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Hybrid Greenhouse Dryer for Paddy

M. Madhava[1], Sivala Kumar[2], D. Bhaskara Rao[3], D. D. Smith[4] and H. V. Hema Kumar[5]

[1]Senior Scientist, Regional Agricultural Research Station, Anakapalle. Andhra Pradesh; [2]Associate Dean (Rtd.), College of Food Technology, Bapatla. Andhra Pradesh; [3]Registrar, ANGRAU, Guntur, Andhra Pradesh; [4]Associate Dean, College of Food Techonology, Pulivendula; [5]Professor, College of Agricultural Engineering, Bapatla. Corresponding author email address: madhava12@gmail.com

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ABSTRACT

A forced convection greenhouse dryer was developed and used for drying of freshly harvested paddy. The solar greenhouse dryer of size 4.47 × 2.13 m with 2.59 m central height was constructed and covered with 6 mm polycarbonates sheet. Photovoltaic power driven direct current fans were used to provide forced ventilation. Freshly harvested paddy was dried at 50, 100 and 150 mm bed thickness in the hybrid greenhouse dryer and open sun drying during *kharif* and *rabi* seasons of 2016. The *kharif* harvested paddy was dried from 25.3 % to 12.0 % (w.b.) moisture content at 100 mm bed thickness within 21 h, 28 h of drying in the hybrid greenhouse dryer and open sun drying, respectively. Highest drying rates were 1.54 $kg.h^{-1}$ and 1.35 $kg.h^{-1}$ in greenhouse dryer and open sun drying, respectively. During *rabi* season, paddy was dried from 22.8 % to 12.0 % (w.b.) moisture content within 19 h and 25 h with highest drying rates of 1.65 $kg.h^{-1}$ and 0.97 $kg.h^{-1}$, respectively, in the hybrid greenhouse dryer and open sun drying. Thermal efficiency of the greenhouse dryer was 28.15 % and 22.15 %, and pickup efficiency was 15.49 % and 14.88 % during *kharif* and *rabi* seasons, respectively.

Rice (*Oryzasativa* L) is the staple food for 65 % of Indian population, largest consumed calorie source among the food grains, and meets 31 % of the total calorie requirement (Manikantan *et al*., 2014). India is the second largest producer of rice in the world. Paddy occupied the first place both in area and production with record production of 112.91 Mt during the year 2017-18 (Anon., 2018).

Storage and handling of paddy at high moisture content have serious problems in India, particularly at the farm level, where mechanical dryers are not considered to be feasible due to heavy investment and maintenance cost. Traditional method of sun drying is still popular as it fits into the cultural, technological, and economic situation of small-scale farmers, medium-scale paddy traders and rice millers. Sun drying has certain disadvantages of unreliability, uncontrolled heating of grains, thermal stresses leading to grain fissures and breakage during milling, thus reducing its value, vulnerability to infestation and losses due to birds and rodents. Problems are more serious in the incident of rains, floods, and cyclones, to which vast Indian coastal belt is prone. The problems are aggravated with early paddy harvest using combine harvester during high humidity coupled with rains at the time of harvesting (Salvatierra-Rojas *et al*., 2017). Rising labour cost in sun drying and increasing demand for quality rice could be compelling to use improved solar dryers. Several forced convection solar dryers (both cabinet type and tunnel-type) were investigated. Many studies on forced convection solar dryers noticed that most solar dryers had small loading capacity and required grid power for operating the exhaust fan (Barnwal and Tiwari, 2010).

An alternate way of reducing the post-harvest losses and low quality of dried products associated with the traditional open sun-drying method is drying of food grain in forced convection greenhouse dryers (Jain and Tiwari, 2003). A solar greenhouse dryer has thermal mass to collect and store solar heat energy and insulated to retain this heat for use during the night and on cloudy days (EREC, 2013) which reduces the need for fossil fuels for drying (NYSERDA, 2009). Active solar greenhouse dryers need supplemental energy to move solar heated air across the food material inside the greenhouse dryer for faster drying (Svejkovsky, 2006). In many rural areas, supply of grid-connected electricity or other non-renewable sources of energy are either unavailable, unreliable or too expensive. In such areas, photovoltaic powered solar greenhouse dryers appear to be more attractive (Mekhilefa *et al*., 2011; Xingxing *et al.*, 2012). Very few researchers have used photovoltaic powered forced ventilation system in solar greenhouse drying, however, no research was conducted in the development and evaluation of forced convection solar greenhouse dryer for drying of paddy. Hence, the present work was taken up to develop and evaluate a photovoltaic (PV) ventilated hybrid greenhouse dryer for drying of paddy.

MATERIALS AND METHODS

Experimental Set up

A PV ventilated forced circulation solar greenhouse dryer (Fig. 1, 2) was developed for paddy drying at the College of Agricultural Engineering, Bapatla, Andhra Pradesh, India, located at 15.8889º N and 80.4700º E and at 7 m elevation from MSL. The foundation of the dryer was laid in an east-west orientation.

A single standing greenhouse dryer of 4.47 × 2.13 m size with central height of 2.59 m was selected for construction. The greenhouse dryer structure was constructed using 50.8 × 25.4 mm mild steel pipe and 19 × 30.2 mm MS angle. Clear twin-wall polycarbonate 6 mm thick sheet was used to insulate the greenhouse dryer structure. North wall of the greenhouse dryer was insulated to reduce the heat loss from the north side of the greenhouse. The drying chamber of the solar greenhouse dryer was divided into multiple tiers. The trays were used for holding the paddy inside the drying chamber. Each tray was of 1.43 × 0.80 × 0.15 m in dimensions, fitted with good quality stainless steel woven wire mesh. Forced ventilation was provided with four 40 W direct current fans. Two photo voltaic panels with 150 W power capacity, 18.5 V rated voltage and 8.10 A rated current were used to drive the direct current exhaust fans. The solar panel surface was always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of use.

