# Performance Evaluation of forced Convection solar dryer under Jimma condition

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***Abstract-*** Drying is a post-harvest process that consumes significant energy. It can affect the quality of the agricultural product. Using solar dryer most agricultural product can be preserved efficiently. The objective of the study is evaluating the forced convection mixed-mode solar dryer design under Jimma Ethiopia condition in drying parchment coffee bean and red pepper.

The temperature and humidity inside and outside the drying Chamber was measured with digital thermohygro meter and Collector outlet temperature, drying chamber outlet temperature are measured by means of digital type thermometer. A digital electronic balance was used to weigh the samples; drying oven method is used to determine the amount of moisture in the products. The speed of air from the blower was controlled using air inlet valve on the blower. The comparison is done with the open sun drying on same day and at same time during the drying process.

Since the speed of air from the blower has an effect on the transfer of hot air to the drying chamber, One third opening valve position of the blower was selected. The Minimum and maximum temperature observed within the drying chamber and ambient temperature respectively Min. 31.40 and 19.10, Max. 56.60 and 30.00 ºC during drying of red pepper and min 28.90 and 20.00, Max. 45.70 and 29.00ºC during drying of parchment coffee bean. Observed System drying Efficiency of the solar dryer on the Bottom and upper drying Tray is 10.4 and 12.27% respectively for parchment coffee bean drying and 29.07 and 30.5 % was observed respectively in the Bottom and upper drying Tray in the drying of red pepper.

Drying parchment coffee bean and red pepper by forced convection mixed-mode solar dryer it takes 71hours to dry red pepper of 9.1 kg with final moisture content of 9.22% and 8.24% on bottom and upper drying try respectively. Similarly, it takes 26 hours to dry parchment coffee bean of 18.2kg with final moisture content of 13% and 9% on bottom and upper drying try respectively. But, the drying in open sun takes much more time.

***Index Terms***- Coffee, drying, red pepper, Solar, Temperature

## I. INTRODUCTION

Drying is one part of the post-harvest process that is accountable for the removal of excess moisture to a level that is safe for long time storage without affecting the quality of the final product [1] .

Pepper production in Ethiopia probably the most earliest than any other vegetable produce. Ethiopians have solid connection to red pepper, which has high value principally for its high pungency. The fine powdered pungent substance in the popular traditional sauce "Wot" is an essential flavoring and coloring ingredient while the green pod with other food products is consumed as a vegetable. Ethiopians are generally belief that a person who frequently consumes hot pepper has resistance to various diseases. Ethiopian adult is estimated to eat 15 grams of hot pepper average daily, which is higher than tomatoes and most other vegetables. Total pepper production in the country was estimated at 3.1 million quintals for the 2016/2017 Ethiopian main cropping season. The region's share of total red pepper production in the country is 69 percent, followed by the Amahara region, which accounts for about 27 percent of the country's total output. In the crop year 2014/2015 the total area cultivated land and output was 67,072 hectares and 1,970,068 quintals respectively[2].

Coffee is one of the world's largest agricultural export commodities, next to oils, and it is the most important and strategic commodity on which the economy of Ethiopia depends. It has always been the main cash crop and export product in Ethiopia, accounting for 90 per cent of exports and 80 per cent of total jobs[3]. Coffee quality directly influences coffee farmers' prices because when coffee quality is high, coffee prices are also high and vice versa [1].

Jimma Zone is Ethiopia's largest and popular coffee-producing region; has a range of small-scale coffee pulping industries located along river banks and/or streams [4]. 105,140 ha of coffee-covered land contributing 27% of the country's export coffee and 43% of the Oromia region's export share [5].

Over one million small-scale coffee farming households therefore produce around 90 per cent of Ethiopian coffee. In addition, about 25% of the Ethiopian population depends directly or indirectly on the production, processing and marketing of coffee. It is estimated that 40 per cent of the quality of coffee is calculated in the field, 40 per cent in primary processing after harvest and 20 per cent in secondary / export processing and handling including storage [6].

