

A DEVELOPMENTAL STUDY OF A SOLAR-ASSISTED MAIZE DRYER FOR QUALITY DRYING

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ABSTRACT

This study was conducted for the design and development of solar assisted maize dryer to encounter the post-harvest losses. The development and experimental study was carried out in the Department of Farm Machinery and Power, University of Agriculture Faisalabad. The solar maize dryer consisted of a V-groove solar collector having 1.89 m² collector area, drying chamber having diameter and height of 1.05m and 0.6m respectively. Three air ducts having diameter 0.15m have been provided within the drying chamber for drying homogeneity. In each of the experiments, 100 kg of maize with the initial moisture content of 24% (on average basis) was dried to 14% final moisture content. The average increase in temperature at the collector was 10 to 15 °C more than ambient temperature. Solar assisted maize dryer and open sun drying took 9 hours and 4 days respectively to dry maize up to desired moisture level. The maize samples were evaluated for quality analysis after drying. The percent (%) fats, carbohydrates, proteins and fiber ranged between 3.86-3.89%, 76.86-76.89%, 6.89-6.91% and 7.26-7.29% respectively. The breakeven analysis of the dryer showed that at 970 hours of working total revenue cost equals to the total cost of the dryer.

Keywords: Solar energy, collector, drying chamber, breakeven analysis.

<https://doi.org/10.36899/JAPS.2020.3.0087>

Published online March 25, 2020

INTRODUCTION

The global food demand is increasing steadily and food prices have reached unprecedented levels causing food insecurity especially in developing countries. In most of the developing countries post-harvest losses are one of the major reasons for the food insecurity (Aulakh, 2013). A significant amount of agricultural produce is lost during post-harvest operations due to lack of knowledge, inadequate techniques and poor infrastructure for storage (FAO, 2014). These losses can be broadly categorized as weight loss, quality loss and nutritional loss. The magnitude of post-harvest losses varies greatly among different crops, area and economics. The overall global post-harvest losses of major cereal crops ranged between 20-25% (Gustavsson, 2011). These losses occurred during harvesting, threshing, winnowing, drying, transportation and storage. On the other hand the post-harvest losses during harvesting ranged between 10-15% that is mainly due to high moisture content at harvest. The amount of moisture contents in major cereal crops at harvest varies between 20-30% that allows rapid bacterial and fungal growth during preservation (Belessiotis and Delyannis, 2011; Shah, 2013). The basic requirement to overcome this problem is limiting the moisture content before preservation. Thus, agricultural products should be dried up to 12-14% moisture content

(wet basis) according to the type of crop and storage time (Kenneth, 2013; Igbeka, 2013).

Therefore drying is critical step to reduce moisture content, maintain product quality, minimize storage losses and transportation cost (Abass *et al.* 2014). Drying involves the transfer of heat, mass and momentum. The moisture is vaporized and swept away from a solid surface of material by passing air through products (Can 2000). Natural or open sun drying of crop is traditional and economical method practiced in developing countries. The drying material is spread over the roof of house, mate or on the earth in open sun drying thus exposed to direct solar radiation and stirred many times in a day. However the natural drying is not recommended as it is weather dependent, require high labor, slow process, high drying cost and inferior quality of product (Abass *et al.* 2014).

Mechanical drying offers advantages over natural drying such as reduction in handling losses and control over drying air temperature. These dryers are efficient and remove moisture in a short time (Alavi *et al.* 2011). If pre-heated air is used the efficiency of dryers can be improved. Solar energy provides a means to heat up the air before entering the dryer. Pakistan is receiving an extensive amount of solar radiation throughout the year owing to its unique location. The average net available solar radiations ranged between 10-15 MJ m⁻² day⁻¹, and the sunshine time period is 12 h/day from

March to October in Pakistan (Munir *et al.* 2012). Thus, solar dryers are better option to dry agricultural products up to safe moisture contents. The previous literature revealed that drying time of most of the solar dryers observed to be high due to uneven distribution of air in drying chamber that results in higher drying time, lower performance, low quality and higher energy consumption (Roman *et al.* 2012).

Keeping in view the above problems of drying and inferior quality of cereals especially maize, the developmental study was carried out on solar assisted maize dryer for quality oriented product.

MATERIALS AND METHODS

Basic Design Theory of Solar Assisted Maize Dryer:

By taking into account all facts and recommendations, the developmental study was initiated to evaluate the performance of the dryer. The considered design parameters, equations and calculations are shown in Table 2.