Experimental Procedure

Separate drying experiments were conducted at three different bed thickness of 50 mm, 100 mm and 150 mm in the day time between 9.00 AM and 5.00 PM during the month of January for *Kharif* harvested paddy. Fresh combine harvested paddy (Variety: BPT 5204) harvested in the evening of 01.1.2016 was filled in 18 trays up to the predetermined depth and were placed inside the greenhouse dryer in the morning of the next day in three tiers and two rows. Each row had bottom, middle and top tiers. Paddy was agitated manually in the individual trays at every two hours for uniform drying. Drying was continued till 12 % moisture content (w.b.) of product was achieved. During the period of study, there was no rainfall and clear sunny weather prevailed. The ambient temperature varied in the range of 30-39 ºC and relative humidity was in the range of 31-49 per cent. Similarly, *rabi* paddy harvested on

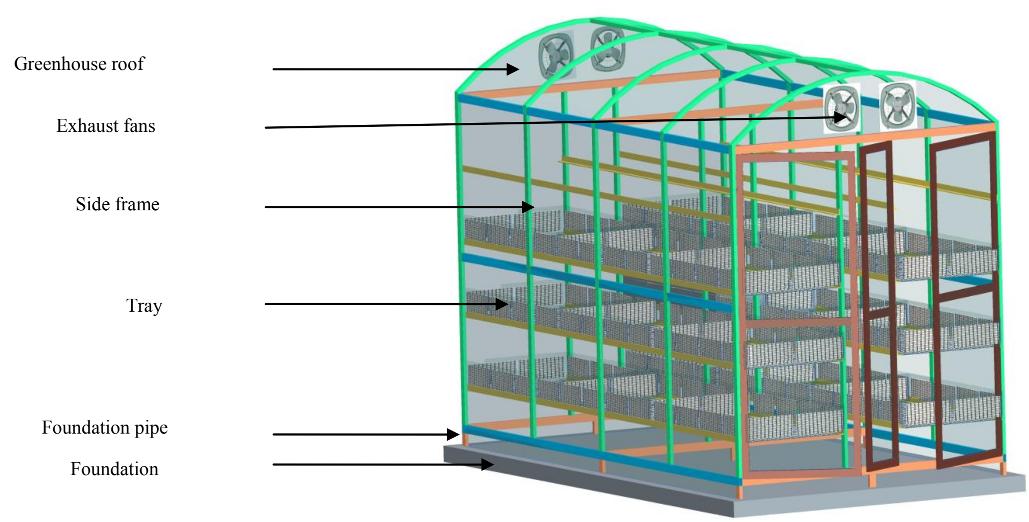

Fig. 1: Structural details of hybrid greenhouse dryer

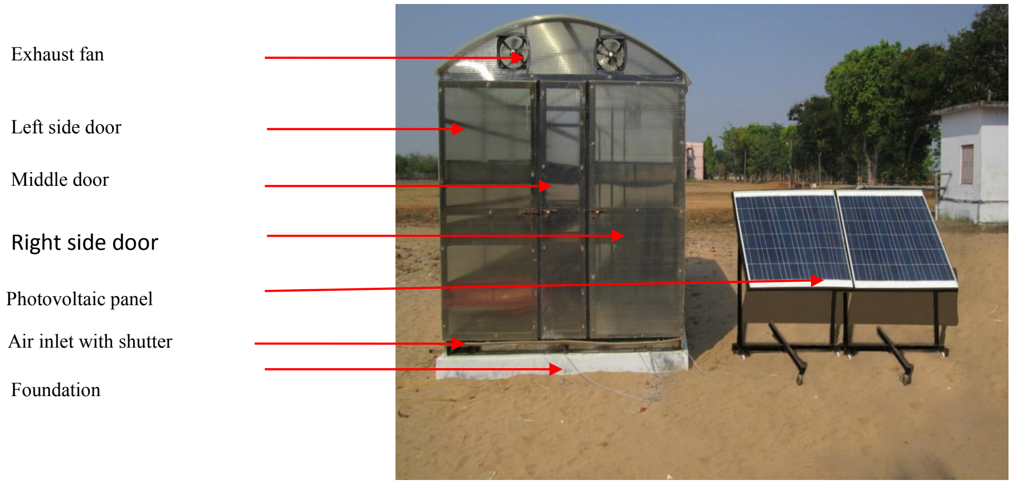

Fig. 2: Fabricated hybrid greenhouse dryer

11.5.2016 evening was loaded in the hybrid greenhouse dryer at early morning of the next day, and drying was continued till the 12 % (d.b.) final moisture content was reached.

Greenhouse air temperature, relative humidity, grain temperature, grain moisture content, exhaust air velocity was recorded at every one-hour interval in thee replications. The greenhouse air inlet was closed during night time, and exhaust fans were switched off to aid tempering and prevent entry of moist air from outside to the greenhouse.

In open sun drying, paddy in a single layer was spread on floor with different thicknesses. Drying was carried out from 9.00 AM to 5.00 PM. Paddy was heaped up and covered with LDPE plastic sheet after 5.00 PM to avoid absorption of moisture during night.

Measurement of Parameters

Paddy sample were collected randomly for each tray of the hybrid greenhouse dryer and open sun drying. Three replicated samples were used for determination of the moisture content.

Temperature and relative humidity

Temperature was measured using a T-type thermocouple with measuring range of (-) 200°C to 350°C. The tolerance of T-type thermocouple was 0.5°C. Eight thermocouples used to measure the inlet, outlet air temperature and six randomly selected points in greenhouse representing two points in each tier were connected to first eight channels of a process interface module of data logger. Relative humidity (RH) was measured using a hygrometer with a measuring range of 0-100 per cent. Eight hygrometers used to measure the inlet, outlet air humidity and six randomly selected points in the greenhouse, representing two points in each tier to record data at every one-minute interval, were connected to channel interface module of the data loggers.