Sun drying is the oldest way of drying agricultural produce ever known to man and it involves simply placing the agricultural products in the sun on mats, roofs or drying floors. It has many drawbacks because farm produce is spread out in the open sky and there is a greater chance of spoilage due to adverse climatic conditions such as wind, rain, moist and dust, loss of product to insects, birds and rodents. Totally dependent on good weather and very slow drying rate with danger of mold formation, causing the product to deteriorate and decompose. The method often demands vast areas of land, it takes time and intensively labor. The solar dryer can be seen as one of the solutions to the food and energy shortages of the nation and can be preserved effectively by using a solar dryer. [7].

Nonetheless, Jimma region coffee is the least-priced coffee relative to other sources that is mostly due to poor methods of processing. Approximately 48 percent of producers spread their coffee on the ground, while 49.5 percent use bamboo mats or wire meshes to dry the crop on raised drying beds and just 2.5 percent use cemented / brick floors[5].

Despite the coffee's economic value in Ethiopia, many rural coffee farmers have not prioritized proper drying mechanisms. The coffee is primarily dried by spreading on the surfaces of bare earth, where it is subjected to radiation from the sun. Although it is cheap and relatively efficient, it has some outstanding disadvantages, such as increased free land costs, which limit the area of the sun-drying floor, high labor requirements, pollution from dust and dirt, and exposure to intermittent rains during the drying. Such disadvantages result in high moisture content of coffee, which is vulnerable to mould attack. In addition, the price of the coffee will decrease dramatically. Consequently, this results in low farmer prices [1].

Also as rising populations place pressure on food sources, about one-third of the total food produced for human consumption is lost, with the majority of the loss occurring between harvest and user in developing countries. Controlling product dryness is the most critical factor for maintaining quality in stored non-perishable foods[8].

The purpose of solar drying is to supply more heat to the crop than is available under atmospheric conditions, thereby increasing sufficiently the vapor pressure of the moisture retained within the crop and significantly decreasing the relative humidity of the drying air. This consequently increases the moisture carrying capacity of drying air, which sufficiently lowers the equilibrium moisture content of the crop being dried.

Experiments carried out in many countries have clearly demonstrated that solar energy can be used effectively to dry farm crops. Some essential targets of food dehydration are weight and volume reduction, intended to reduce transport and storage costs [9].

This research was aimed at evaluating the solar dryer fabricated in the center under Jimma condition in drying parchment coffee bean and red pepper.

## II. MATERIAL AND METHODS

### Description of the study area

The research was conducted at Jimma Agricultural Engineering Research Center, Jimma Zone, Ethiopia's Oromia region 353 km southwest of Addis Ababa. The total area of the zone is 18415 $km^2$ and ranges between 7 ° 18′N and 8 ° 56′N latitudes and 35 ° 52′E and 37 ° 37′E longitudes. The area's main soil types are nitosol and combbsols and receives an average annual rainfall of 1,467 mm per year [10].

The zone has an elevation of 880 to 3360 meters (masl) above sea level. For 8 to 10 months receives an average annual rainfall of 1000 mm. The main rainy season stretches from May to September and there is a minor rainy season in February, March and April. Jimma zone temperatures range from 8 - 28°C. The average temperature is 20°C annually. The study area agro-ecologies have a range of altitudes of 1000-1500 (lowlands), 1500-2500 (intermediate) and 2500-3360 masl (highlands)[11].

**Experimental procedure**

Fig. 1 Photo of the produced solar dryer design

The temperature and humidity inside and outside the drying Chamber (ambient) was measured with digital thermohygro meter model ETH-1 measuring temperature range of -40 to 70ºC resolution of 0.1ºC and Relative humidity range 20 to 90%RH resolution of 1%RH. Collector outlet temperature, drying chamber outlet temperature are all measured by means of Therma 1 digital type thermometer measuring over the range of -50 to 1370°C with a 0.1/1°C resolution.

