Experimental investigation on performance of domestic type solar crop dryer under free convection

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ABSTRACT

Drying of food items/crops under the sun (open conditions) is presumably one of the conscious and purposeful technological activity undertaken since long. Drying of products using solar crop dryer is very much advantageous over drying done in open conditions and mechanized form of drying. Many investigations on drying of crops/food products by using the solar crop dryers with different modifications have been reported in the literature. In the same direction, it has been thought to modify the dryer in which the wiremesh type of tray is used as an alternative to perforated trays and reflector plate was also attached for having more solar radiation on to the solar crop dryer. The present solar crop dryer is fabricated in such a way that it can be used under free and forced convection conditions. However, the present experimental investigation on performance of domestic type solar crop dryer has been carried out only under free convection for drying ginger and green chilli crops. Maximum average temperature of 54.8°C was recorded inside the solar crop dryer. Moisture removal from ginger and green chilli with drying in solar crop dryer was found much higher than that found with drying of the crops in open conditions. Maximum moisture removal of 23.7% was found in the case of ginger when reflector was used and shading plate was not used. Maximum thermal efficiency of solar crop dryer has been found as 14.4% for drying of ginger crop.

1. Introduction

Drying is one of the dehydration method used to process and preserve food products and crops for long time period. The heat from the sun coupled with the wind has been used to dry food for preservation over thousands of years. Drying of food items/crops under the sun (open conditions) was presumably one of the conscious and purposeful technological activity undertaken since long. Open sun drying has gradually become more and more limited because of the requirements for a large area, the possibilities of quality degradation, pollution from the air, infestation caused by birds/insects, longer drying periods and inherent difficulties in controlling the drying process. With the awareness of inadequacies involved in open sun drying, a more scientific method of solar energy utilization started with the development of solar crop dryer.

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The rate of moisture movement from the product inside to the air outside differs from one product to another and depends on whether the material is non-hygroscopic or hygroscopic. Non-hygroscopic materials can be dried to zero moisture level while the hygroscopic materials (most of the food products) will always have residual moisture content. This moisture in hygroscopic material may be bound moisture which remains in the material due to closed capillaries or surface forces. The unbound moisture in the hygroscopic material may be due to the surface tension as shown in Fig. 1.

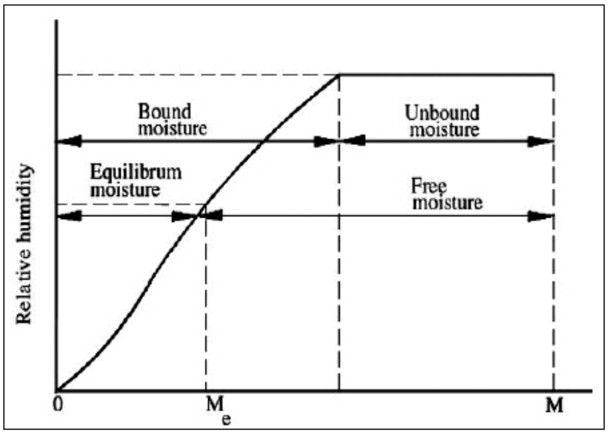

Fig. 1. Moisture in the hygroscopic material [4].

2. Solar Crop Dryers

Solar crop dryers are available in the range of size and design and are used for drying of various agricultural products. Solar crop dryers may be classified as active and passive solar dryers. Active dryers are also termed as forced circulation solar dryers. Passive dryers are conventionally termed as natural circulation solar dryers.

3. Literature Review

Experimental investigations carried out by researchers/scientists in order to study the drying of crops/food products by using the solar crop dryers have been reviewed and discussed in the present section.

Ezekwe [1] modified the conventional design of cabinet dryer. It had wooden plenum used to guide inlet air into the dryer. Long chimney was also used to boost natural circulation. Drying rate of this type of dryer was reported five times the open sun drying. Sodha et al., [2] investigated an analytical and experimental study of the solar cabinet dryer. The analytical models were based on the principle of simultaneous heat and mass transfer at the product surface and include the effects of wind speed, relative humidity, product thickness and heat conducted to the ground. The analysis was carried out in summer (June) and winter (December) with apples, peaches, cherries and mango flesh. The experimental results revealed that, on a typical summer day fruit mango flesh, with 95% initial moisture content dries up to 13% final moisture content in 12 sunshine hours. It was concluded that the cabinet type driers were very useful for domestic applications for drying of fruits and vegetables.

Khattab [3] tested and compared two arrangements of air heaters. First, elongating the air path through the collector and second, using two glass covers between which the air is allowed to flow before it enters the heater. For both configurations, an inexpensive reflecting surface was used to increase heat input heater Average increase of daily energy input was found to be 40% and 57% for the first and second arrangement respectively. Second type was found to be more efficient and economical than the first one.

Hallak et al., [4] investigated staircase design of direct type of solar dryer. Authors plotted temperature variation of the dryer compartments with time of day. Drying curves for various fruits and vegetables were also plotted. The efficiency of collector was found between 26% and 65%.

Ekechukwu and Norton [5] developed tent type natural circulation solar dryer with the help of locally available bamboo framework. Front side facing to the solar radiation and upper half portion of backside was covered with transparent plastic cover. Black colored plastic covered the remaining bottom half portion of back side and also lies on the floor of tent to increase the solar radiation absorption. Small vent was provided at top of one triangular side of tent for air movement.

Ahmad et al., [6] carried out study on standardization of a solar cabinet dryer. Evaporation rate in the dryer was found out ranging from 0.091 to 0.106 $g/cm^2/h$. Highest temperature in summer and winter recorded were 80°C and 60°C respectively. It was established that fruits (persimmon, apple) and vegetables (potato, onion) were dried successfully.

Desai et al., [7] constructed multi rack solar dryer. The experiments indicated that the drying time required for solar drying using the dryer was 50 hours and moisture content was reduced from 83.0% (w.b) to 15.0% (w.b). On the other hand, drying time for open sun drying was 80 hours. Therefore, net saving of 37.5 per cent in drying time was found over open sun drying.

Singh et al., [8] developed a domestic solar dryer with features including variable inclination to track more solar radiation, option to dry under shade or without shade as per need. They found efficiency by introducing continuous mode of loading. Annual saving was found much higher than the capital investment.

Akoy et al. [9] constructed cabinet type solar dryer to dry mango slices. It had a collector area of 16.8m^2. 195.2 kg of fresh mangoes were dried to 10% moisture content. Mangoes were dried in two days under ambient conditions during harvesting period. Average ambient conditions were 30^{o}C air temperature and 15% relative humidity with daily global solar radiation incident on horizontal surface of about 20MJ/m^2/day. The dryer was tested under various loading conditions.

Andoh et al., [10] designed and constructed the natural convection solar dryer using local materials and then tested to dry cassava, bananas and mango. Authors analyzed kinetics behavior of the dryer and drying heat balances were established. The influence of significant parameters governing heat and mass transfers, such as solar incident radiation, drying air mass flow and effectiveness were analyzed in order to evaluate the thermal performance. The moisture content of cassava and sweet banana were reduced to 80% in 19 and 22 h.

Afriye et al., [11] investigated chimney dependent direct mode solar crop dryer by varying angle. A model of` direct mode dryer was designed and constructed with three replaceable drying chamber roofs, each at different angle with respect to the vertical plane. Roof angles 810, 640 and 510 were used. The width and length of the chamber were 440 and 420 mm respectively. The total height of the chamber was 530 mm. The base of the chamber was made of wood (40 mm thick) with the top surface painted black to act as absorber in the drying chamber. The results showed that the chimney can increase the airflow rate of a direct-mode dryer especially when it is well designed with the appropriate angle of drying chamber roof.

