International Journal of Advance Research in Science and Engineering
Volume No 06, Special Issue No. (02), September 2017, ICITTESE-17
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Comparison of thin layer drying process in solar dryer and under open sun

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ABSTRACT

Present work involves experimental investigation of drying characteristics of red chili. In this study, an indirect-type forced convection solar dryer consisting of solar air heater and drying chamber was developed and used in the experiments. An experimental study was performed to determine the thin layer drying characteristics in a solar dryer and under open sun with natural convection of red chili. The drying data were fitted into four different thin layer drying models by using software originpro 8.5. The performance of these models was investigated by comparing the coefficient of determination (R^2), reduced chi-square(X^2) and root mean square error (RMSE) between the observed and predicted moisture ratio. Among these models, Wang and Singh model was found best to explain the thin layer behavior of red chili.

Keywords: convection solar dryer; natural convection; root mean square error; moisture ratio

I. INTRODUCTION

Drying is an important technique to remove the moisture of the product by the virtue of heat and mass transfer. It is also one of the important methods for the conservation of agricultural product. Drying is an effective method to minimize post-harvest loss. Prime objective of drying is to extend storage life of the product and to improve quality of the product. There are various drying techniques to dry different agricultural products. Each technique has its own advantage and limitation. So, choosing the right drying techniques is very important in the process of drying. Present work is based on the drying by using solar energy. Solar energy for crop drying is environmentally friendly and economically viable in developing countries. The raw agricultural products with 80-90% initial moisture content are brought down to equilibrium moisture content for keeping in the short or long term storages was done by open sun drying and solar drying

In India, chilies are traditionally sun dried. The farmers expose their chilies to the open sun on a mat, earthen floor, and cemented floor. In this method, drying cannot be controlled and a relatively poor quality dried product is obtained. Drying rate is very slow depending on the weather conditions. In this traditional sun drying method, chilies become contaminated with dust, dirt, rainfall, animals, birds, rodents, insects and microorganisms. Under these conditions, losses are very high. Therefore to avoid the problem occurred in open sun drying, solar drying is used. Solar drying is an efficient system of utilizing solar energy in which products are dried under controlled atmosphere.

The study of thin layer drying behavior of different product has been subject of interest for various investigators on both theoretical and application grounds during past many years. There have been many studies on drying behavior of various vegetables and fruits such as red pepper (Akpinar, E.K., Bicer, Y. &Yildiz, C, 2003) long green pepper (Akpinar E.K. & BicerY, 2008), Rough Rice (Zaman M.L. & Bala B.K, 1989), sultana grapes

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

(Yaldız, O., Ertekin, C. & Uzun,2001), chili pepper (Akintunde T.Y, 2011), Hot Chili (Hossain M.A. & Bala B.K, 2007), eggplant (Ertekin C. & Yaldiz, O, 2004), Apple (Meisamiasl E. & Rafiee S, 2009), potato slices (Aghbashlo M, Kianmehr M.H., & Arabhosseini A, 2009), Soya bean (Rafiee, Sharifi M, JafariA, Mobli H. & Tabatabaeefar, 2009), black tea (Panchariya, P.C., Popovic, D.& Sharma, A.L., 2002). Present work is emphasized on drying behavior of red chili. Red chili is an important spice and condiment in the tropics and subtropics. It is an important item in the kitchen for every day cooking in India. Red chili is dried to make chili powder and to store it for both short and long term storage. A large quantity of chili is lost during the production season when the supply is abundant due to storage problem. Farmers do not get a proper return from their harvest during the peak period of harvest due to the low market price of the abundant supply of chili. Sometimes they just have to sell the fresh chili at a price far below the production cost, whereas, the price of dried chili always remains high even at the harvesting season. In this study thin layer drying behavior of red chili in a solar dryer has been investigated and mathematical modeling by using thin layer drying models from the literature has been performed.