Air velocity at drier inlet and exit was measured by using portable Digital Anemometer MS 6250 measuring over the range of 0.4 to 30.0 m/s, Air Velocity Resolution : 0.1 m/s and Air Velocity Accuracy : ±2.0%. A digital electronic balance Model CTI200-s of 6 and 1.2 kg capacity having precision 1 and 0.1 g respectively was used to weigh the samples. Drying oven method is used in this study to determine the amount of moisture. The initial moisture content was determined by the oven method at 103°C for 72 h, samples were weighted every two hours during processing in the drying oven. Measurements continued until the change between two measurements was less than 0.04% [12, 13]. Others are measured by means of infrared temperature measuring instrument.

The given experiments are conducted in the forced convection mixed-mode solar dryer under no load condition for evaluating the effect of blower of diameter 4” and with parchment coffee bean and red pepper loading. The speed of air from the blower was controlled using air inlet valve on the blower (Valve closed, one third open, two third open and fully opening of the valve).

The comparison is done simultaneously with the open sun drying during the drying process of parchment coffee bean and red pepper on the selected air speed of the blower.

**Measurements and calculations**

Moisture content ($M_c$) of substance is express as percentage by weight on wet basis and dry basis. The moisture content wet basis was calculated according

$$M_c = \frac{M_w - M_d}{M_w} * 100$$

where, $M_w$ is the mass of the wet material and $M_d$ is the mass of dry materials

Amount of moisture to be removed can be calculated as

$$M_w = \frac{M_{cI} - M_{cF}}{100 - M_{cF}} * M_p$$

Where, $M_w$ is amount of water to be removed of water, kg, $M_{cI}$ is initial Moisture content, $M_{cF}$ is Final Moisture content, $M_p$ is initial mass of product to be dried, kg.

Drying rate $D_R$ depends on the total mass of water to be evaporated to the time interval required in seconds

$$D_R = \frac{M_w}{t}$$

System drying efficiency for Forced convection solar dryer in day time is defined as the ratio of energy supplied to evaporate the moisture of the product to the Energy supplied to the drier.

$$\eta_S = \frac{M_W * L}{A_S * I * t + E} * 100$$

Where L= Latent heat of vaporization in kJ/kg

$I$ is the solar Intensity in $k\frac{W}{m^2}$

$A_s$ is the surface area of the solar collector in $m^2$

t total time of drying in seconds

E Energy supplied to the Blower in Joule

Effectiveness factor:

It can be defined as ratio of drying rate in the Cabinet Solar dryer to the drying rate in the open sun drying.

$$E_f = \frac{\text{Drying rate in solar dryer}}{\text{Drying rate in open sun drying}}$$

## III. Result and Discussion

**Effect of blower valve position**

Table 1. One-way ANOVA: Blower valve position versus Drying chamber Temperature

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Blower | 4 | 560.6 | 140.16 | 15.64 | 0.00000000808 *** |
| Residuals | 60 | 537.8 | 8.96 | | |

| | Mean | sd | data: n | Multi comparisons of means |
|---|---|---|---|---|
| BC | 43.38 | 2.67 | 13 | "b" |
| BFO | 39.57 | 3.59 | 13 | "a" |
| BOThO | 39.32 | 3.35 | 13 | "a" |
| BTThO | 40.57 | 1.76 | 13 | "ab" |
| No | 47.11 | 3.22 | 13 | "c" |