Solar radiation

A pyranometer (Apogee SP 110) was used to measure the global solar radiation. The response time of the instrument was 1 ms. The instrument could measure solar intensity in the range of 0-2800 $W.m^{-2}$. The sensitivity of the pyranometer employed was 0.2 $\mu V.Wm^{-2}$.

Air flow rate

Exhaust air velocity was measured using a Lutran 4201 anemometer at every one-hour interval during experimental trials. Accuracy of the anemometer was 0.10 $m.s^{-1}$ in the temperature range of 0-50°C and operating relative humidity less than 80 per cent. It consisted of naked-bead type-k thermocouple probe to sense the temperature, conventional twisted vane arms with low-friction ball-bearing air velocity sensor , and 18 mm LCD. The anemometer was placed in front of the exhaust fan to record air velocity.

Volumetric air flow rate was obtained using the following equation:

Flow rate ($m^3.min^{-1}$) = Air velocity ($m.min^{-1}$) × Cross section area (m^2) ... (1)

Data logger

Sixteen channel data logger [Process precision instruments (PPI), India] was used to record the temperature and relative humidity readings at one minute interval. It recorded the data with accuracy of (±) 0.25 % in continuous or batch mode of recording. First 8 channels were connected to thermocouples, which were used to measure the greenhouse air temperature at six locations, ambient and exhaust air temperature. Channels from 9-16 were connected to relative humidity sensors, which were used to measure the greenhouse air relative humidity at six locations, ambient and exhaust air relative humidity.

Moisture content

Paddy samples were collected from each tray of the greenhouse dryer and open sun drying after thoroughly mixing. Moisture content of paddy was determined by standard oven drying method (AOAC, 1985), and was computed using the following equation:

$$M.C.\%\,(w.b.) = \frac{W_1 - W_2}{W_1} \times 100 \qquad ...(2)$$

$$M.C.\%\,(d.b.) = \frac{W_1 - W_2}{W_2} \times 100 \qquad ...(3)$$

Where,

M.C. (w.b.) = Moisture content(wet basis), %,
M.C. (d.b.) = Moisture content on dry basis, %,
W_1 = Initial weight of sample, g, and
W_2 = Final dried weight of sample, g.

Drying rate

Drying rate is approximately proportional to the difference in moisture content between the product being dried and EMC at the drying air state. Drying rate (DR) was estimated by differentiation of water content with respect to time as:

$$DR = \frac{M_{t+dt} - M_t}{dt} \qquad ...(4)$$

Where,
DR = Drying rate, kg.h^{-1},
M_t = Moisture content at time t, % (d.b.),
M_{t+dt} = Moisture content at time t + dt, % (d.b.), and
dt = Time of successive measurements, min.

Efficiency of greenhouse dryer

According to Boonyasri *et al*. (2012), the drying efficiency of a dryer is defined as the ratio of energy output of the dryer to energy input in the dryer.

The efficiency of the greenhouse dryer was calculated using the following formula:

$$\text{Dryer efficiency} = \frac{Mw\lambda}{IAt} \text{ X } 100 \qquad \ldots (5)$$

Where ,

Mw = Moisture evaporated, kg,
λ = Latent heat, kJ.kg^{-1},
I = Average solar radiation input, kJ.m^{-2},
A = Dryer area, m^2, and
t = Drying time, s.

Pickup efficiency

Pickup efficiency is useful for estimating the actual quantity of moisture evaporated from the product. The pick-up efficiency is defined as the ratio of the amount of moisture picked up by air inside the dryer to the theoretical capacity of air to absorb moisture (Senadeera and Kalugalage, 2004; Hii *et al*., 2006). It is a direct measure of how efficiently the heated air is utilized to absorb moisture.

Pickup efficiency was calculated using the following formula:

$$\eta = \frac{h_0 - h_i}{h_a - h_i} \qquad ...(6)$$

Where,

h_o = Absolute humidity of air leaving the drying chamber, kg.kg^{-1},
h_i = Absolute humidity of air entering the drying chamber, kg.kg^{-1}, and
h_a = Adiabatic saturation humidity of the air entering the dryer, kg.kg^{-1}.

RESULTS AND DISCUSSION

Results of the paddy drying experiments conducted in hybrid greenhouse dryer as well as under open sun drying at 50, 100 and 150 mm bed thickness during *Kharif* and *Rabi* seasons are compared and reported with more emphasis on drying at 100 mm bed thickness.

Drying of *Kharif* Paddy in Greenhouse Dryer under Full Load

Drying was carried out on clear sunny days. About 1250 kg of paddy harvested on previous evening was loaded next early morning in the greenhouse dryer as well as at open sun drying yard up to 100 mm bed thickness. Variation of moisture content, drying rate, temperature, relative humidity and solar radiation are reported.

Variation of moisture content

Paddy was dried from the initial moisture content of 25.30 % (w.b.) to final moisture content of 12.0 % (w.b.). It was observed from Fig. 3 that the moisture content decreased with drying time, reached to 12.0 % (w.b.) after 21 hours (3 days) of greenhouse drying (GHD). It took 28 h (4 days) of open sun drying (OSD). It was also observed that the moisture content reduced from 25.3 % to 19.8 % (w.b.), 19.8 % to 15.5 % (w.b.) and 15.3 % to 12.0 % (w.b.) during first, second and third day of greenhouse drying, respectively. About 5.5 %, 4.5 % and 3.3 % moisture were removed from paddy during the respective day of greenhouse drying. Apart from saving in 25.0 % drying time, the grain quality was improved by prevention of contamination with dust.