Saleh and Badran [12] designed and tested the domestic solar dryer with transparent external surfaces. Thin layer drying method was used to describe the drying phenomena regardless of the controlling mechanism. The performance was analyzed under different operational conditions and drying characteristics were experimentally investigated. Solar tracking mechanism was used to enhance the performance. Experiments were conducted on two herbs, Jew's mallow and mint leaves. Products were found to be reduced to 6 % of moisture level on wet basis.

Rajeshwari and Ramalingam [13] designed a portable and cheap rectangular box type solar dryer by making use of locally available materials. The collection efficiency was found by using the different parameters depending on climatic conditions including ambient temperature, solar radiation, relative humidity, air velocity and atmospheric pressure. The drying rate and average collection efficiency and percentage of moisture removed for drying potato slice, chilly and grapes during the test period was found to be 1kg/h and 69.6% respectively. The hourly variation of the plate temperature and air temperature inside the solar dryer was found higher than surrounding temperature during the period of observation. The highest observed temperature of plate was 62 °C at noon time.

Hii et al., [14] studied applications and innovations involved in solar drying. Authors compared traditional and solar energy drying. Direct solar dryers and indirect solar dryer were also discussed. Advantages and disadvantages associated with both the types of dryers were also mentioned.

Gutti et al., [15] mentioned effectiveness of solar energy in drying of agricultural products and also benefits gained from the same. It was discussed that how different types of solar dryers according to the requirement have enhanced the efficiency of farming. It was also reported that the selection of dryers for a particular application largely depends upon availability and the type of dryer being currently used.

Eke [16] developed a small scale direct mode natural convection solar dryer for drying tomato, okra and carrot by making use of affordable materials. Sliced crops of 15mm were loaded in the dryer and at the same time, results were compared with that of open sun drying. Tomato, carrot and okra dried in solar dryer attained 21.80%, 21.18% and 24.95% system drying efficiencies respectively as compared to open sun drying efficiencies of 10.59%, 12.71% and 15.19% for the same. Results showed that drying of vegetables can best be achieved by solar dryers than open sun drying. Also, it was reported that onion cannot be dried in open sun because the pungent aroma is lost when exposed to unconfined space.

Ozuomba et al., [17] fabricated a low cost direct absorption solar dryer. The maximum margin between the internal and external temperatures recorded was 55^{0}C. The dryer had the potential for application in drying various agricultural products and also, eliminate most of the problems associated with open air sun drying. Ultra violet stabilized polythene sheet was used to protect the glass roof in order to prevent the adverse effects of UV radiation on agricultural products.

Yelttiwar et al., [18] fabricated cabinet solar dryer integrated with stainless steel reflectors for drying green chilli. Maximum temperature recorded was 59°C at no load test during day time in the month of December corresponding to the average ambient temperature of 24°C and solar intensity of 477.92 W/m^2. Drying time required for drying of 5 kg green chilli for reducing moisture content of 83.93% to 3.21% was found to be 36 h in the cabinet solar dryer. Thermal efficiency of the solar dryer with reflector system was found to be 35.6% and also, the colour of the solar dried chilli was observed to be much better than the open sun dried chilli.

Chaudhari and Bhavsar [19] developed a low cost hybrid dryer cum cooker to minimize the problem of high initial cost in rural areas. It was operated by both electric and solar energy, to overcome the less solar energy in early morning hours and on cloudy days, or when solar radiation decreases or disappears either as a dryer or as a cooker. A thermal analysis was conducted for solar and for hybrid solution and data were evaluated by automatic sensor system on hourly basis. The thermal efficiency of solar dryer was found to be 23.42% and of hybrid dryer and solar cooker were 38.56% and 29.39%.

Gupta et al., [20] reported solar dryer to dry agricultural products and food items to an appreciable moisture level. To make it cheap, locally available materials were used. Main components were air heater with the baffles and a solar drying chamber containing rack of four trays. The air was allowed to enter through air inlet, gets heated up in the solar collector chamber and further channeled through the drying chamber where it was used to remove moisture from the products being loaded in it.

In order to make the solar crop drying process as more efficient, many design modifications have been reported in conventional type of solar crop drying system. In the same direction, the design of trays has been modified from perforated to wiremesh type. Also, by incorporating the reflector plate, more solar radiation has been made available for the drying process. Also, polycarbonate sheet has been used as transparent cover in place of glass material in order to reduce the cost of solar crop dryer. Provision has also be made to do the drying under shade and no shade conditions. Accordingly, an experimental investigation has been carried out by using the modified design of solar crop dryer in order to dry ginger and green chilli under free convection (with/without use of reflector and with/without use of shading plate over crop tray). Simultaneous drying of same amount of ginger and green chillihas also been carried out in open conditions for comparison purpose. Thermal efficiency of solar crop dryer has also been evaluated.

4. Experimental Investigation

Photographic view of solar crop dryer used in the present experimental investigation is shown in the Fig. 2. The inside surface of drying cabinet was coated with black paint in order to increase absorptivity of the surface to the solar radiation. Sides of the drying cabinet were insulated by using the thermocole sheet. The four number of trays were used to hold crop inside the drying cabinet and these were constructed from MS wire mesh fitted on MS angles. Wiremesh was having fairly open structure in order to allow hot air to pass through the crop stack. Polycarbonate sheet has been used in place of glass due to light weight, low price, unbreakable, high rigidness and having almost equal transmissivity. A piece of anodized aluminum sheet has been used as reflector to boost the solar energy entering into drying cabinet. In order to give provison for conducting experiments under forced convection, an arrangement was provided to make flow of air through the drying cabinet with the help of a SPV (solar photovoltaic) operated DC fan. SPV panel of 5 Watt was installed to operate the fan with the help of solar energy. However, experimental investigation reported in the present paper has been carried out under free convection.

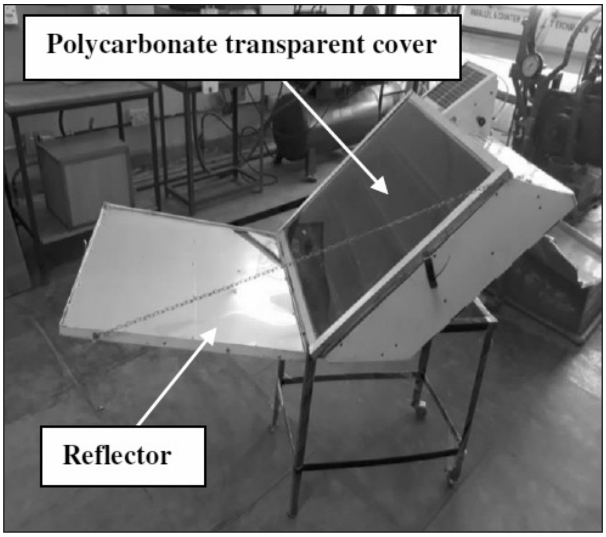

Fig. 2. Photographic view of solar crop dryer.

Before starting each set of the experiment on ginger crop, two kilogram of fresh ginger (properly cut into pieces) was kept ready to use for the experimentation under different conditions. In order to start the experiment, solar crop dryer was placed facing south in the shadow free area for receiving the maximum amount of solar radiation. The case in which reflector is not used; its effect was stopped by covering it with the piece of a cardboard. 1 kg of ginger was put in top tray of the dryer with/without using shading plate and remaining 1 kg was put in the tray placed on the floor near to the solar crop dryer in order to let it dry in open conditions. This was done to set up comparison between crop drying in the solar dryer and open conditions. Drying of the ginger crop for both the cases was done from 11 AM to 4 PM on each day of conducting the experiment. Temperature inside the dryer and ambient temperature was noted on hourly basis. Intensity of solar radiation and change in mass of ginger crop due to moisture removal were also noted after every hour. The same procedure was followed for the green chilli crop. Four schemes used to carry out the present experimental investigation have been discussed in the following section.