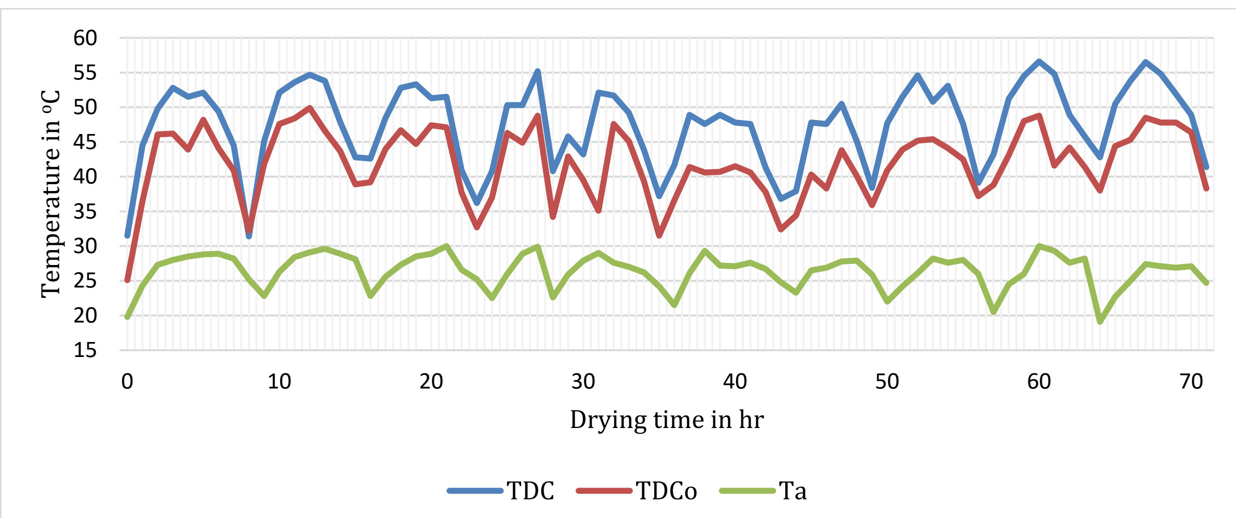
**significant at p<0.05, Means with different letter indicates significant difference

There was significant effect of blower valve position on drying chamber Temperature distribution $p < 0.05$. Tukey's multiple Paired comparison test indicated that BC (Valve closed position) was significantly different from the valve open position fully open (BFO), One-third open(BOThO) and Two-third open(BTThO), but within the valve opening position BFO, BOThO and BTThO significant difference is not seen from each other. The control, without blower (NO) was significantly different from other. This clearly shows the reliance of the dryer's output on air speed, the device efficiency increased as the air speed increased [14]. If the Blower's speed increases then the temperature will also increase. This is in accordance with the theory of kinetic gas that explains the relationship between speed and temperature is comparable, because the particles in a certain room move faster due to the speed increase [15]. Variation of moisture removal rate with air velocity is typically increased as air velocity increases for a given grain layer thickness. This is because at greater velocity, the air was able to carry away more moisture[16]. The variation of air flow velocity from the solar collector to the drying chamber using the exhaust fan (Blower) showed that the airflow velocity provides the highest drying room temperature increase, indicating that the speed of the exhaust fan has an effect on the transfer of hot air flow to the dryer chamber temperature[17].

With increase in mass flow rate of air the outlet air temperature of collector is going to decrease which reduces the drying temperature required and thus increases drying time [18]. So blower with valve One-third open (BOThO) position of air velocity 17.57m/s was selected for testing parchment coffee bean and red pepper testing.

**Temperature distribution during drying time**

The temperature in the drying chamber was uninterruptedly registered with loaded chamber. Figures 1 and 2 shows the temperature distribution in drying chamber and the ambient temperature during drying of each red pepper and parchment coffee bean. The result shows that the characteristic of the temperature distribution is suitable for drying coffee seeds that requires the optimum temperature in the range of 45-50 degree Celsius and 55 degree Celsius for pepper drying [19]. Red pepper drying process was takes place for ten days of 71hrs. Whereas parchment coffee bean drying process was takes place for four days of 26hrs. The average and minimum solar radiation (kwh/m2/d) in the study area is 5.4 and 4.60 respectively.




Where TDC-Temperature of drying chamber, TDCo- Temperature at drying chamber outlet and Ta – Ambient Temperature

Fig.1 Temperature Distribution during Red pepper drying

On fig.1 the Minimum and maximum temperature observed within the drying chamber respectively with ambient temperature as Min. 31.40 and 19.10, Max. 56.60 and 30.00 °C during drying of red pepper.