II. MATERIALS AND PROCEDURE

A. Experimental set up

The experimental set up mainly consists of an indirect forced convection solar dryer with a solar air heater (1000mm×300mm), a suction fan and a drying chamber. The air heater is connected to the drying chamber through 75.5 mm PVC pipe insulated with polyurethane foam. The solar air heater is constructed from the locally available wooden material. The heater consists of two aluminum plate of thickness 0.5 mm. One of the aluminum plates is painted black and used as an absorber plate. The other plate is used as bottom plate. The plates are fitted into a rectangular box made of plywood and wood. The top surface of the wooden box is fitted with a 4 mm transparent glass. The gap between the transparent glass, the absorber and the bottom plate is same and is equal to 6 mm. The absorber plate is directly exposed to the solar radiation. The coating of the absorber plate enhances the absorptivity. The solar heater is designed as double-pass which is 10-15% more efficient than a single pass solar air heater. The solar air heater was oriented southwards with the collector angle of 21^0. This angle was fixed by the support of stand. The stand was made of wood.

Drying chamber has a trapezoidal structure made up of wooden material provided with exhaust fan at the top on the back side of the chamber. The size of the drying chamber is (0.3 ×0.3 × 0.6) m^3. Drying trays of steel wire mesh are provided to the chamber. One side of the drying chamber is of hinge type which facilitates the in and out of the tray from the drying chamber. Hot air coming out of the solar air heater via PVC pipe enters in to the drying chamber through a hole of 75.5 mm diameter provided at the bottom of the chamber. The sides of the drying chamber are insulated with polyurethane foam to minimize the heat loss. The suction fan operates at a constant speed of 2300 rpm at the rated power of 55 Watts. Sweep of the exhaust fan is 230 mm and it works on the range of 220-240 volt and AC supply of 50 Hz.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

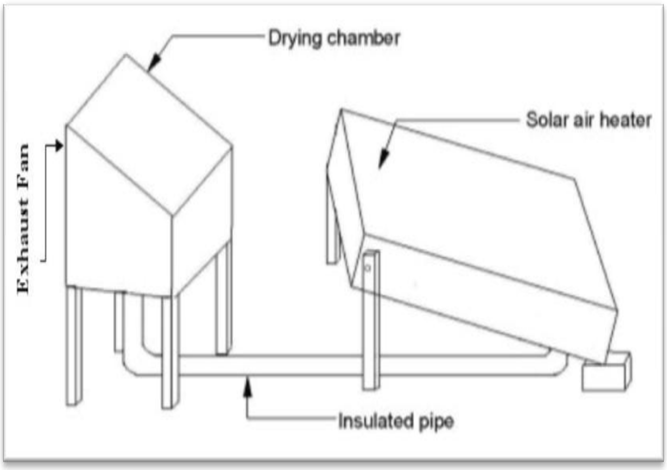

Fig 2.1 Schematic view of the experimental setup

B. Experimental procedure

Fresh red chili samples obtained from local market were used. Generally, samples of uniform size were selected. Solar drying experiments were performed during periods of October-November 2015 in Raipur, India. Raipur has a tropical wet and dry climate (Latitude 21°.25'N and Longitude 81°.63'E) and 298 m above sea level in central part of India.

In the experiments, temperature at the inlet and outlet of the solar air heater, temperature at the various point of the drying chamber were measured. The exhaust fan running at a constant speed mounted on the drying chamber sucks control amount of air which is heated up by the solar heater by trapping solar energy. The temperature of the air in the solar air heater depends upon the solar radiation intensity. Hot air from the solar air heater is passed to the dryer. Weight loss of the chili was measured at a regular interval of time of 1 hr. Reduction in weight of the chili provided the amount moisture removed during the drying process. Drying process was continued till the moisture content of the chili was reduced up to 10% on wet basis.