5. Results and Discussion

5.1 Drying under free convection without use of reflector and shading plate on the tray in solar crop dryer

Fig. 3 shows the variation of mass of ginger due to moisture removal during drying process under above mentioned conditions and open conditions. It can be noted that mass of crop decreases with time in both the cases of drying in solar crop dryer and open conditions. It can also be noted that the mass reduction of crop is much more in case of solar crop dryer than that of open conditions. Under these conditions, mass of ginger was reduced to 801 gram from 1000 gram in solar crop dryer and it was reduced to 901 gram from 1000 gram in open conditions. Similarly, Fig. 4 shows the variation of mass of green chilli due to moisture removal during drying process under these conditions. Mass of green chilli was reduced to 832.5 gram from 1000 gram in solar crop dryer and it was reduced to 915 gram from 1000 gram in open conditions.

Fig. 5 shows the moisture removal from ginger during drying process under these conditions.

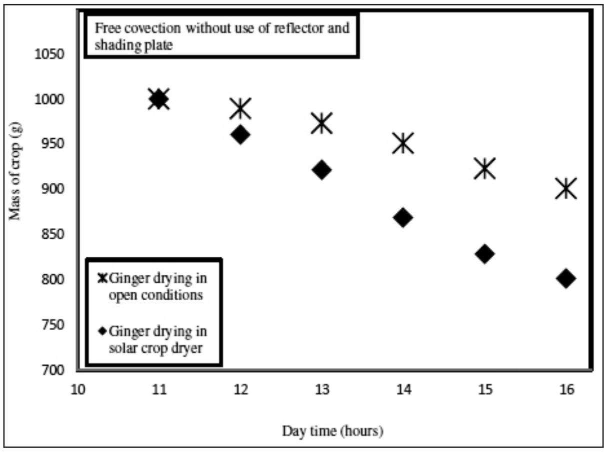

Fig. 3. Mass variation of ginger during drying in solar crop dryer and open conditions.

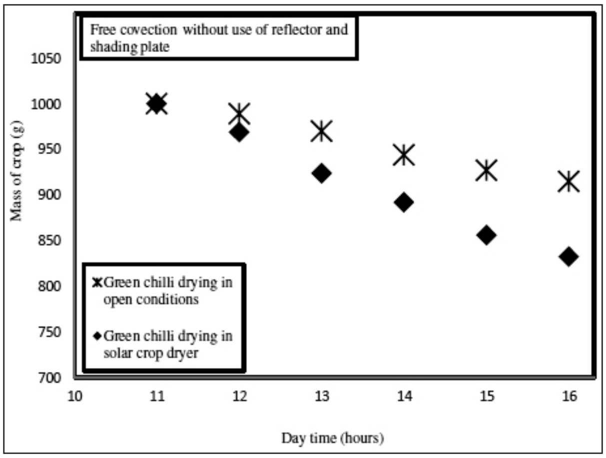

Fig. 4. Mass variation of green chilli during drying insolar crop dryer and open conditions.

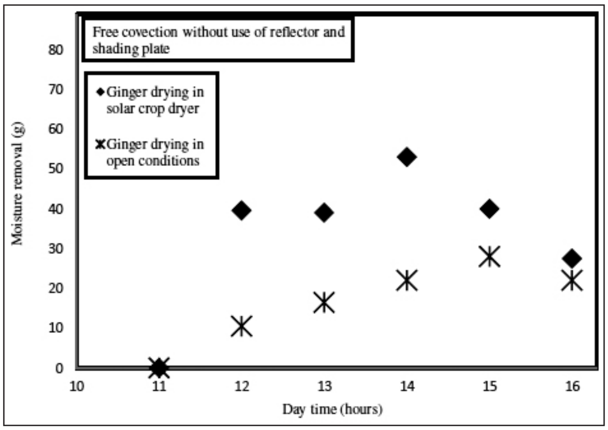

Fig. 5. Moisture removal from ginger during drying in solar crop dryer and open conditions.

It can be observed that maximum amount of moisture removal of 53 gram took place during 13 to 14 hours. It may be due to the highest intensity of solar radiation during this interval of time. Total 199 gram of moisture was removed with drying in solar crop dryer and total 99 gram

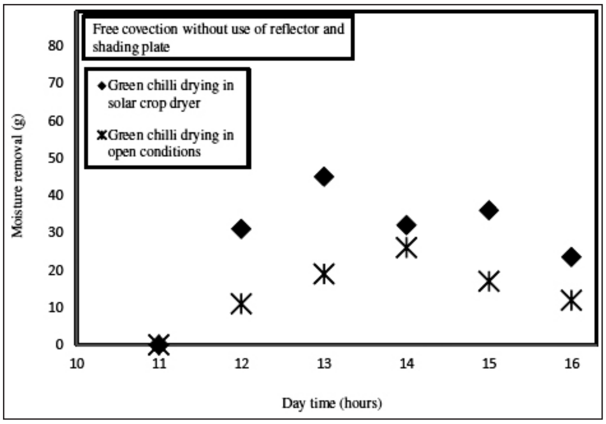

Fig. 6. Moisture removal from green chilli during drying in solar crop dryer and open conditions.

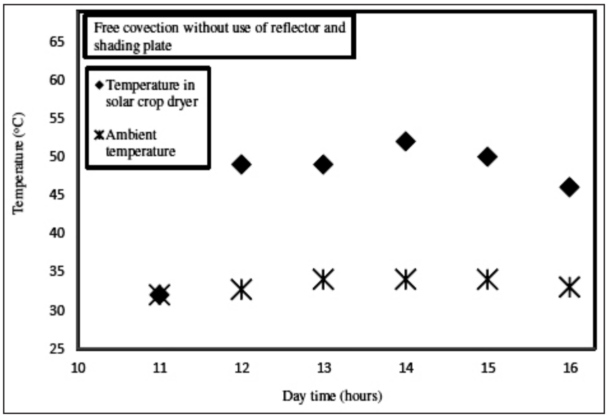

Fig. 7. Solar crop dryer temperature and ambient temperature during drying of ginger in solar crop dryer and open conditions.

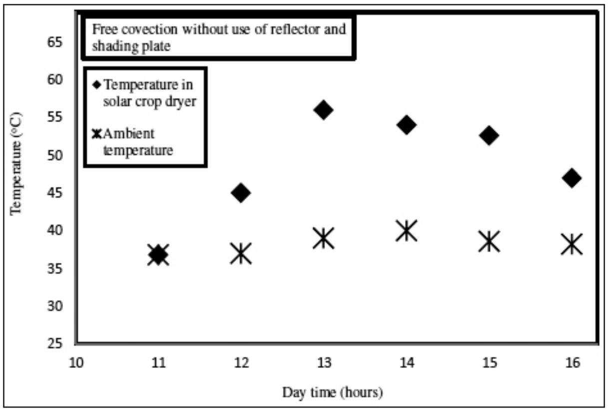

Fig. 8. Solar crop dryer temperature and ambient temperature during drying of green chilli in solar crop dryer and open conditions.

of moisture was removed in open conditions. It can also be noted that moisture removal in solar crop dryer is two times as compared to drying in open conditions. Similarly, Fig. 6 shows the moisture removal from green chilli during drying process under these conditions. It can be observed that maximum amount of moisture removal of 45 gram took place during 12 to 13 hours. Total 167.5 gram of moisture was removed with drying in solar crop dryer and total 85 gram of moisture was removed in open conditions. It can also be observed that moisture removal in solar crop dryer is more than 1.9 times as compared to drying in open conditions.