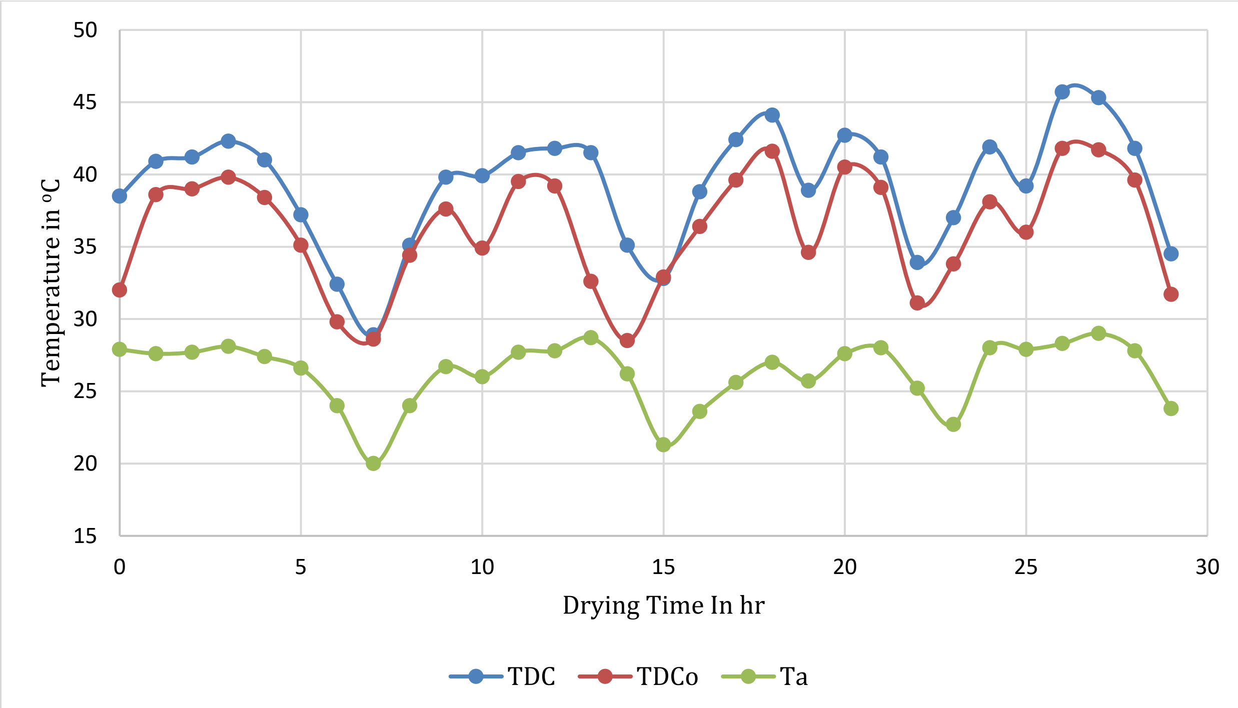



Fig.2 Temperature Distribution during parchment coffee bean drying

Similarly, on fig.2 the Minimum and maximum temperature observed within the drying chamber respectively with ambient temperature as min 28.90 and 20.00, Max. 45.70 and 29.00°C during drying of parchment coffee bean. The temperature in the ambient is relatively low. Thus, the hourly variation of temperatures within the drying chamber during most hours of daylight is much higher than the ambient temperature. The temperature increase inside the drying chamber was averagely up by 12.98°C and 21.13°C for the time of exposure respectively for parchment coffee bean and red pepper drying. This suggests a possibility of better results than open-air sun drying[20].