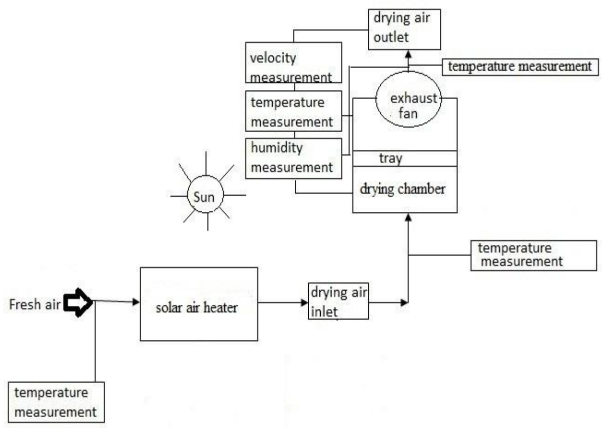

Fig. 2.2 Flow diagram of thin layer forced solar drying process

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ISSN (O) 2319 - 8354
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III. MATHEMATICAL PROCEDURE OF DRYING CURVES

Mathematical modeling of the red chili was done on the basis of drying characteristics obtained from the experimental investigation. Thin layer drying requires some of the important parameters to get the drying characteristics of the product.

C. Abbreviations and Acronyms

a, b, c, g, h, n : - Empirical constants in the drying models
k, k_0, k_1 : - Empirical constants in the drying models
n : - Number constants
N : - Number of observations
MR : - Moisture ratio
MRexp : - Experimental moisture ratio
MRpre : - Predicted moisture ratio
M : - Moisture content, (% dry basis)
Me : - Equilibrium moisture content, (% dry basis)
Mo : - Initial moisture content, (% dry basis)
Mt : - Moisture content at t (% dry basis)
M_{t+dt} : - Moisture content at t+dt (% dry basis)
t : - Time, (min)
T : - Temperature, (^{0}C)
Tabs : - Absolute temperature, (K)
wb : - Wet Basis
db : - Dry basis
RMSE : - Root mean square error

D. Important Parameters

- Moisture content

The quantity of moisture present in a material can be expressed either on the wet basis or dry basis and expressed either as decimal or percentage. The moisture content on the wet basis is the weight of moisture present in a product per unit weight of the un-dried material, represented as,

$$M_{wb} = (w_0 - w_d) / w_0 \qquad (1)$$

While the moisture content on the dry basis is the weight of moisture present in the product per unit weight of dry matter in the product and represented as,

$$M_{db} = (w_0 - w_d) / w_d \qquad (2)$$

The moisture contents on the wet and dry basis are inter-related according to the following equation,

$$M_{wb} = 1 - [1/(M_{db} + 1)] \qquad (3)$$

- Equilibrium moisture content (Me)

  A crop has a characteristic water vapor pressure at a particular temperature and moisture content. The equilibrium moisture content is the moisture content at which the product is neither gaining nor losing moisture. It is a dynamic equilibrium which changes with relative humidity and temperature.

- Moisture ratio (MR)

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ISSN (P) 2319 - 8346

Moisture ratio is one of the important criteria to determine the drying characteristics of agricultural product. MR can be determined according to external conditions. If the relative humidity of the drying air is constant during the drying process, then the moisture equilibrium is constant too. In this respect, MR is determined as in Eq. (4).

$$MR= (M_t-M_e) / (M_0-M_e) \qquad (4)$$

If the relative humidity of the drying air continuously fluctuates, then the moisture equilibrium continuously varies so MR is determined as in Eq.(5) given by Diamante and Munro[26]

$$MR= M_t/ M_0 \qquad (5)$$

- Drying rates

Drying rate is expressed as the amount of evaporated moisture over time.

$$\textbf{Drying rate} = (M_{t+dt} - M_t) /dt \qquad (6)$$

Where M_{t+dt} & Mt (g water /g dry matter h) are the moisture content at the moment t and the moisture content at the moment t+dt, respectively.

E. Determination of appropriate model:

Mathematical modeling of the drying of chili often requires the statistical methods of regression and correlation analysis. Thin layer drying equations require MR variation versus time'‘t’. Therefore, MR data plotted with time t and curve fitting was done for the models shown in Tab. 3.1. The validation of models can be checked with different statistical methods.

Table 3.1 Thin layer drying curve models

Model no.	Model name	Model	References
1	Newton	MR=exp(-kt)	Mujumdar [10]
2	Page	$MR=exp(-kt^n)$	Diamante and Munro [6]
3	Henderson and Pabis	MR=a exp(-kt)	Zhang and Litchfield [16]
4	Wang and Singh	$MR=1+at+bt^2$	Wang and Singh [13]

The coefficient of determination ($R^{2)}$ is one of the primary criteria to select the best model compare with the experimental data. In addition to R^2, reduced chi-square (X^2) and root mean square error (RMSE) are also be used to compare the goodness of the fit.

