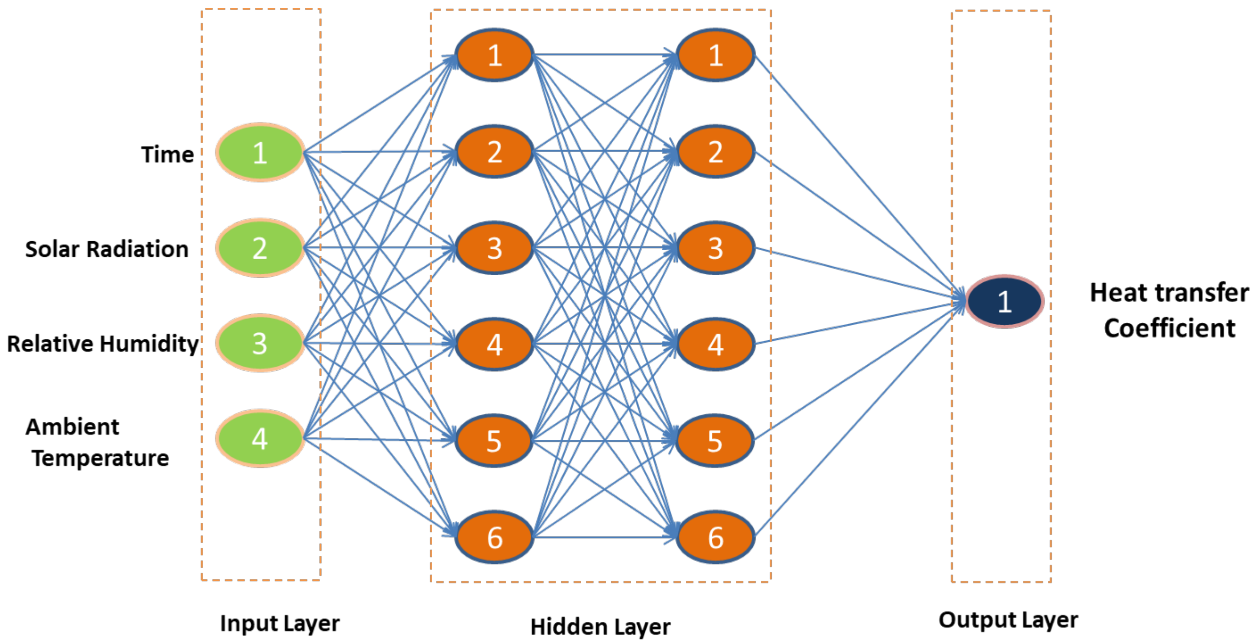


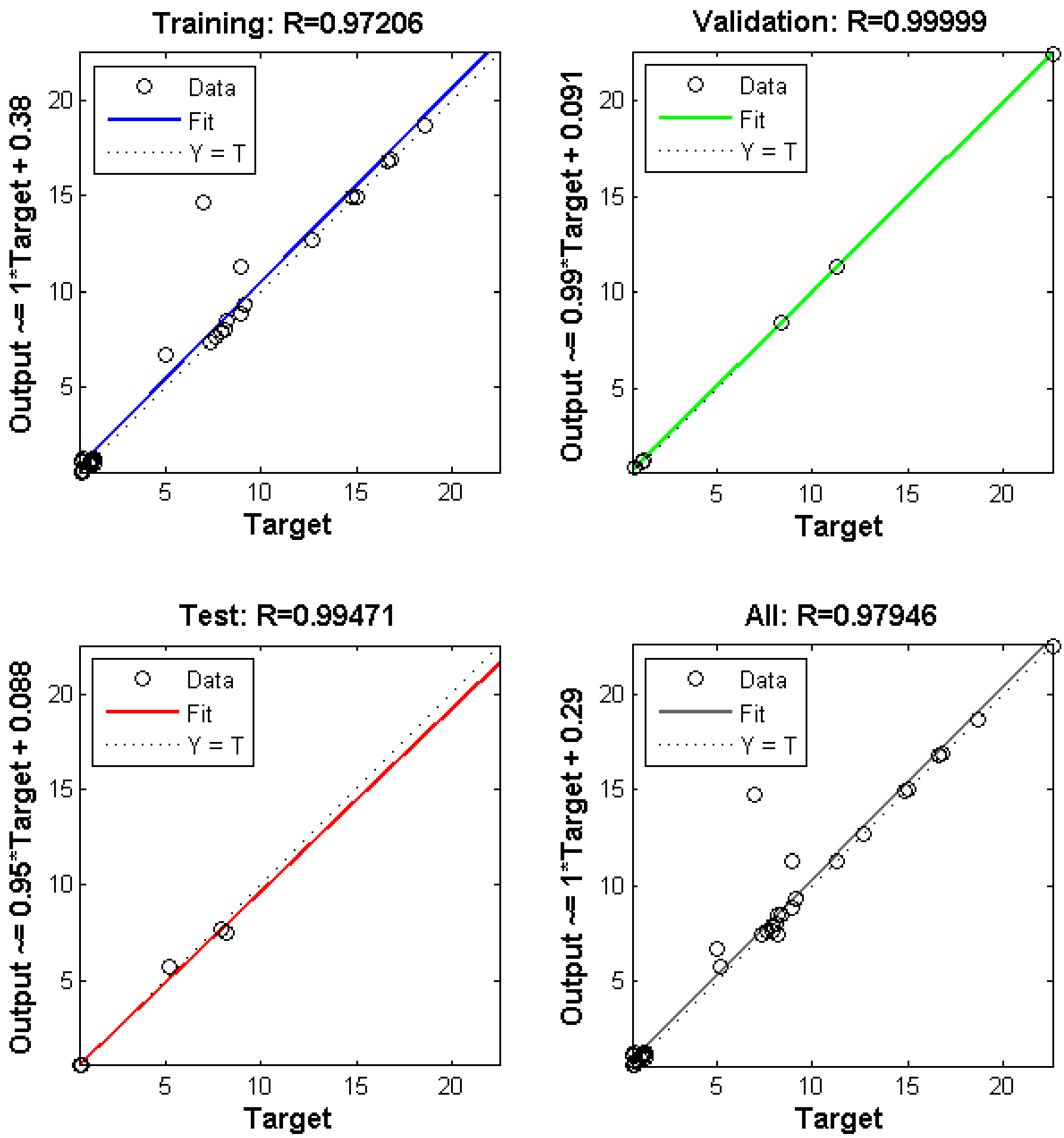
Figure 9. Configuration of ANN for predicts HTC.