**Change in Moisture content during drying time**

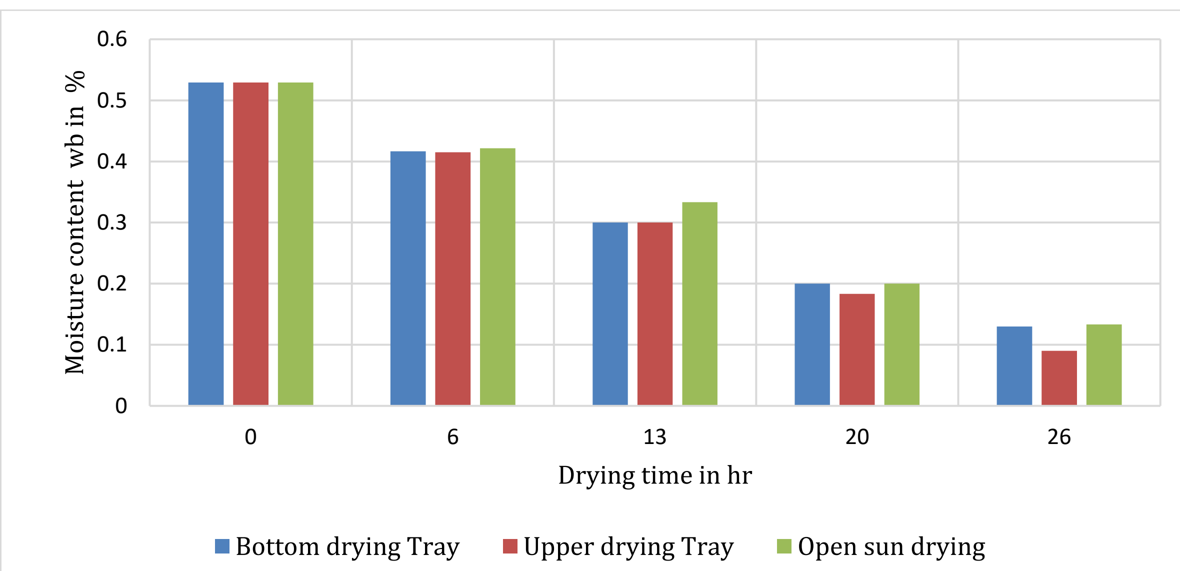



Fig.3 Moisture Content of the parchment coffee bean

The average initial moisture content of the freshly pulped parchment coffee bean was 52.93% wb while the average final moisture content obtained from the oven dry method was 13, 9 and 13.33% wb respectively for Bottom drying tray, Upper drying tray and open sun drying within the drying time. The initial moisture content lies within the range of 45 to 65% wb reported by [1]. From the result, the deviation of the final moisture content may be attributed to variation in tray position within the drying time.

Previously it was considered that sun dried coffee are the best in quality but now a days increase in the production and as a seasonal crop it is very difficult to go for only sun drying method. Sun drying of coffee in patios takes 7 to 15 days for parchment and 12 to 21 days for cherries, depending on climatic conditions [21].

The solar dryer could reduce the moisture content of coffee beans in 2 days from 54.8 percent to below 13 percent (w.b.) compared with the 5–7 days needed for sun drying [22]. Coffee beans are generally dried under the sun, where drying may take 4-5 days depending on the weather condition[23]. A drop in the drying time occurred when the temperature was high, since a high drying temperature raises the kinetic energy of a water molecule until it breaks free from the cohesive force[24].

Initial moisture content of the red pepper 75.37% was reduced to 11.3%, 9.2% and 8.24% respectively for open sun drying, Bottom drying tray and upper drying tray within the drying time. The upper tray gets more temperature than the lower tray because of the geometry of the solar dryer. Drying rate is very slow and takes 7-15 days, depending on the weather conditions red peppers are infected with dust, debris, rainfall, animals, birds, rodents, insects and micro organisms based on the environmental conditions.

The final drying stage of red chili was obtained after 41 h in the upper tray and 46 h in the lower tray, but in the open sun drying method with the same weather conditions it took around 91 h. For solar drying a major saving in drying time was obtained compared to open sun drying. Solar drying system under forced convection can be substantially higher than the open sun drying system[25]. The drying times of greenhouse and open-sun drying methods for red peppers were 72 h (3 days) and 117 h (5 days), respectively[26].