Reduced chi-square (X^2)

$$X^2 = \frac{\sum_{i=1}^{n_1} (MR_{exp,i} - MR_{pre,i})^2}{N - n_1} \qquad (7)$$

Root mean square error (RMSE)-

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

$$RMSE = [\sum_{i=1}^{N}\frac{1}{N}(MR_{exp,i} - MR_{pre,i})^{2} \quad (8)$$

IV. RESULTS AND DISCUSSION

Drying characteristics of red chili

The variation of moisture content of 300 g of red chili with drying time is shown in Fig. 4.1. The final moisture content (10% wb) of the chili was achieved in 27 h in solar dryer, while it was achieved in 38 h in open-sun drying. The open-sun drying took more time to reach the final moisture content due to slow drying rate. It is observed that the drying of chili occurred only in the falling rate period and the constant rate period was completely absent in the drying period.

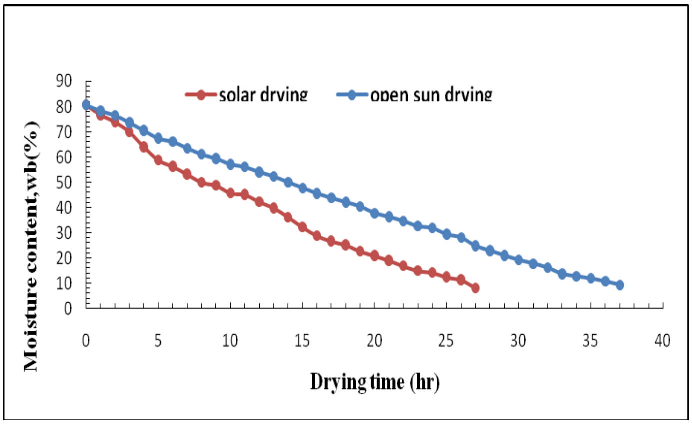

Fig.4.1 Moisture content variation with drying time on wet basis.

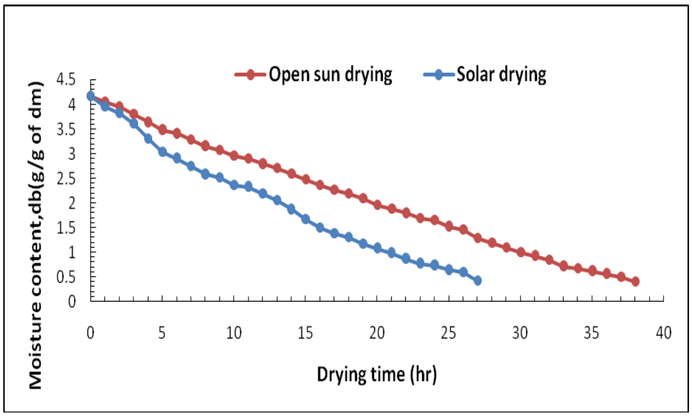

Fig.4.2 Moisture content variation with drying time on dry basis.

The variation of drying rates with drying time is shown in Fig. 4.3. It is obvious that the drying rate in solar drying is faster than the open-sun drying, and the drying rates decrease continuously with drying time. The drying rate is found to be fluctuating in nature both in the solar drying and the open-sun drying, which is mainly caused by variation of solar radiation during the experiment. During summer, solar radiation changes frequently due to clouds in the sky. The drying rate in solar drying is faster than the open-sun drying till the first 18 h of the drying hour. However, the drying rate in the solar drying is almost same as the open sun drying in the later part of the drying hour.