Fig. 7 shows solar crop dryer and ambient temperature variation during drying of ginger in solar crop dryer and open conditions. An average temperature of 46.33^{o}C was recorded in solar crop dryer. Also, average ambient temperature was 33.28^{o}C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 13.05^{o}C under these conditions. It can also be noted that temperature of solar crop dryer firstly increases during time period from 11 to 14 hours and decreases from 14 to 16 hours. Similarly, Fig. 8 shows solar crop dryer and ambient temperature variation during drying of green chilli in solar crop dryer and open conditions. An average temperature of 48.56^{o}C was recorded in solar crop dryer. Also, average ambient temperature was 38.26^{o}C. Therefore, difference between average solar crop dryer temperature and average ambient temperature was 10.3^{o}C under these conditions. It can also be noted that temperature of solar crop dryer firstly increases during time period from 11 to 13 hours and then decreases from 13 to 16 hours.

It can be observed that average solar crop dryer temperature in case of green chilli was higher than that obtained in case of ginger under the above mentioned conditions. Figs. 5 and 6 show that amount of moisture removal in the case of ginger is higher than that of green chilli even though average temperature of solar crop dryer was less in case of ginger as compared to green chilli. This may have happened due to the fact that ginger was properly cut into pieces which resulted large surface area exposure to the flowing hot air.

5.2 Drying under free convection with use of reflector and without use of shading plate on the tray in solar crop dryer

Fig. 9 shows the variation of mass of ginger due to moisture removal during drying process under above mentioned conditions and open conditions. It can be noted that mass of crop decreases with time in both the cases of drying in solar crop dryer and open conditions. It can also be noted

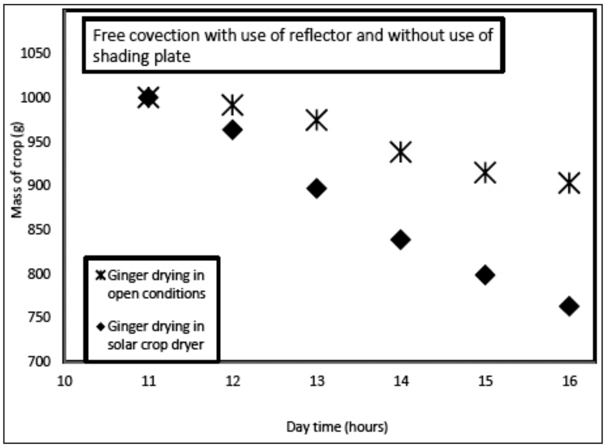

Fig. 9. Mass variation of ginger during drying in solar crop dryer and open conditions.

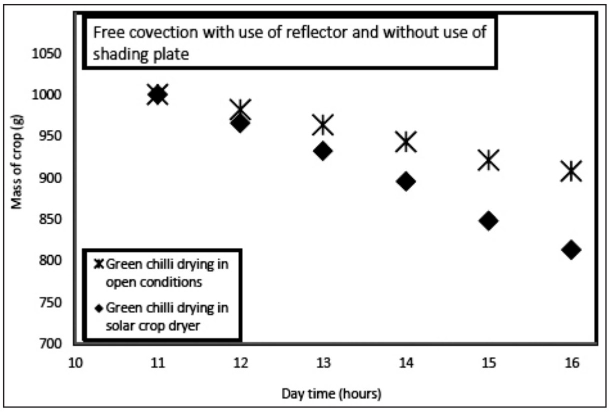

Fig. 10. Mass variation of green chilli during drying in solar crop dryer and open conditions.

that the mass reduction of crop is much more in case of solar crop dryer than that of open conditions. Under these conditions, mass of ginger was reduced to 763 gram from 1000 gram in solar crop dryer and it was reduced to 903 gram from 1000 gram in open conditions. Similarly, Fig. 10 shows the variation of mass of green chilli due to moisture removal during drying process under these conditions. Mass of green chilli was reduced to 813 gram from 1000 gram in solar crop dryer and it was reduced to 908 gram from 1000 gram in open conditions.

Fig. 11 shows the moisture removal from ginger during drying process under these conditions. It can be observed that maximum amount of moisture removal of 66.5 gram took place during 12 to 13 hours. It may be due to the highest intensity of solar radiation during this interval of time. Total 237 gram of moisture was removed with drying in solar crop dryer and total 97 gram of moisture was removed in open conditions. It can also be noted that moisture removal in solar crop dryer is more than two times as compared to

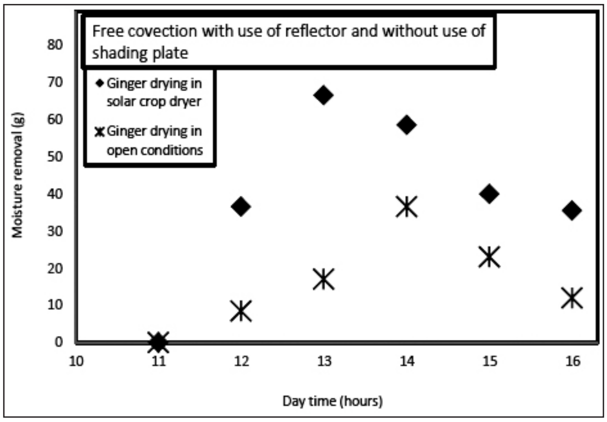

Fig. 11. Moisture removal from ginger during drying in solar crop dryer and open conditions.

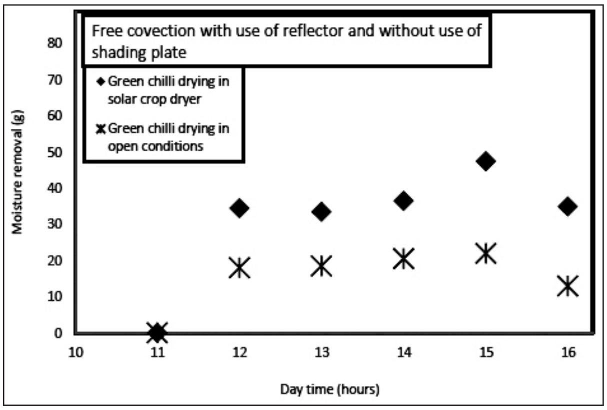

Fig. 12. Moisture removal from ginger during drying in solar crop dryer and open conditions.

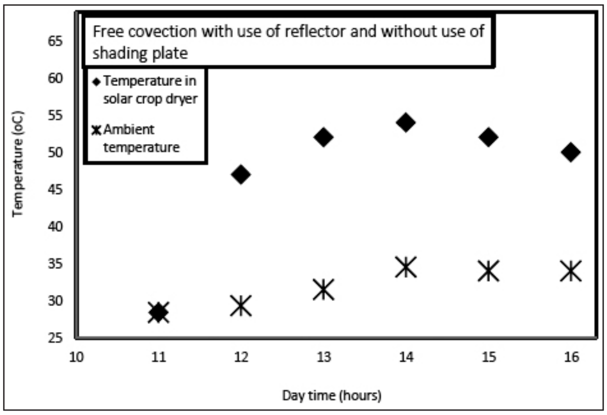

Fig. 13. Solar crop dryer temperature and ambient temperature during drying of ginger solar crop dryer and open conditions.

drying in open conditions. Similarly, Fig. 12 shows the moisture removal from green chilli during drying process under these conditions. It can be observed that maximum amount of moisture removal of 47.5 gram took place during 14 to 15 hours. Total 187 gram of moisture was removed with drying in solar crop dryer and total 92 gram of moisture was removed in open conditions.