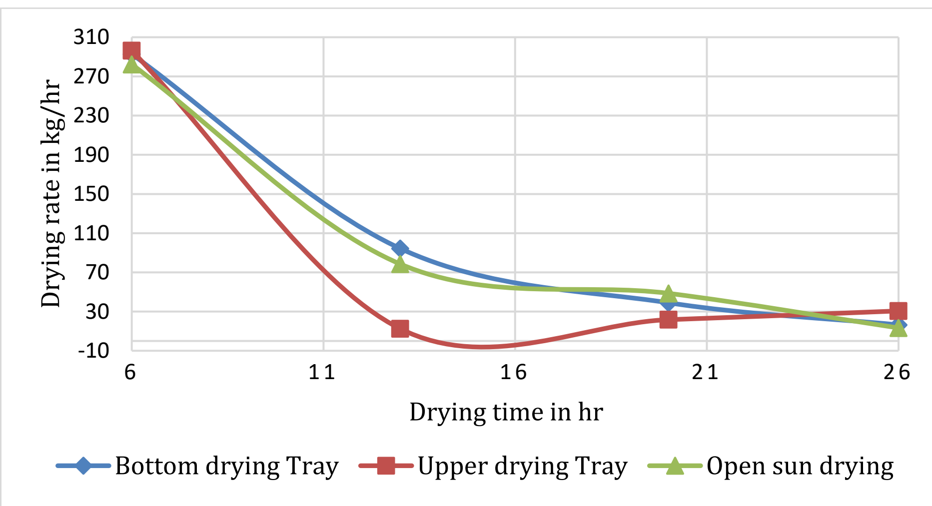



Fig.4 Drying rate of the parchment coffee bean

The result in fig.4 of drying rates versus drying time shows as the temperature of the drying air are influencing drying rate. Increasing drying temperature can be used to enhance efficiency of the process. However, sensitivity of the coffee beans should be taken into account. A rise of drying medium velocity does have an impact on the process, as long as drying medium becomes saturated. Lower relative air humidity has small impact on drying rate, but strongly affect the equilibrium humidity of the coffee. In order to optimize the drying process, the application of higher gas temperature at the beginning of the process and lower temperature at the end of the drying process is recommended[27]. As seen in the figure the drying rate of parchment coffee bean on the upper drying tray is higher than the other for the first day and then becomes decreasing for the second day and then increasing at slow rate for the other remaining time. Because the air passing the upper tray additionally heated on the top. The rate of drying is more and is found to be decreasing as time increases. This is due to the removal of moisture from the surface, first accompanied by the transfer of moisture from the product's internal component to its surface. Within the drier the temperature was higher than the ambient temperature, and the corresponding relative humidity in the drier was lower than the relative humidity in the atmosphere. As a result, drying rate of chili in a force convection drier was found to be higher than that of open sun drying. High drying rate was observed during the initial stages of drying. Drying rate decreases as drying time increases. Drying takes place during the falling rate cycle with a sharp drop in the moisture content in the initial stages of drying and in the later stages is very low[28].

Diffusion of moisture is the dominant physical process influencing the reduction in drying levels during the drying of natural products [29].

It can be observed that the constant drying rate period could not be detected under the tested conditions but only the increasing drying rate period was detected. This period occurs when the drying rate is not constant and it decreases due to the water activity reduction on the grain surface. So that, the drying rate is governed due to the intense internal water and vapor flow[30]. The variation in drying rates is attributed to the differences in the position of parchment coffee bean in the drying trays. For all the three loading trays position, the moisture content falls rapidly at first but as the coffee loses moisture the rate of drying slows[1].

The behaviour of the physical properties of coffee is significantly different from that of most agricultural products due to the grain structure (endocarp or parchment). These differences are present even before drying. An air layer between the grain and the endocarp is created because of the presence of the endocarp. This characteristic, may lead to differences in the drying process and its consequences (heat and mass transfer, drying rate, shrinkage, diffusivity, etc.). The parchment will also alter the behavior of the physical properties with respect to the moisture content. Therefore, the drying process is regulated mainly by the conditions of drying air. While the parchment forms a physical barrier to loss of moisture, it does not influence the coffee's final moisture content. The drying rate and the physical properties are affected by the presence of the parchment on the coffee grain[31].