Drying rate increased during the first half (till 1.00 pm) of a day both in greenhouse and under open sun drying, and later decreased till the evening, Fig. 4. The drying rate was high in the greenhouse dryer (1.54 kg.h^{-1}) as compared to open sun drying (1.35 kg.h^{-1}). During first day's early hours of drying, the drying rate increased due to the removal of surface moisture from the grains. The increase of temperature, airflow rate and decrease of relative humidity aided to increase the drying rate during the subsequent hours in the first half of the day. During night hours, tempering allowed moisture diffusion, which resulted in increase of drying rate at early hours of drying on subsequent day. During the second day's first half, drying rate increased, but the peak of the drying rate curve was low (1.40 kg.h^{-1}) as compared to the peak value on the first day (1.50 kg.h^{-1}).

Variation in temperature, relative humidity, air flow rate

Variations in greenhouse air temperature (T_{avg}), grain temperature (GTG), ambient temperature (Ta) and solar radiation intensity (I) are shown in Fig. 5. Greenhouse air temperature had always been higher than the ambient air temperature. The temperature increased till the middle of the day(1.00 pm), and later decreased with time till the evening. The average greenhouse dryer air temperature varied in the range of 26.50-40.30 ^{0}C during drying, whereas ambient temperature varied in the range of 22-35 ^{0}C. It was observed that the average grain temperature followed the ambient air temperature curve till the middle of the day (1.00 pm), further continued to rise till 3.00 pm, and subsequently decreased to near to the greenhouse air temperature, but above the ambient air temperature at 5.00 PM. The grain temperature variation was in the range of 24.30-34.70 ^{0}C.

Airflow rate (Q_{fan}) increased sharply in the early part of the day (9.00-11.00 a.m), became fairly constant at the middle of the day (11.00 AM-1.00 PM) and then dropped sharply in the afternoon (1.00-5.00 pm) (Fig. 6). The pattern of change in airflow rate followed the pattern of the changes in solar radiation since the airflow was regulated by three fans powered by a PV module. The maximum air flow rate observed was 3112.8 m^3.s^{-1}, whereas the minimum was 2038.2 m^3.s^{-1}. Reduced air relative humidity, increased air temperature and air velocities improved the performance of the dryer. These results were in accordance with Janjai *et al*. (2009) for peeled longan and banana in photovoltaic ventilated greenhouse dryer.

Variation of relative humidity (Fig. 6) showed that the greenhouse dryer air relative humidity (Hg) (75.50 %) was higher than ambient relative humidity (Ha) (64.00 %) during the early hours of drying (9.00 AM) on the first day. It was due to addition of grain surface moisture to greenhouse air. Due to low exhaust air

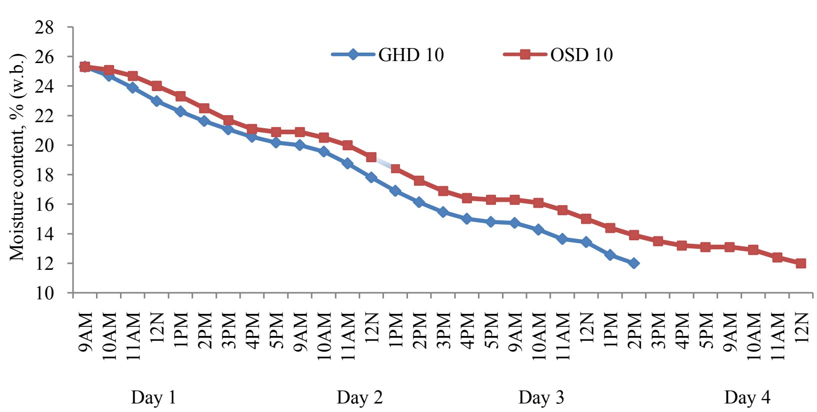

Fig. 3: Comparison of moisture reduction with respect to grain bed thickness during *kharif* paddy drying

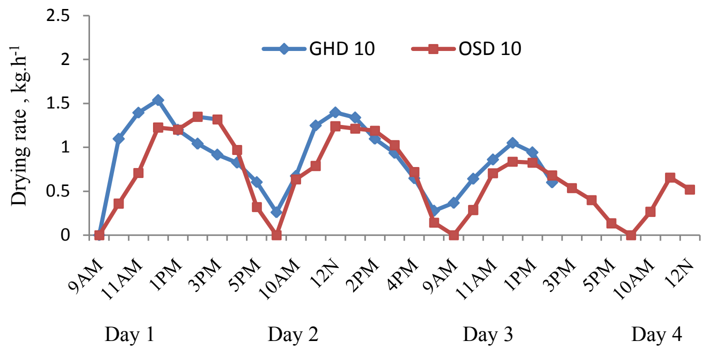

Fig. 4: Comparison of drying rates with respect to time during *kharif* paddy drying

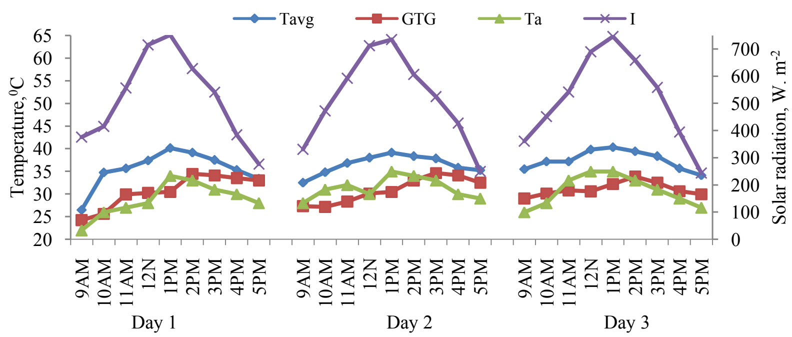

Fig. 5: Comparison of greenhouse air, ambient and grain temperature and solar radiation during *kharif* paddy drying