Modelling of moisture ratio according to drying time for thin layer drying

Open sun drying of Red chili

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

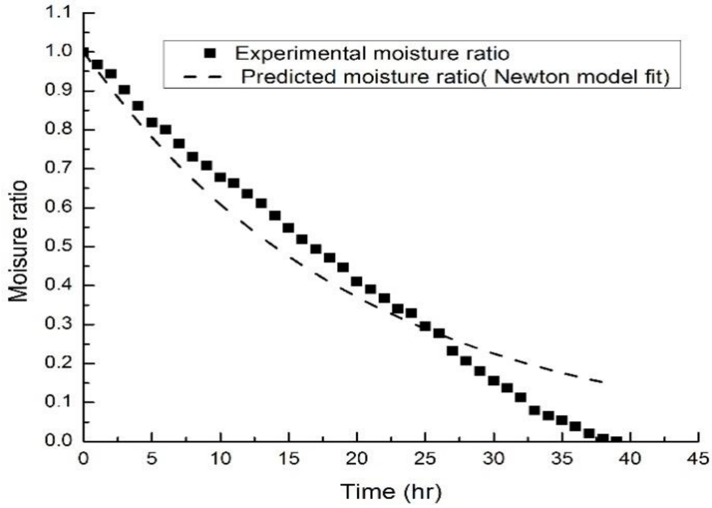

Fig. 4.4 Newton model fit

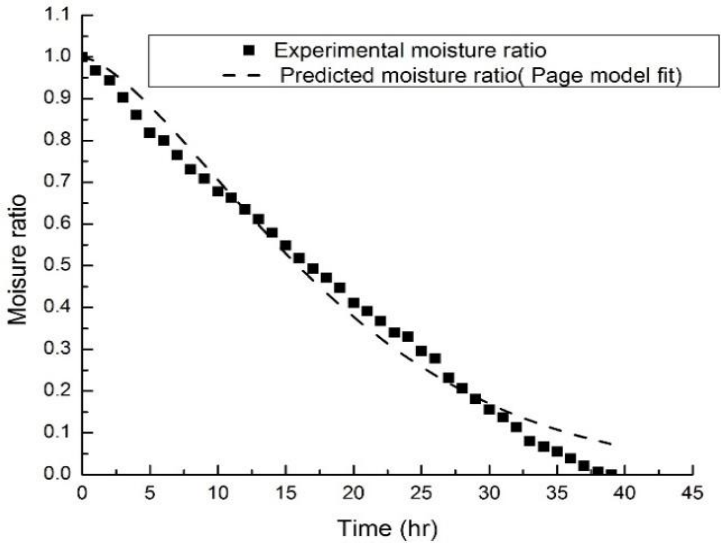

Fig. 4.5 Page model fit

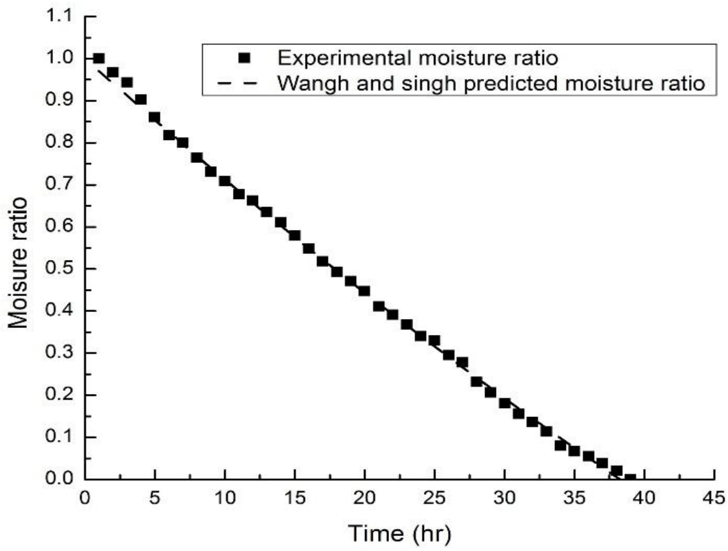

Fig. 4.6 Wang and singh model fit

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ISSN (O) 2319 - 8354
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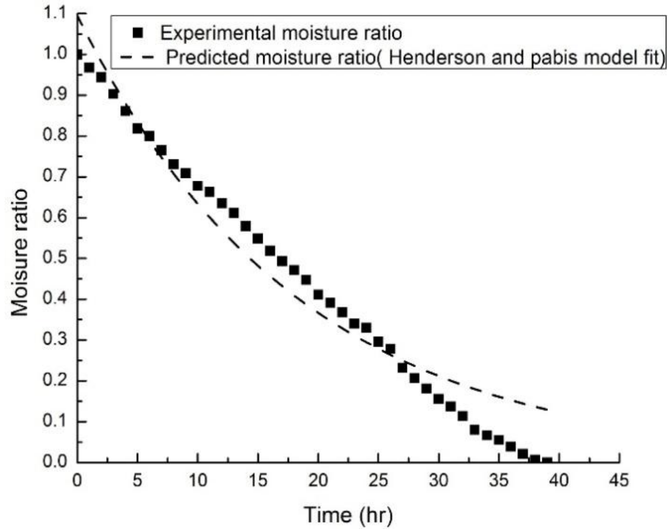

Fig. 4.7 Henderson and pabis model fit

Table 4.2 Results of the fitting statistics of various thin layer models for solar drying.

Model no.	Model name	Coefficients and constants	R^2	X^2	RMSE
1	Newton	k=0.07696	0.96307	0.00339	0.05822
2	Page	K=0.03325,n=1.31756	0.98626	0.00126	0.03551
3	Henderson and Pabis	a=1.07169,k=0.08277	0.96916	0.00283	0.05321
4	Wangh and Singh	a= -0.05515,b=0.0007045	0.99646	0.00032	0.01802

Fitting of the four thin layer drying models has been done with the experimental data of chili drying using open sun and solar drying. Drying models which were fitted with the experimental data of drying were the Newton, Page, Henderson and Pabis, and Wangh and Singh model. Drying experimental data fitted the model of drying in the form of changes in moisture ratio versus drying time. These drying models were fitted into experimentally obtained moisture ratio versus drying time curve with the help of origin pro 8.5 software. The results of the statistical analysis undertaken on these models for open sun drying and solar drying are given in table 4.1 and 4.2.The models were evaluated based on R^2, X^2 and RMSE .The model which was having the higher value of R^2 and the lower values of X^2 and RMSE was selected to better estimate the drying curve.