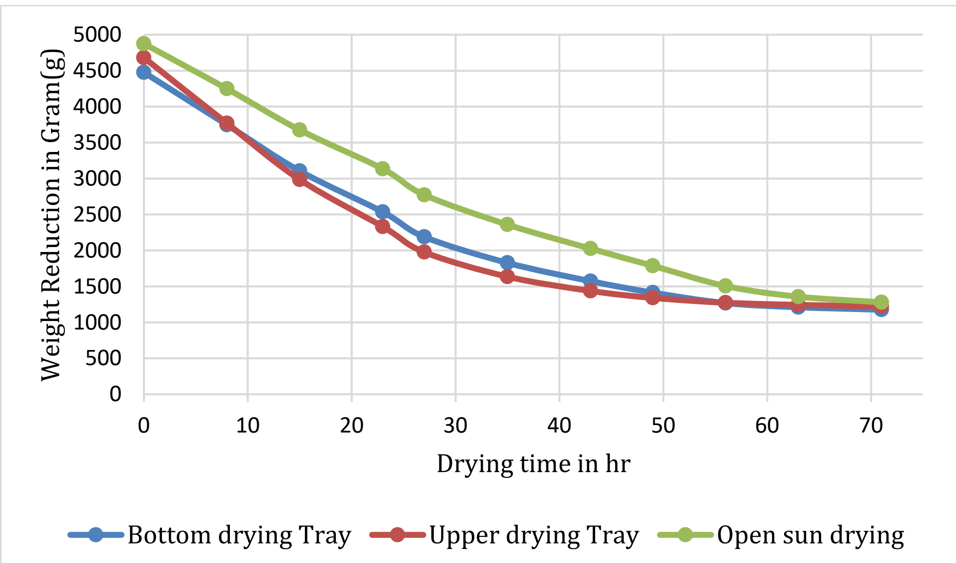



Fig.5 weight reduction during red pepper drying.

The higher rate of weight loss is determined on red pepper placed in the solar dryer than in the open sun drying. Observed System drying Efficiency of the solar dryer on the Bottom and upper drying Tray is 10.4 and 12.27% respectively for parchment coffee bean drying. With Effectiveness Factor of 1.23 and 2.31 respectively for Bottom and upper drying Tray. As reported [32,21,33,34] the efficiency of solar dryers drying of coffee varies between 2 and 50% on average.

System drying Efficiency of 29.07 and 30.5 % was observed respectively in the Bottom and upper drying Tray in the drying of red pepper. The efficiency of the solar collector ranged from 42.18 to 71.4% with an average value of 35 % at a drying air flow rate of 0.01kg/s [35]. The efficiency of the solar collector ranges from 20% - 43%[36]. The average collector and dryer efficiency was about 48% and 34% respectively[37]. At an average solar radiation of 420 W / $m^2$ and an air flow rate of 0.07 kg / s, the collector, drying system and pick-up efficiency values of about 28%, 13% and 45% respectively[38]. The maximum, minimum and average solar collector efficiency are approximately 12.0%, 54.6% and 35.1% respectively, with an air mass flow rate of around 0.1254 kgs−1[39]. The solar drier's thermal efficiency was measured at around 21 per cent with a particular moisture extraction rate of around 0.87 $kg/_{kwh}$ [28 ].

## IV. CONCLUSION

From the experiment conducted using forced convection mixed-mode solar dryer the Minimum and maximum temperature observed within the drying chamber and ambient temperature respectively Min. 31.40 and 19.10, Max. 56.60 and 30.0ºC during drying of red pepper and min 28.90 and 20.00, Max. 45.70 and 29.00oC during drying of parchment coffee bean. Observed System drying Efficiency of the solar dryer on the Bottom and upper drying Tray is 10.4 and 12.27% respectively for parchment coffee bean drying, 29.07, and 30.5 % was observed respectively in the Bottom and upper drying Tray in the drying of red pepper. Drying by forced convection mixed-mode solar dryer it takes 71hours to dry red pepper of 9.1 kg with final moisture content of 9.22% and 8.24% on bottom and upper drying try respectively. Similarly, it takes 26 hours to dry parchment coffee bean of 18.2kg with final moisture content of 13% and 9% on bottom and upper drying try respectively. However, the drying in open sun takes much more time. As can be seen from the result the design of the solar dryer geometry, the drying tray position, drying air speed flow, drying temperature and drying time greatly affects the final moisture content of the products to be dried which governs the product quality.

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