Description of Solar Assisted Maize Dryer:

The development of batch type solar maize dryer was carried out in the Department of Farm Machinery and Power, University of Agriculture, Faisalabad Pakistan. A schematic view of the dryer is shown in Figure 1. The dryer consisted of a heating source (collector), drying chamber, plenum chamber and air ducts for aiding drying homogeneity. The collector was provided to receive solar radiation directly from the sun to raise the ambient temperature. It was adjusted horizontally at an angling 32° N-S according to longitude and latitude of experimental site to receive maximum solar radiation. The drying chamber was constructed to place the product for drying. It consisted of a plenum chamber to calm down the air coming from plenum chamber. Air

distribution system consisted of three perforated ducts for air homogeneity within the drying chamber. The components and specifications of dryer pertinent parts are shown in Table. 2.

Experimental Procedure: The experiments on maize grain drying were carried out in month of October under local conditions of Pakistan. The samples of maize for drying were obtained from Agriculture farm of University of Agriculture Faisalabad, Pakistan. The dryer was operated under no load conditions for one hour to stabilize the temperature and air velocity within drying chamber. Then it was loaded with 100 kg maize grain at 24% moisture content to dry up to 14% moisture content at 8:00 am to 5:00 pm. Another sample was dried in open-air under the sun to compare the performance of the dryer. The weight loss during open sun and moisture contents were measured at one-hour interval. The dried samples of maize grain were collected and cooled to ambient temperature and sealed it in a plastic bag. The performance of the dryer was evaluated by drying rate and collector efficiency. Air velocity, ambient temperature, collector inlet and outlet temperature, dryer inlet and outlet temperature, solar radiation and relative humidity were measured using anemometer, pyranometer, humidity meter and thermocouples.

Quality Analysis: The maize samples were dried up to desired moisture level, later evaluated for proximate analysis using standard methods recommended by AOAC (2000).

Cost Analysis of Dryer: The economic analysis was made on maize dryer based on information gathered from an experimental study. The methodology followed in this study was presented by Kenneth and Tommy (1987). Table 3. Shows the worksheet for calculating the cost analysis of dryer.

Table 1. Solar-assisted dryer design parameters and equations used for their calculation.

Parameter	Equation	Results	Source
Amount of water to be removed (kg)	$M_w = \frac{W(M - M_1)}{M_1 - M}$	13.63	Henderson and Perry (1980)
Average drying rate (kg _w h ⁻¹)	$m_{dr} = \frac{m}{t_i}$	1.15	Tonui <i>et al.</i> (2014)
Amount air needed for drying (kg)	$m = \frac{m}{\Delta W * n}$	9086.6	Ichsani and Dyah (2002)
Volumetric flow rate, V _a (m ³ s ⁻¹)	$M_v = m_a * v_s$	0.2442	Axtell (2002)
Total useful energy, Q (MJ)	$Q = M_w L + M h_{fg}$	18.51	Iodo <i>et al.</i> (2002)
Collector area, A _c (m ²)	$Q = A_c (I_t \delta_a) - U_{L1} (T_p - T_a) F_R$	1.89	Exell (1980)
Fan capacity (hp)	$H_p = \frac{Q * S}{3}$	0.75	Ashfaq <i>et al.</i> (2016)
Dryer efficiency	$\eta = \frac{m * c * (T_2 - T_1)}{I_t}$	<35%	Ashfaq <i>et al.</i> (2016)

Variation of Temperature and Solar Intensity: The performance of the dryer was evaluated by conducting a series of experiments on maize. The variation of solar radiation, relative humidity and ambient temperature

during experiment are shown in fig. 2 for typical days of October 2017 in Faisalabad. The mean values of ambient temperature, solar radiation and relative humidity during experiment observed to be 28.5 to 35.3°C, 680-840 W/m²

and 71-43% respectively. The highest curve of ambient air temperature and solar radiation were observed at 1:00 pm. On the other hand, the relative humidity was found to be low with the increase in ambient temperature. It was

observed that dryer inlet temperature was 10-15°C more than ambient temperature that increased the drying rate of maize within the drying chamber (Agbossou *et al.* 2016).