and partial pressure of water vapor. Drying air temperature, air velocity, and characteristic length of mushroom play a significant role in deciding value of drying rate as well as EHTC. The internal uncertainty has been calculated for experimental measurement throughout drying of mushroom. External uncertainty has been carried out for error throughout observation of temperature, Rh, m_{evp}. The overall percentage of uncertainty was evaluated as ±1.46%. The experimentally observes that $M.R_{exp}$ decrease slowly with rise in time. Higher value of R^2, and lower value of χ^2 and RMSE b/w observed value of mushroom vs. drying period and those models that provide the optimum $M.R_{pre}$.

The most suitable model of dried mushroom was found to be Midili-Kucuk model (MKM) with R^2 = 0.99847, χ^2 = 0.00043, and RMSE = 0.0304. Therefore drying kinetics performance of mushroom in HGSD is defined by the MKM (Discussed in Table 5).

Artificial Neural Network Model (Ann)

In the present study to predict the CHTC and EHTC for the case of OSD and HGSD, the neural network is trained and evaluated using the neural network toll in MATLAB R2014a. To train the network, drying period, atmospheric air temperature, Rh, and solar intensity are provided as the input value, and experimentally observed CHTC and EHTC are taken as the target value. By the hit and trial method, it was observed that the model performed better in two hidden layers with six neurons in each layer. Also, the Log function is found suitable for the first layer while the Tan function for the second hidden layer. The multilayer feed-forward back-propagation method and Leven berg-Marquardt Learning algorithm are used in the trained network [45], [46]. The Epoch has been kept to 10,000 and 300 validation check has been done to train the network so



(a)

Figure 10. Validation of CHTC and EHTC for optimal topologies (a) for OSD (b) For HGSD.