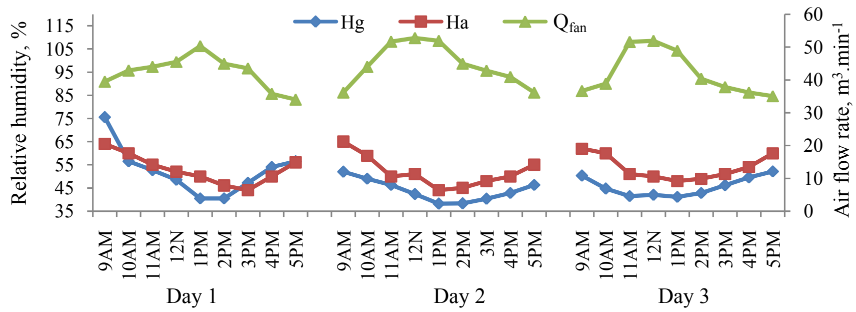

Fig. 6: Comparison of relative humidity and airflow rate during *kharif* paddy drying

flow rate (39.46 $m^3.min^{-1}$), the moist air could not be totally discharged from the greenhouse. The greenhouse air relative humidity decreased till the middle of the day (1.00 PM), and later increased with time till the evening. During the first day, relative humidity varied between 44-75.5 % and 43-64 % inside and outside of the greenhouse dryer, respectively. During the second day of drying, mean relative humidity within the dryer varied between 52 % and 38.2 %, whereas, the ambient relative humidity varied between 65 % and 44 per cent. During the third day, relative humidity of the greenhouse dryer varied between 50.30 % and 41.20 %, whereas, the ambient relative humidity varied between 62 % and 48 per cent. During three days of experimental drying period, relative humidity in the dryer was less than that of ambient relative humidity due to high temperature prevailing inside the dryer (due to the greenhouse effect). This ensured that in the solar greenhouse dryer, paddy could be dried within less time than the open sun drying. These results are in line with the results of Arun *et al.*, (2014) for drying of tomato.

Effect of bed thickness during *Kharif* paddy drying

Drying behaviour of paddy with respect to bed thickness (Fig. 7) indicated that the bed thickness had significant effect on the drying behaviour of paddy. Drying time

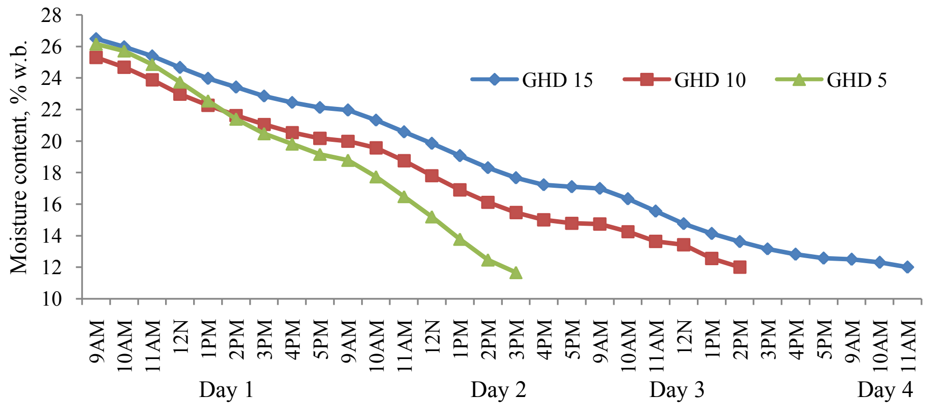

Fig. 7: Comparison of moisture with respect to grain bed thickness during kharif paddy drying

increased with increase in bed thickness. Paddy was dried from initial moisture content of 26.50 % to final moisture content of 12 % (w.b.) in bed thicknesses of 150 mm, 100 mm and 50 mm bed within 25 h, 21 h and 13 h of drying, respectively. At 50 mm bed thickness, paddy was thus dried with least duration of 13 h. Considering the difficulties in handling the loaded trays, drying of paddy in 100 mm bed thickness was convenient for use.

Drying rates also varied with paddy bed thickness (Fig. 8). With increase in bed thickness, drying rate decreased. The highest drying rate observed during the first day of drying was 2.02 $kg.h^{-1}$ at 50 mm bed thickness, whereas, 1.54 $kg.h^{-1}$and 1.27 $kg.h^{-1}$ drying rates were observed with bed thickness of 100 mm and 150 mm, respectively. During the second day of drying, drying rate reduced to 1.90 $kg.h^{-1}$, 1.40 $kg.h^{-1}$ and 1.20 $kg.h^{-1}$ in 50 mm, 100 mm and 150 mm bed thickness, respectively. During the third day of drying, drying rate further dropped to 1.04 $kg.h^{-1}$ and 1.10 $kg.h^{-1}$ in 100 mm and 150 mm bed thickness, respectively.

Drying of *Rabi* Paddy in Greenhouse Dryer

1250 kg of paddy was equally distributed in 18 trays up to 100 mm of bed thickness, and placed in the greenhouse dryer at 9.00 AM on 12.5.2016. Drying was carried till the designed moisture content of grains could be achieved.

Variation of moisture content during *Rabi* paddy drying

Paddy was dried in the month of May in the greenhouse dryer from its initial moisture content of 22.80 % (w.b.) to the final moisture content of 12 % (w.b.) within 19 h, whereas, open sun drying took 25 h for drying. Greenhouse drying saved 24 % of drying time. It was also noted from Fig. 9 that the moisture content of paddy reduced from 22.80 % to 17.07 %, and 17.07 % to 12.73 %