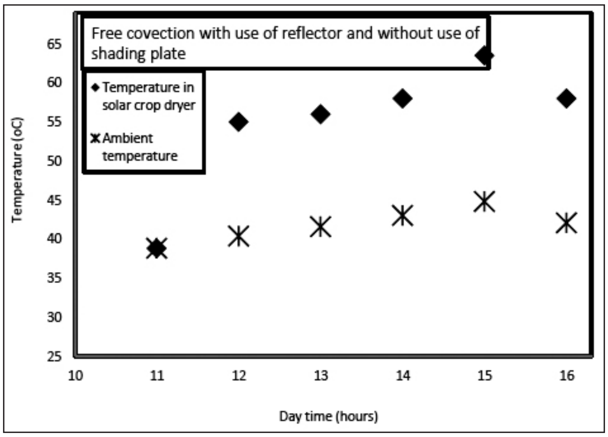

Fig. 14. Solar crop dryer temperature and ambient temperature during drying of green chilli solar crop dryer and open conditions.

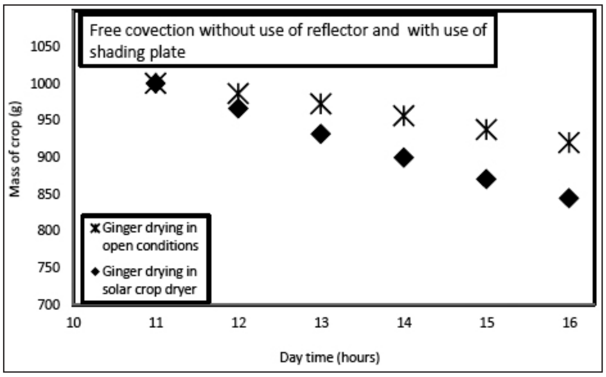

Fig. 15. Mass variation of ginger during drying in solar crop dryer and open conditions.

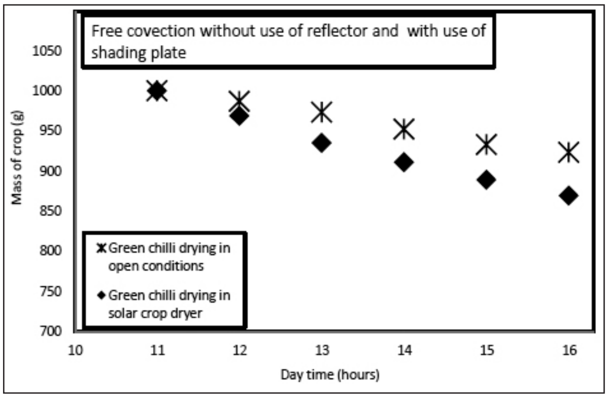

Fig. 16. Mass variation of green chilli during drying in solar crop dryer and open conditions.

It can also be observed that moisture removal in solar crop dryer is two times as compared to drying in open conditions.

Fig. 13 shows solar crop dryer and ambient temperature variation during drying of ginger in solar crop dryer and open conditions. An average temperature of 47.2°C was recorded in solar crop dryer. Also, average ambient temperature was 31.9°C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 15.28°C under these conditions. It can also be noted that in case of ginger, temperature of solar crop dryer firstly increases during time period from 11 to 14 hours and decreases from 14 to 16.Similarly, Fig. 14 shows solar crop dryer and ambient temperature variation during drying of green chilli in solar crop dryer and open conditions. An average temperature of 54.8°C was recorded in solar crop dryer. Also, average ambient temperature was 41.7°C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 13.1°C under these conditions. It can also be noted that in case of green chilli, temperature of solar crop dryer increases during time period from 11 to 15 hours and decreases from 15 to 16 hours.

It is important to mention that average temperature difference obtained in case of ginger is higher than that of green chilli under the above mentioned conditions but maximum solar crop dryer temperature obtained is in the case of ginger is less than that of green chilli. This may be due to more ambient temperature. It can also be observed from Figs. 11 and 12 that amount of moisture removal in the case of ginger is higher than that of green chilli even though average solar crop dryer temperature was less in case of ginger as compared to green chilli. This may have happened due to the fact that ginger was properly cut into pieces which resulted large surface area exposure to the flowing hot air.

5.3 Drying under free convection without use of reflector and with use of shading plate on the tray in solar crop dryer

Fig. 15 shows the variation of mass of ginger due to moisture removal during drying process under above mentioned conditions and open conditions. It can be noted that mass of crop decreases with time in both the cases of drying in solar crop dryer and open conditions. It can also be noted that the mass reduction of crop is more in case of solar crop dryer than that of open conditions. Under these conditions, mass of ginger was reduced to 844 gram from 1000 gram in solar crop dryer and it was reduced to 919.5 gram from 1000 gram in open conditions. Similarly, Fig. 16 shows the variation of mass of green chilli due to moisture removal during drying process under these conditions. Mass of green chilli was reduced to 869 gram from 1000

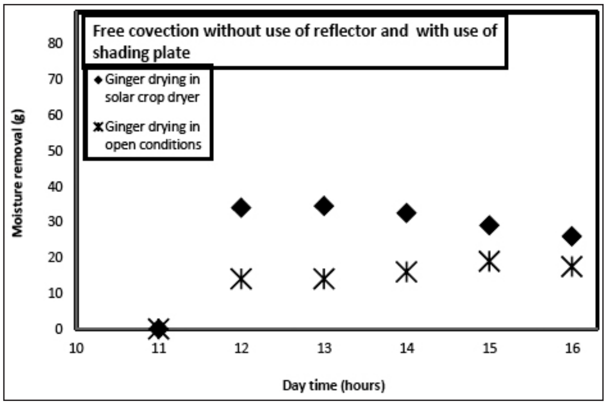

Fig. 17. Moisture removal from ginger during drying in solar crop dryer and open conditions.

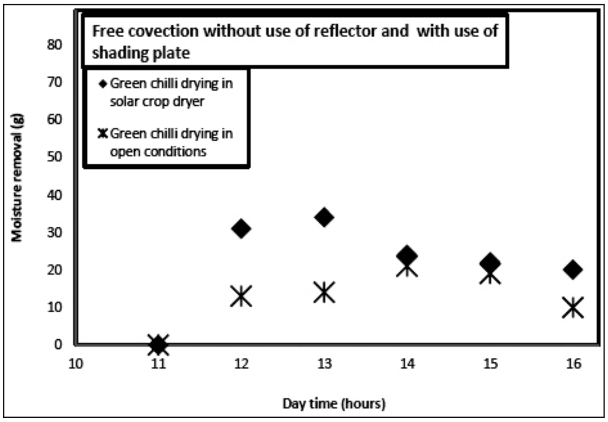

Fig. 18. Moisture removal from green chilli during drying in solar crop dryer and open conditions.

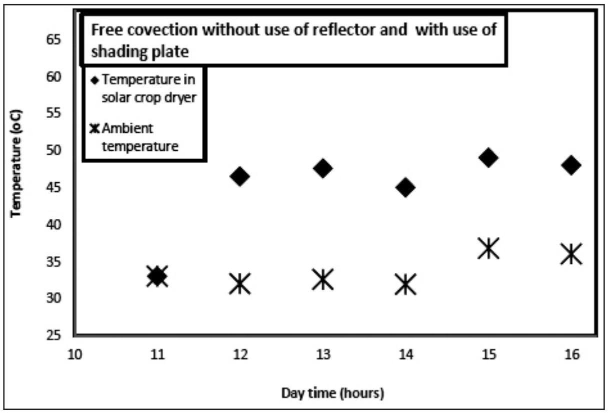

Fig. 19. Solar crop dryer temperature and ambient temperature during drying of ginger solar crop dryer and open conditions.

gram in solar crop dryer and it was reduced to 923 gram from 1000 gram in open conditions.