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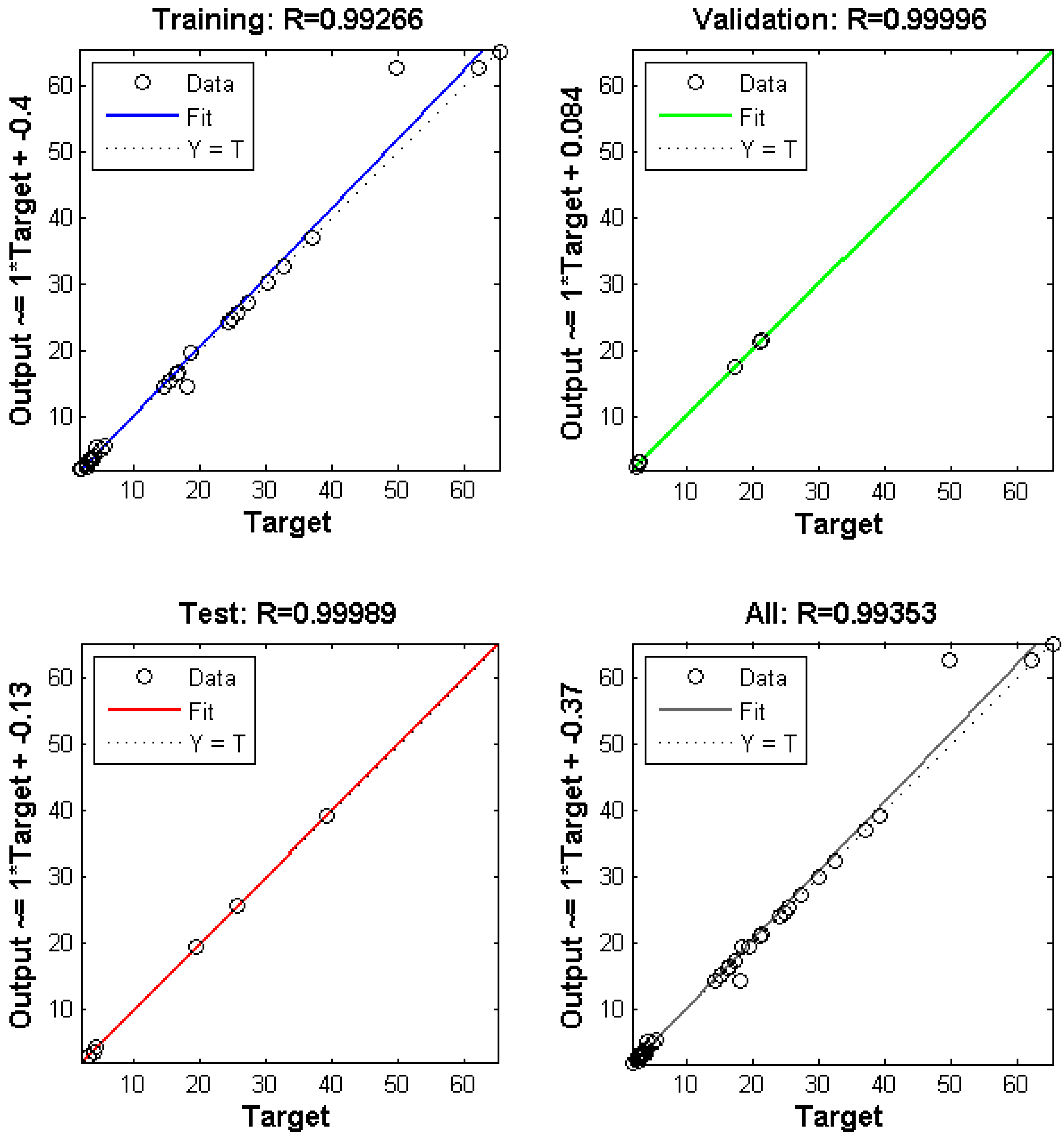

(b)

Figure 10. Continued

it can predict the close result [47]. The configurations of the artificial neural network to validate heat transfer coefficient is shown in Figure 9. Relationships b/w experimental as well as predicted values of CHTC and EHTC for optimum topologies (a) For OSD (b) For HGSD is shown in Figure 10.

The coefficient of correlation for training, validation and testing of data are 0.97206, 0.9999, and 0.9947 correspondingly for OSD. Coefficient of correlation for the overall data set is 0.97946. As the coefficient of correlation is very close to 1, this indicates that ANN shows good relation with the experimental value and predicting the very close to results. Similarly the coefficient of correlation for training, validation and testing of data are 0.99266, 0.99996, and 0.99989 correspondingly for HGSD. Coefficient of correlation for the overall data set is 0.99353. As the coefficient of correlation is very close to 1, this indicates that ANN shows good relation with the experimental value and predicting the very close to results.

CONCLUSION

CHTC and EHTC play a vital role in moisture removal rate (MRR) from the dried product. It is found that EHTC is directly proportional to solar radiation. As the solar intensity increased ambient air temperature also increased. During experimentation, the maximum values of h_c and h_e is 3.43 and 49.85 W/m^2°C. In novel drying system, inside room temperature is higher than the atmospheric air temperature by 12–25°C. High room temperature inside the HGSD assisted with ETSC decreases the drying period by 60% in comparison to OSD. MKM gives the good fit for the thin layer drying kinetics of mushroom dried in HGSD. The ANN model predicts the CHTC and EHTC very close to calculated value as value of R^2 is 0.99. The ANN reduces the effort required in doing the mathematical calculations and the make the determination of heat transfer coefficient easier. Although the ANN model can be made more accurate by using the large input data set for training the model.

ABBREVIATION

A_t	Area of tray (m^2)
c	Constant
C_v	Specific heat of humid air (J/kg°C)
G_r	Grashof number $= \frac{g\beta L_c^3 \rho_v^2 \Delta T}{\mu_v^2}$
K_v	Thermal conductivity of humid air (W/m°C)
L_c	Characteristic length (m)
T_c	Above mushroom surface temperature (°C)
T_m	The temperature of mushroom (°C)
Re	Reynolds number $= \frac{\rho_{Vvd}}{\mu_v}$
t	Time (sec)
HTC	Heat Transfer Coefficient
H.E	Heat Energy
β	Coefficient of volumetric
γ	Relative humidity (%)
σ	Surface tension of liquid vapor
λ	Latent of Heat of Vaporization
U_v	Dynamic viscosity (kg/m sec)
ρ_v	Density (kg/m^3)
RMSE	Root mean square error
R^2	Coefficient of determination
χ^2	Chi-square
M.R	Moisture Ratio
$M.R_{exp}$	Moisture Ratio experimental value
$M.R_{pre}$	Moisture Ration predict the value
OSD	Open sun drying
HGSD	Hybrid Green House Dryer

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