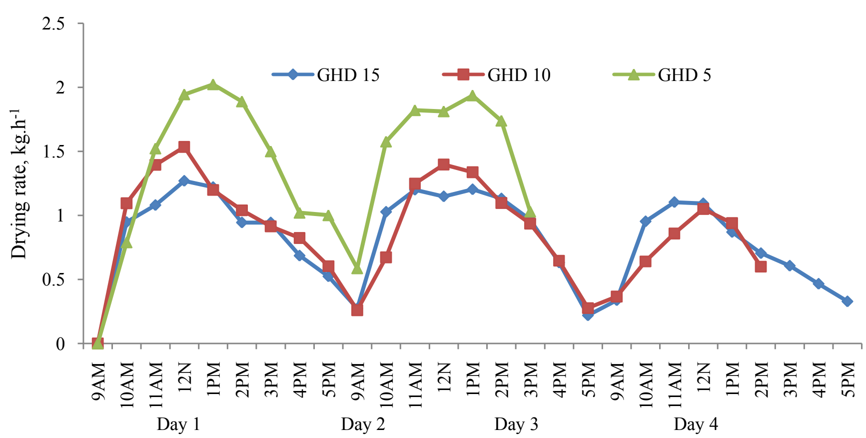

Fig. 8: Variation in drying rates with respect to grain bed thickness during *kharif* paddy drying

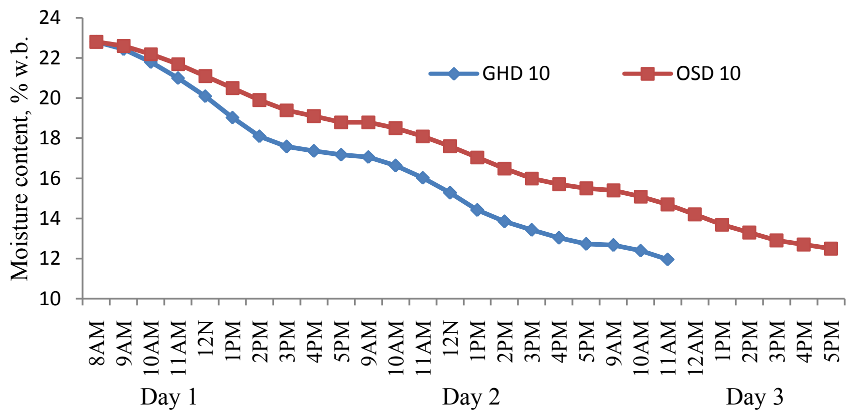

Fig. 9: Comparison of moisture reduction with respect to paddy grain bed thickness during *rabi* paddy drying

during the first and second day of drying, respectively. At the end of drying on the third day at 11.00 AM, the moisture content of paddy was 12 % (w.b).

Drying rate was high in the greenhouse dryer as compared to open sun drying as shown in Fig. 10. Highest drying rate of 1.65 $kg.h^{-1}$ was achieved in the greenhouse dryer, whereas, in open sun drying it was 0.97 $kg.h^{-1}$ at 1.00 PM on the first day of drying. Higher drying rates were observed in greenhouse dryer due to relatively higher greenhouse air temperatures, low relative moisture content and higher air velocities than ambient conditions.

Variation of temperature, relative humidity and air flow rate during drying

Variation of greenhouse temperature (GT), ambient temperature (Ta) and solar radiation intensity(I) is shown in Fig. 11. The maximum greenhouse dryer temperature was 48.10 ^{0}C, and the minimum

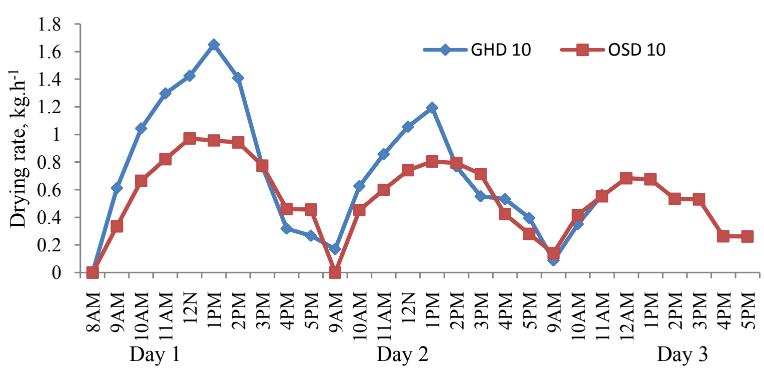

Fig. 10: Variation in drying rates with respect to time during paddy drying in *rabi* season

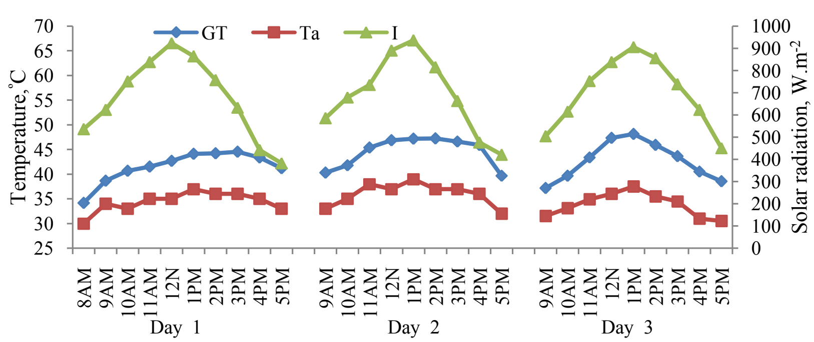

Fig. 11: Variation in greenhouse air, ambient air temperature and solar radiation during *rabi* paddy drying

temperature was 34.20 ^{0}C. The maximum ambient temperature recorded was 39 ^{0}C, and the minimum was 30.0 ^{0}C. The airflow rate increased sharply in the early part of the day(9.0-11.0 AM), then remained fairly constant (11.00 AM -1.00 PM), and subsequently sharply dropped in the afternoon (1.00-5.00 pm), Fig. 12. The pattern of changes in airflow rate followed the pattern of the changes in solar radiation since the airflow was regulated by three fans powered by a PV module. The maximum air flow rate (Q) was 4531.2 $m^3.s^{-1}$, whereas the minimum was 2055 $m^3.s^{-1}$.