Fig. 17 shows the moisture removal from ginger during drying process under these conditions. It can be observed that maximum amount of moisture removal of 34.5 gram took place during 12 to 13 hours. It may be due to the highest intensity of solar radiation during this interval of

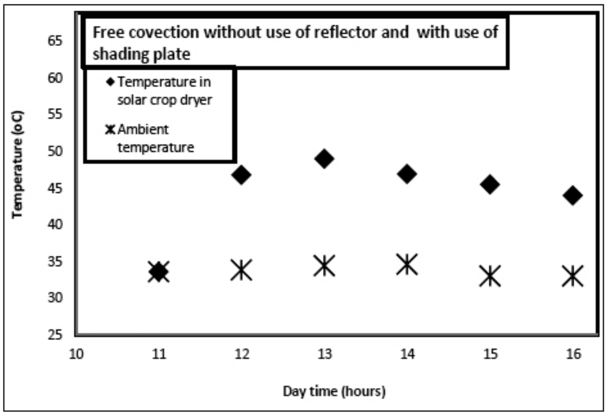

Fig. 20. Solar crop dryer temperature and ambient temperature during drying of green chilli solar crop dryer and open conditions.

time. Total 156 gram of moisture was removed with drying in solar crop dryer and total 80.5 gram of moisture was removed in open conditions. It can also be noted that moisture removal in solar crop dryer is 1.9 times as compared to drying in open conditions. Similarly, Fig. 18 shows the moisture removal from green chilli during drying process under these conditions. It can be observed that maximum amount of moisture removal of 34 gram took place during 12 to 13 hours. Total 131 gram of moisture was removed with drying in solar crop dryer and total 77 gram of moisture was removed in open conditions. It can also be observed that moisture removal in solar crop dryer is 1.7 times as compared to drying in open conditions.

Fig. 19 shows solar crop dryer and ambient temperature variation during drying of ginger in solar crop dryer and open conditions. An average temperature of 44.85°C was recorded in solar crop dryer. Also, average ambient temperature was 33.71°C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 11.14°C under these conditions. It can also be noted that in case of ginger, temperature of solar crop dryer firstly increases during time period from 11 to 13 hours and then decreases to 14 & again increases to 15 hours & decreases to 16 hours in case of ginger. Similarly, Fig. 20 shows solar crop dryer and ambient temperature variation during drying of green chilli in solar crop dryer and open conditions. An average temperature of 44.3°C was recorded in solar crop dryer. Also, average ambient temperature was 33.73°C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 10.57°C under these conditions. It can also be noted that in case of green chilli, temperature

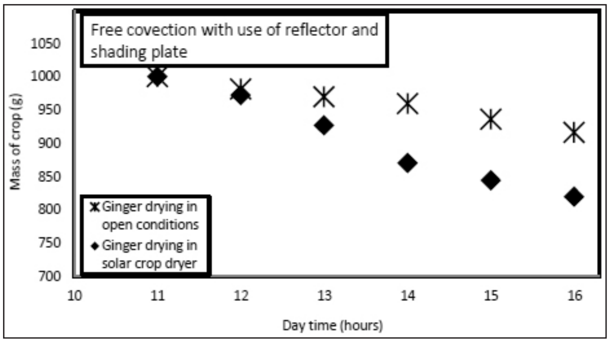

Fig. 21. Mass variation of ginger during drying in solar crop dryer and open conditions.

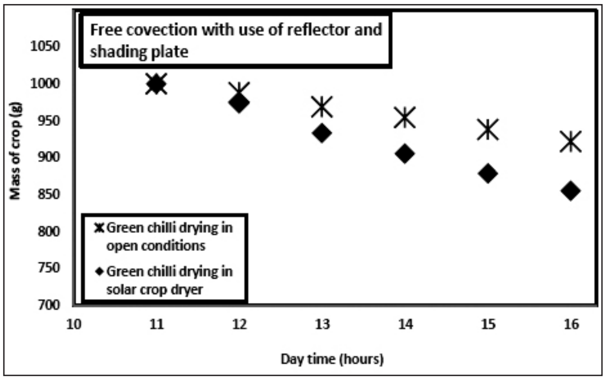

Fig. 22. Mass variation of green chilli during drying in solar crop dryer and open conditions.

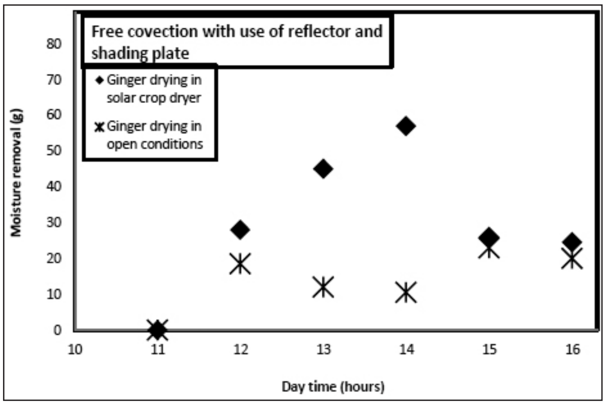

Fig. 23. Moisture removal from ginger during drying in solar crop dryer and open conditions.

of solar crop dryer firstly increases during time period from 11 to 13 hours and decreases from 13 to 16 hours.

It can be noted that average temperature differences are almost equal in both the cases of ginger and green chilli under the above mentioned conditions. It can also be observed that average solar crop dryer temperature is almost same in the case of green chilli and ginger under the above mentioned conditions. Figs. 17 and 18 show that amount of moisture removal in the

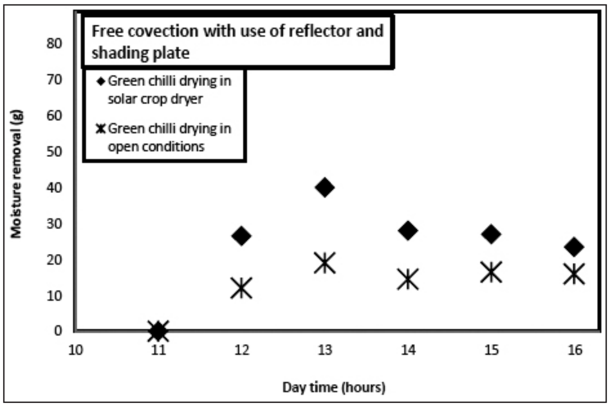

Fig. 24. Moisture removal from green chilli during drying in solar crop dryer and open conditions.

case of ginger is higher than that of green chilli even though almost same average temperature of solar crop dryer was attained in both the cases of ginger and green chilli. This may have happened due to the fact that ginger was properly cut into pieces which resulted large surface area exposure to the flowing hot air. It can also be noted from Figs. 5.17 and 5.18 that moisture removal differences of solar crop dryer and open conditions are almost equal in both the cases of ginger and green chilli under the above mentioned conditions.

5.4 Drying under free convection with use of reflector and shading plate on the tray in solar crop dryer

Fig. 21 shows the variation of mass of ginger due to moisture removal during drying process under above mentioned conditions and open conditions. It can be noted that mass of crop decreases with time in both the cases of drying in solar crop dryer and open conditions. It can also be noted that the mass reduction of crop is more in case of solar crop dryer than that of open conditions. Under these conditions, mass of ginger was reduced to 819.5 gram from 1000 gram in solar crop dryer and it was reduced to 916 gram from 1000 gram in open conditions. Similarly, Fig. 22 shows the variation of mass of green chilli due to moisture removal during drying process under these conditions. Mass of green chilli was reduced to 855 gram from 1000 gram in solar crop dryer and it was reduced to 922 gram from 1000 gram in open conditions.