For the thin layer open sun drying of red chili Wang and Singh model gave R^2 =0.99876, X^2 =0.000115 and RMSE=0.01072. For the thin layer solar drying of red chili Wang and Singh model gave R^2 =0.99646, X^2 =0.00032 and RMSE=0.01802.Wang and Singh model is considered as best model for thin layer solar drying and open sun drying of red chili.

Thin layer drying modelling equation for open sun drying of red chili is given by

$$MR=1+(-0.0327)t+0.000171t^2$$

Thin layer drying modelling equation for solar drying of red chili is given by

$$MR=1+(-0.05515)t+0.0007045t^2$$

V. CONCLUSION

The present work involves investigation of drying behavior and mathematical modeling of thin layer drying of red chili under the open sun and in an indirect-type forced convection solar dryer. To carry out the drying experiment, an indirect-type forced convection solar dryer consisting of solar air heater, drying chamber and exhaust fan was developed and experiments were conducted. In order to get the drying behavior of red chili, drying characteristics data were fitted to Newton, Page, Henderson and Pabis, and Wang and Singh thin layer drying models. Three statistical tool coefficient of determination (R^2), reduced chi square (X^2) and root square mean error (RMSE) were used to quantify the goodness of fitting. The goodness of fit was determined based on the higher values of R^2 and lower values of X^2 and RMSE. The results showed that Wang and Singh model was found to be the best model to describe the drying behavior of red chili for both solar drying and open-sun drying with R^2 = 0.99876, X^2 = 0.000115 and RMSE = 0.01072 in open sun drying and R^2 = 0.99646, X^2 = 0.00032 and RMSE = 0.01802. It was also observed that the product dried under the open sun had inferior quality to the product dried in the solar dryer.

VI. ACKNOWLEDGEMENT

The authors wish to thank the Rewa institute of technology for their continuous support during the research phase. Authors would like to thanks their parents for their immeasurable love and financial support during research phase.

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