The relative humidity in the greenhouse dryer (HG) varied between 37.80-20.70 % and 32.80-21.70 % during the first and second days of drying,with the corresponding ambient relative humidity (Ha) varying between 49.0-31.0 % and 46.0-33.0 % during the first and second days of drying, respectively. During the third day of drying, relative humidity in the dryer varied between 34.30 % and 23.70 %, whereas the ambient relative humidity varied between 47.0 % and 34.0 per cent. During the experimental period, the relative humidity of the dryer was less than that of ambient relative humidity due to higher temperature prevailing inside the dryer due to greenhouse effect.

Effect of bed thickness on drying characteristics

Bed thickness had a considerable effect on the drying behaviour of paddy. It was noticed that as the bed thickness increased, drying time also increased (Fig. 13). Paddy dried from 22.80 % to 12.00 % moisture content (w.b.) within 21 h, 19 h and 12 h of drying with 150 mm, 100 mm and 50 mm bed thickness, respectively. At 50 mm bed thickness, paddy dried faster as compared to 100 mm and 150 mm bed thickness. It was also observed that the drying rate varied with the bed thickness (Fig. 14). Higher drying rates were achieved at lower bed thickness. The highest drying rate observed during the first day of drying was 2.00 $kg.h^{-1}$ with 50 mm bed thickness, whereas, 1.65

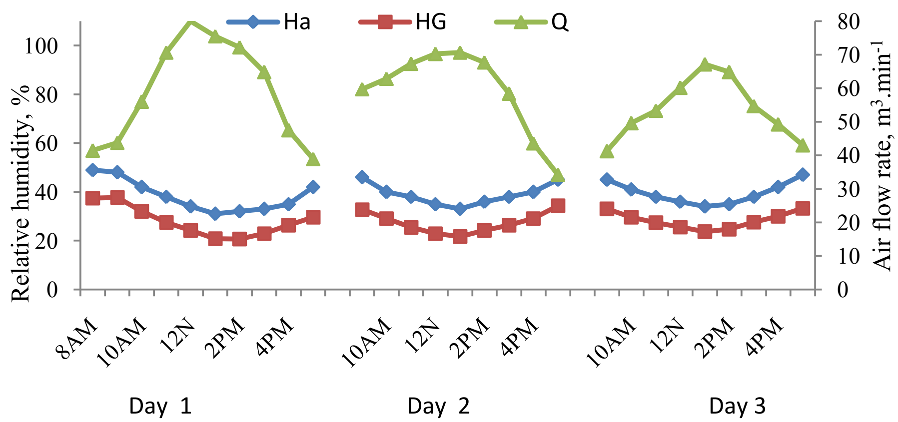

Fig. 12: Variations in greenhouse air, ambient air relative humidity and air flow rate during *rabi* paddy drying

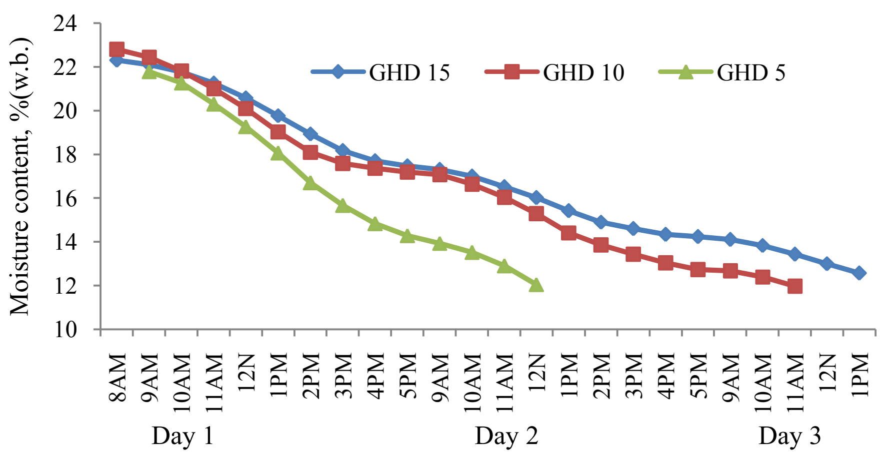

Fig. 13: Variation in moisture content during *rabi* paddy drying at different bed thickness

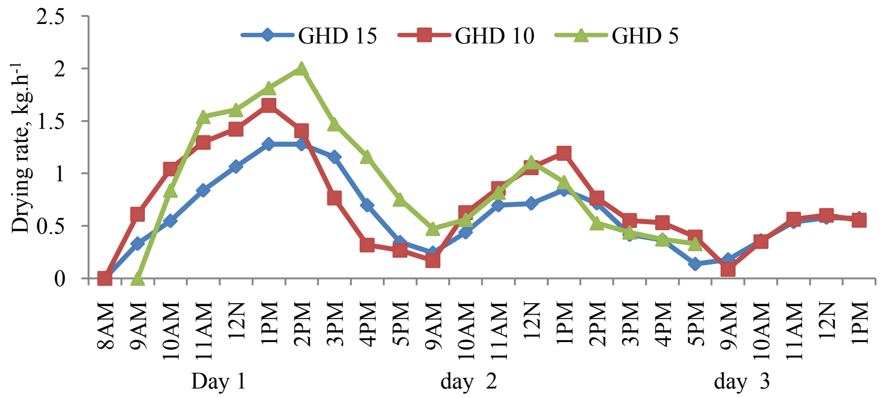

Fig. 14: Variation in drying rate with respect to bed thickness in *rabi* season

kg.h^{-1} and 1.27 kg.h^{-1} drying rates were achieved with 100 mm and 150 mm, respectively. On the second day of drying, drying rate of 1.11 kg.h^{-1}, 1.10 kg.h^{-1} and 0.84 kg.h^{-1} were achieved in bed thickness of 50 mm, 100 mm, and 150 mm bed thickness, respectively. During the third day of drying, 0.60 kg.h^{-1} and 0.60 kg.h^{-1} drying rates were achieved in 100 mm and 150 mm bed thickness, respectively.