Fig. 23 shows the moisture removal from ginger during drying process under these conditions. It can be observed that maximum amount of moisture removal of 57 gram took place during

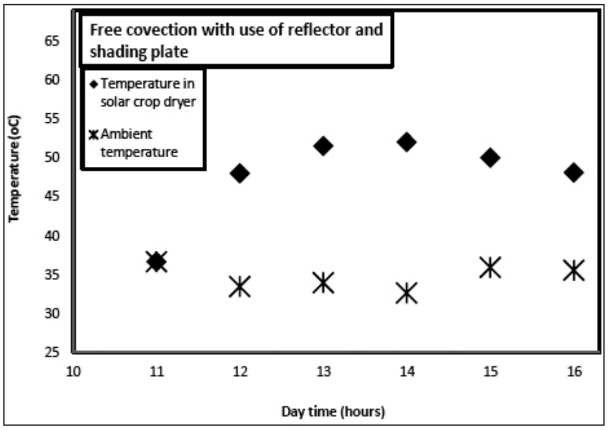

Fig. 25. Solar crop dryer temperature and ambient temperature during drying of ginger solar crop dryer and open conditions.

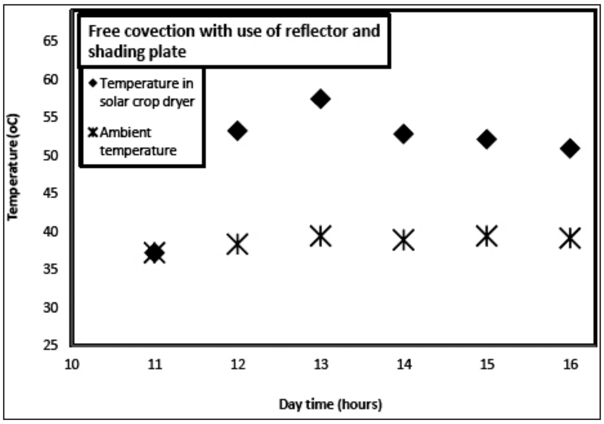

Fig. 26. Solar crop dryer temperature and ambient temperature during drying of green chilli solar crop dryer and open conditions.

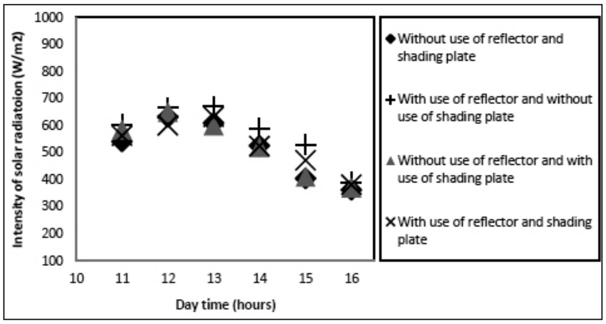

Fig. 27. Solar intensity variation over a day for different conditions under free convection in the case of drying ginger.

13 to 14 hours. It may be due to the highest intensity of solar radiation during this interval of time. Total 180.5 gram of moisture was removed with drying in solar crop dryer and total 84 gram of moisture was removed in open conditions. It can also be noted that moisture removal in solar crop dryer is more than two times as compared to drying in open conditions. Similarly,

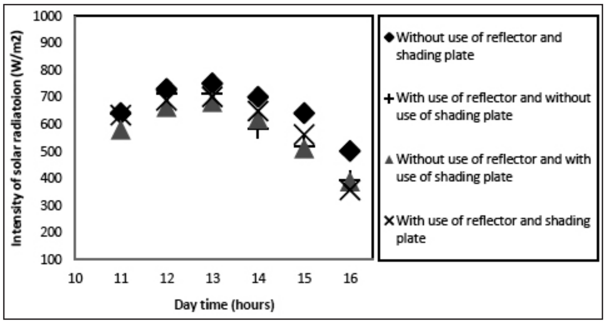

Fig. 28. Solar intensity variation over a day for different conditions under free convection in the case of drying ginger.

Fig. 24 shows the moisture removal from green chilli during drying process under these conditions. It can be observed that maximum amount of moisture removal of 40 gram took place during 12 to 13 hours. Total 145 gram of moisture was removed with drying in solar crop dryer and total 78 gram of moisture was removed in open conditions. It can also be observed that moisture removal in solar crop dryer is more than 1.8 times as compared to drying in open conditions.

Fig. 25 shows solar crop dryer and ambient temperature variation during drying of ginger in solar crop dryer and open conditions. An average temperature of 47.7^{o}C was recorded in solar crop dryer. Also, average ambient temperature was 34.65^{o}C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 13.05^{o}C under these conditions. It can also be noted that in case of ginger, temperature of solar crop dryer firstly increases during time period from 11 to 14 hours and decreases from 14 to 16 hours. Similarly, Fig. 26 shows solar crop dryer and ambient temperature variation during drying of green chilli in solar crop dryer and open conditions. An average temperature of 50.6^{o}C was recorded in solar crop dryer. Also, average ambient temperature was 38.71^{o}C. Therefore, difference between average solar crop dryer temperature and average ambient temperature is 11.89 C under these conditions. It can also be noted that in case of green chilli, temperature of solar crop dryer firstly increases during time period from 11 to 13 hours and then decreases from 13 to 16 hours.

It can be observed that average solar crop dryer temperature in case of green chilli was higher than that obtained in case of ginger under the above mentioned conditions. Figs. 23 and 24 show that amount of moisture removal in the case

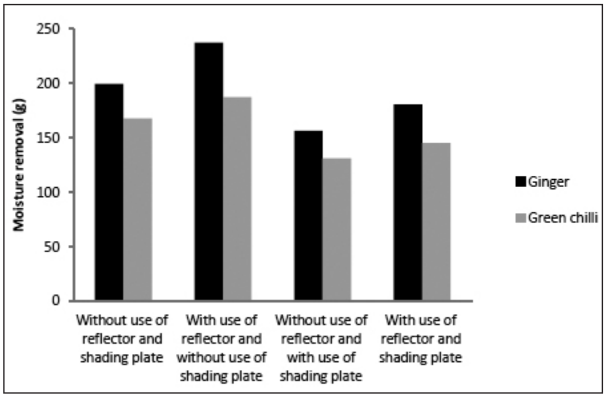

Fig. 29. Moisture removal from ginger and green chilli for different conditions under free convection.

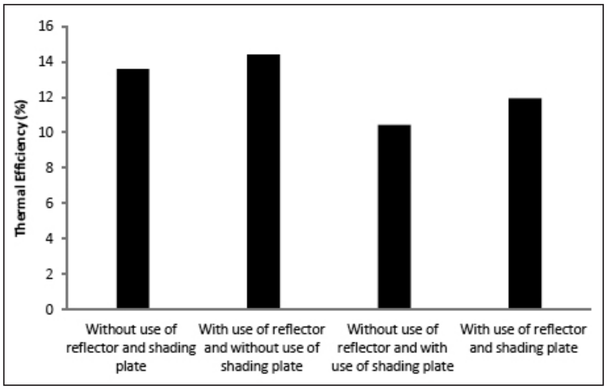

Fig. 30. Thermal Efficiency for different conditions in the case of ginger drying under free convection.