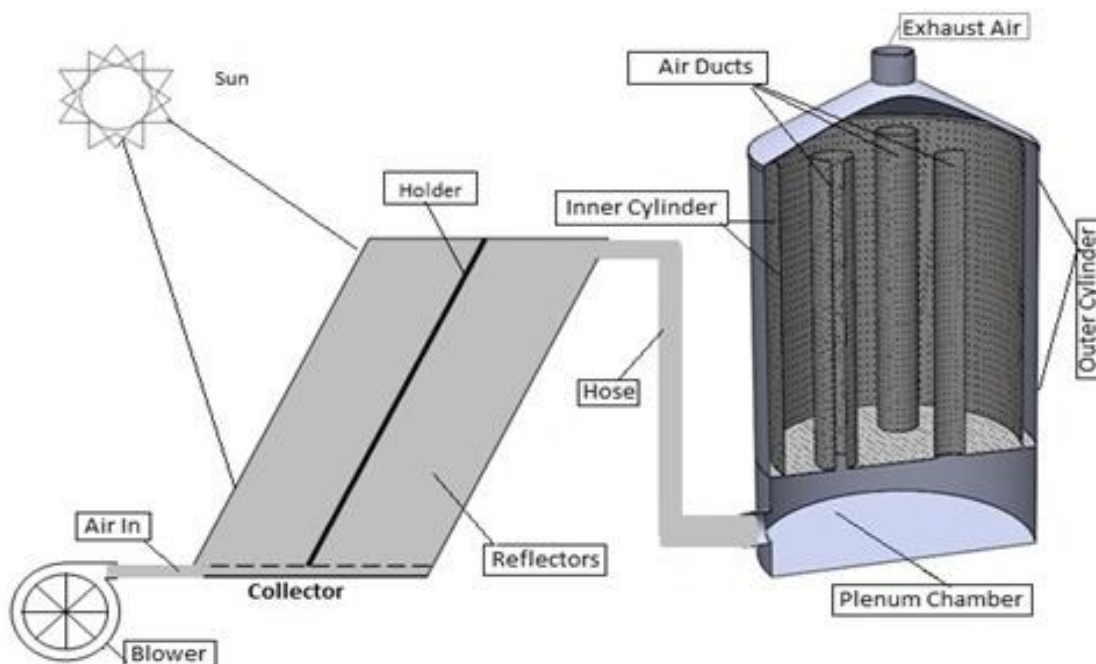


Figure. 1. Schematic diagram of a batch type solar assisted maize dryer.

Table 2. Design specifications and assumption of maize dryer

Components	Conditions & Specifications of dryer
1. Solar collector	
a. Type	V-groove solar collector
b. Area	1.89 m ²
c. Covering	Transparent Glass 5 mm thick
d. Transmittance	80%
e. Absorber Plate thickness	2 mm
f. Collector tilt	32° N-S (horizontal)
g. Insulation	Polystyrene 50 mm thick
2. Drying chamber	
a. Diameter	1.050 m
b. Height	0.6 m
c. Volume	0.138 m ³
d. Type	Perforated 3 mm
3. Air distribution system	
a. Diameter	0.150 m
b. Height	0.6 m
c. No of ducts	3
d. Perforation	3 mm
4. Blower	
	0.75 hp

Table 3. Worksheet of economic analysis of dryer.

Cost	Parameters	Formulae
Capital cost	Depreciation	Rate × (Purchase price- Salvage value)
	Interest on avg. investment	$(\text{Current rate} - \text{Inflation rate}) \times \frac{P}{2}$
	Insurance	$0.5\% \times \frac{P}{2}$
	Repairs	3% × Purchase price
	Total fixed cost	Total fixed cost/Annual unit dried
Variable cost	Energy cost per unit dried	Total energy cost/Units dried
	Per unit labor cost	Hourly labor rate × Hourly drying rate
Total drying cost	Sum	Fixed or capital cost + Variable cost