Thermal Efficiency of Greenhouse Dryer

Thermal efficiency of the solar greenhouse dryer for paddy drying with 100 mm bed thickness was 28.57 % during the month of January, and 22.15 % during the month of May, 2016. Increase in the thermal efficiency at a low solar radiation was reported by Fudoli *et al.* (2013). The results of the present study are in line with the results reported by Abdallah (2010) and Almuhanna (2012) for sugar beet tops and dates, respectively.

Pickup Efficiency of Solar Greenhouse Dryer

Pickup efficiency is useful for evaluating actual evaporation of moisture from paddy inside the solar dryer. The pickup efficiency of the greenhouse dryer was 15.49 % during January and 14.88 % during the month of May (Table 1). Pick-up efficiency generally decreases with moisture content of the product. The results are in accordance with the results reported by Aliyu and Jibril (2009), Simate and Cherotich (2017) for drying of mango in natural convection greenhouse dryer.

Table 1. Efficiency of greenhouse dryer

Sl. No.	Season	Dryer efficiency, %	Pickup efficiency, %
1.	*Kharif*, 2016	28.57	15.49
2.	*Rabi*, 2016	22.15	14.88

CONCLUSIONS

Photovoltaic ventilated solar greenhouse dryer was developed and effectively used for drying of paddy. Drying time of paddy at 100 mm bed thickness in greenhouse drying was reduced by 25 % and 24 % during *kharif* and *rabi* season, respectively, as compared to open sun drying. Apart from reduction in drying space, contamination with dust was prevented in greenhouse dryer. The thermal efficiency of the greenhouse dryer was 28.57 % during *kharif*, 2016 and 22.15 % during *rabi*, 2016.

REFERENCES

Abdallah S E. 2010. Thermal efficiency enhancement of a solar drier for hay making from sugar beet tops. Agric. Mech. Asia Afr. Lat. Am., 41(4), 87-98.

Aliyu A B; Jibril H. 2009. Utilization of greenhouse effect for solar drying of cassava hips. Int. J. Phys. Sci., 4 (11), 615-622.

Almuhanna E A. 2012. Utilization of a solar greenhouse as a solar dryer for drying dates under the climatic conditions of the Eastern Province of Saudi Arabia Part I: Thermal performance analysis of a solar dryer. J. Agric. Sci., 4 (3), 237-246.

Anon. 2018. Annual Report 2017-18. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, 11-12.

AOAC. 1985. Official Methods of Analysis. Association of Official Analytical Chemists (Vol-II), Washington DC, 777-788.

Arun S; Ayyappan S; Sreenarayanan V V. 2014. Experimental and comparison studies on drying characteristics of sliced cut tomatoes and cube cut tomatoes. Int. J. Recent Technol. Eng., 3 (4), 26-31.

Barnwal P; Tiwari G N. 2010. Experimental validation of hybrid photovoltaic-thermal (PV/T) greenhouse dryer under forced mode. Int._J. Food_ Eng., 6(6), 1-27.

Boonyasri M; Lertsatitthanakorn C; Wiset L; Poomsa-ad N. 2012. Performance analysis and economic evaluation of a greenhouse dryer for pork drying. KKU Eng. J., 38, 433-442.

EREC. 2013. Energy Efficiency and Renewable Energy Cleaning House. Agricultural Applications of Solar Energy, United State Department of Energy. http://infohouse.p2ric.org/ref/24/23989.htm. Date of accession: 02.10.2018.

Fudholi A; Othman M Y; Ruslan M H; Sopian K. 2013. Drying of malaysian capsicum annuum L. (Red Chili) dried by open and solar drying. Int. J. Photoenergy, 1-9.

Hii C L; Rahman A R; Jinap S; Man Y C. 2006. Quality of cocoa beans dried using a direct solar dryer at different loadings. J. Sci. Food Agric., 86, 1237-1243.

Jain D; Tiwari G N. 2003. Thermal aspects of open sun drying of various crops. Energy, 28, 37-54.

Janjai S; Lamlert N; Intawee P; Mahayothee B; Bala B K; Nagle M; Muller J. 2009. Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. Sol. Energy, 83(9), 1550-1565.

Manikantan M R; Barnwal P; Goyal R K. 2014. Drying characteristics of paddy in an integrated dryer. J. Food Sci. Technol., 51(4), 813-819.

Mekhilefa S; Saidurb R; Safari A. 2011. A review on solar energy use in industries. Renewable Sustainable Energy Rev., 15, 1777-1790.

NYSERDA. 2009. Introduction to Solar Energy Applications for Agriculture. New York State Energy Research Development Authority, New York. http://www.matchinggrants.org/global/pdf/doc122-87.pdf. Date of accession: 2.10.2018.

Salvatierra-Rojas A; Nagle M; Gummert M; de Bruin T; Müller J. 2017. Development of an inflatable solar dryer for improved postharvest handling of paddy rice in humid climates. Int. J. Agric. Biol. Eng., 10(3), 269-282.

Senadeera W; Kalugalage I. 2004. Performance evaluation of an affordable solar dryer for crops. In: Biennial Conference of the Society of Engineers in Agriculture, 14-16 September, Dubbo, Australia,1-7.

SimateI N; Cherotich Sam. 2017. Design and testing of a natural convection solar tunnel dryer for mango**.** J. Sol. Energy, 2017, 1-10.

Svejkovsky C. 2006. Renewable Energy Opportunities on the Farm. ATTRO National Sustainable Agriculture Information Service, U.S.A. https://attra.ncat.org/attra-pub/download.php? id=306. Date of accession: 02.10.2018.

Xingxing Z; Xudong Z; Stefan S; Jihuan X; Xiaotong Y. 2012. Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. Renewable Sustainable Energy Rev., 16, 599-617.