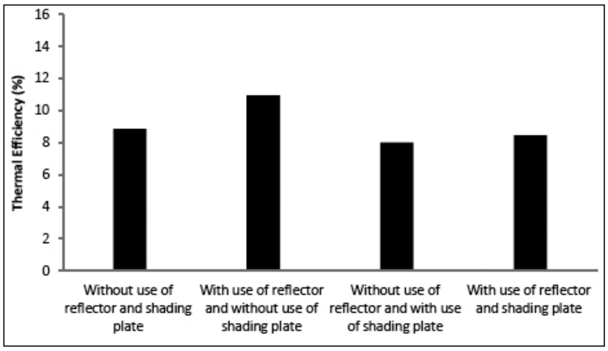

Fig. 31. Thermal Efficiency for different conditions in the case of green chilli drying under free convection.

of ginger is higher than that of green chilli even though average temperature of solar crop dryer was less in case of ginger as compared to green chilli. This may have happened due to the fact that ginger was properly cut into pieces which resulted large surface area exposure to the flowing hot air.

Figs. 5.27 and 5.28 show solar intensity variation over a day for different conditions under free convection in the case of drying ginger and green chilli respectively. Fig. 5.29 shows the drying comparison of ginger and green chilli for different conditions under free convection.

Figs. 30 and 31 show thermal efficiency for different conditions under free convection in the case of drying ginger and green chilli respectively. With drying of ginger under free convection, maximum thermal efficiency of 14.41% has been obtained for the case when reflector was used and shading plate was not used. Also, with drying of green chilli under free convection, maximum thermal efficiency of 10.43% has been obtained for the case when reflector was used and shading plate was not used. This may have happened due to the fact that reflector has enhanced the amount of incident solar radiation on to the solar crop dryer.

With drying of ginger under free convection, minimum thermal efficiency of 10.43% has been obtained for the case when reflector was not used and shading plate was used. Also, with drying of green chilli under free convection, minimum thermal efficiency of 8% has been obtained for the case when reflector was not used and shading plate was used. This may have happened due to the fact that less amount of incident solar radiation could have reached the crop due to the presence of shading plate.

Under free convection, when reflector and shading plate were used simultaneously, thermal efficiency of 11.92% and 8.45% was obtained for drying ginger and green chilli respectively. Similarly, when reflector and shading plate were not used, thermal efficiency of 13.58% and 8.84% was obtained for drying ginger and green chilli respectively.

6. Conclusion

Following major conclusions have been drawn from the experimental investigation reported in the present paper.

- Moisture removal from ginger and green chilli with drying in solar crop dryer is found two to three times higher than that of simultaneous drying of the same in open conditions.
- Drying of ginger resulted in 1.19 to 1.26 times higher moisture removal than green chilli for all conditions under free convection in solar crop dryer.
- Under free convection crop drying, maximum

moisture removal of 23.7% was found in the case of ginger when reflector was used and shading plate was not used.

- Under free convection crop drying, minimum moisture removal of 13.1% was found in the case of green chilli when reflector was not used and shading plate was used over crop tray.
- Maximum average solar crop dryer temperature of 54.8°C over a day has been attained in the case of ginger drying when reflector was used and shading plate was not used.
- Minimum average solar crop dryer temperature of 44.3°C over a day has been attained in the case of green chilli drying when reflector was not used and shading plate was used under free convection.
- Maximum difference of 15.3°C between average solar crop dryer temperature and average ambient temperature has been found in the case of ginger when reflector was used and shading plate was not used.
- Minimum difference of 10.3°C between average solar crop dryer temperature and average ambient temperature has been found in the case of green chilli when reflector and shading plate, both were not used.
- Maximum thermal efficiency of 14.4% has been found in the case of ginger drying when reflector was used and shading plate was not used.
- Minimum thermal efficiency of 8% has been found in the case of green chilli drying when reflector was not used and shading plate was used.

References

1. Ezekwe, C.I. (1981). *Crop drying with solar air heaters in tropical Nigeria*. ISES, Solar World Forum, Brighton, UK. 997-1005
2. Sodha, M.S., Dang, A., Bansal, P.K., & Sharma, S.B. (1985). An analytical and experimental study of open sun drying and a cabinet type drier. *Energy Conversion Management.* 25(3), 263–271.
3. Khattab, N.M.(1996). Development of an efficient family size solar dryer. *Energy sources*. 18(1), 85-93.
4. Hallak, H., Hillal, J., Hilal, F. &, Rahhal, R. (1996). The staircase solar dryer: design and characteristics. *Renewable Energy*.7(2), 177-183.
5. Ekechukwu, O.V., & Norton, B. (1999). Review of solar-energy drying systems II: an overview of solar drying technology. *Energy Conversion and Management*. 40(6)615-55.
6. Ahmad, M., Hauser, J.C., Heijnen, C. &, Chaudry, M.A. (2002). Solar drying of fruits and vegetables. *Pakistan Journal of Agricultural Research.*
7. Desai, S.R., Kumar, V., & Guruswamy, T. (2002). Performance evaluation of mini multi-rack solar dryer for grapes drying. Agricultural Engineering Today. 26(3-4), 30-37.
8. Singh, P.P., Singh, S., & Dhaliwal, S.S. (2006). Multi-shelf domestic solar dryer. *Energy Conversion and Management.* ;47(13-14),1799-1815.
9. Akoy, E.A., Ismail, M.A., Ahmed, E.F., & Luecke, W. (2006). Design and construction of a solar dryer for mango slices. Proceedings of International Research on Food Security, Natural Resource Management and Rural Development-Tropentag. University of Bonn, Bonn, Germany.
10. Gbaha, P., Andoh, H.Y., Saraka, J.K., Koua, B.K., & Toure, S. (2007). Experimental investigation of a solar dryer with natural convective heat flow. *Renewable Energy*. 2007 32(11), 1817-1829.
11. Afriyie, J.K., Nazha, M.A., Rajakaruna, H., Forson, F.K. (2009). Experimental investigations of a chimney-dependent solar crop dryer. *Renewable Energy*. 34(1),217-222.
12. Saleh, A., & Badran, I. (2009). Modeling and experimental studies on a domestic solar dryer. *Renewable Energy*. 34(10):2239-2245.
13. Rajeshwari, N., & Ramalingam, A. (2012). Low cost material used to construct effective box type solar dryer. *Archives of Applied Science Research.* 4(3), 1476-1482.
14. Hii, C.L., Jangam, S.V., Ong, S.P., & Mujumdar AS. *Solar drying: Fundamentals, applications and innovations.* TPR Group Publication, Singapore.
15. Gutti, B., Kiman, S., & Murtala, A.M. (2012). Solar Dryer-An Effective Tool for Agricultural Products Preservation. *Journal of Applied Technology in Environmental Sanitation*. 2(1).

16. Eke, B.A. (2013) Development of small scale direct mode natural convection solar dryer for tomato, okra and carrot. *International Journal of Engineering and Technology*. 3(2).
17. Ozuomba, J.O., Okonkwo, N.A., Uzor, B.C., & Uba, J.I. (2013). Fabrication and characterization of a direct absorption solar dryer. *Advances in Applied Science Research.* 4(3),186-194.
18. Yelttiwar, S.G., Wajire, P.N., & Kalbande, S.R. (2014). Investigation on domestic solar cabinet dryer assisted with reflectors. *International Journal & Magazine of Engineering, Technology, Management and Research.*
19. Chaudhari, R.H., & Bhavsar, S. (2015). Hybrid Solar Box Type Dryer cum Cooker of Chilly Drying For Domestic Usage. *International Journal of Science and Research.* 6(6), 1614-1618.
20. Gupta, P.M., Das, A.S., Barai, R.C., Pusadkar, S.C., & Pawar, V.G. (2017). Design and Construction of Solar Dryer for Drying Agricultural Products. *International Research Journal of Engineering and Technology*.04(03), 1946-1951.

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