RESULTS AND DISCUSSION

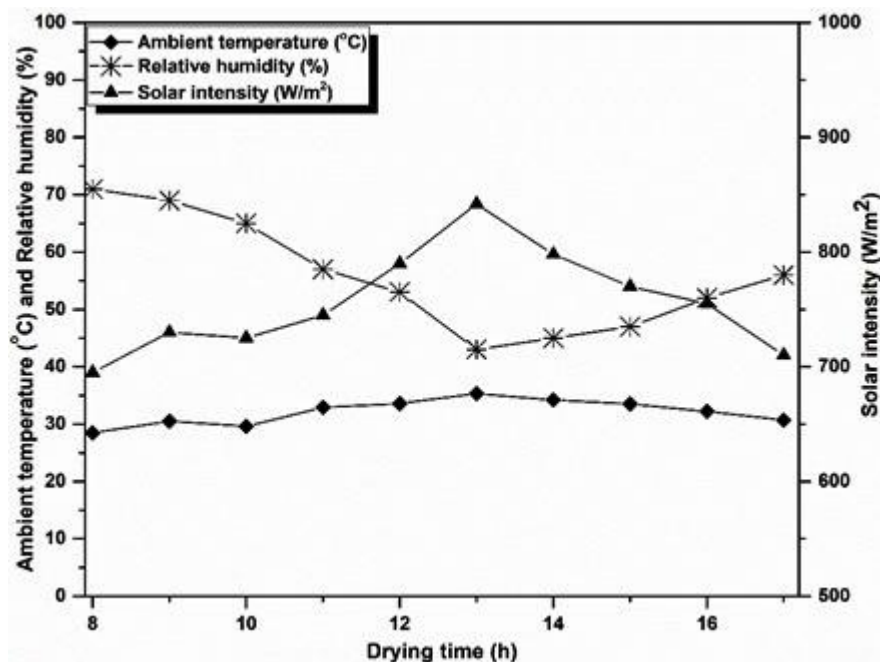


Figure.2. Shows ambient air temperature, relative humidity and solar radiation during experiments Variation of Temperature within the Dryer

The changing curves of mean ambient, solar maize dryer inlet, middle and outlet temperature are shown in the fig. 3. The ambient and dryer inside temperature showed continuously changing behavior from morning to evening with solar intensity. It was investigated that dryer temperature was higher than ambient temperature. The maximum temperature at collector and dryer inlet was recorded 52.3°C at 1:00 pm which was 47.3% more than ambient temperature (35.3°C) at the same time. However, the average increase in dryer temperature was observed to be 45.8% as compared to ambient temperature. The increase in temperature was owing to solar collector that received direct solar radiation and increases the temperature of air moving to the dryer inlet (Ashfaq *et al.* 2016; Vijaykumar *et al.* 2012).

Variation of Relative Humidity within Dryer: The fig. 4 shows the mean difference of relative humidity of ambient air and solar assisted maize dryer inlet, middle and outlet. The relative humidity of air reduced continuously at dryer inlet from morning to noon and then increased up to evening due to variation of solar radiation and ambient temperatures. As the air moved through drying bed the relative humidity increased significantly with time until the maize reached desired moisture content. This may be due to increase in temperature at solar collector. The average relative humidity of the ambient, dryer inlet and outlet varied

between 66-43%, 43-22% and 65-43%. The difference in relative humidity implicated higher drying rates in the dryer (Arun *et al.* 2014).

Comparison of Moisture Content of Maize in Solar Dryer and Open Sun: The pattern of moisture removal from maize grain is shown in fig. 5. The drying process took place in three stages i.e. initial adjustment period, constant rate period and falling rate period. Initially, the free water was removed from the grain followed by the bound water. The graph shows that the sample exhibited a falling rate period that is true for most cereal crops. Previous literature revealed that drying in falling rate period mainly caused by diffusion mechanism. However, the drying in a constant rate period is dependent on external factors like air velocity, temperature and relative humidity. As there is no resistance to mass transfer in constant rate period. Thus, the drying time of the maize was reduced by the variation of these parameters (Ajadi and Sanusi, 2013; Putra and Ajiwiguna, 2017). Figure. 5 shows the comparison of moisture contents of maize dryer and open sun drying of the grain during experimental. The maize grain having average initial moisture contents of 24% were dried up to final moisture contents of 14% in 9 hours of continuous working of the dryer. However, the open sun drying took 4 days to achieve desired moisture content. It can be seen from results that the solar assisted maize dryer dried the maize earlier than open sun drying thus proved more efficient than open sun drying.

Fig 5. shows varying profiles of dryer efficiency with solar radiation during experimental hours. It is clear from the graph that the drying efficiency increased gradually up to 1:00 pm and then reduced with a decrease in solar radiation thus increased the drying rate of maize sample. The maximum and minimum efficiency of the dryer during typical experimental days was found to be 28% and 21% at 8:00 am and 1:00 pm respectively.

Quality Analysis: The determination of proximate and mineral element compositions of maize products provided substantive nutritional information on maize. The moisture content of the maize and its products in the current study was consistent and slightly higher than the earlier research on maize products. The slight variation in proximate analysis may be attributed due to the maize variety used, environmental factors and agronomic practices (Trabelsi *et al.* 1998). The maize was dried for 9 hours and evaluated for fats, carbohydrates, proteins and fiber contents determination. Table. 4 shows percent contents of maize dried using solar assisted maize dryer.

Economic Analysis: The drying cost Comparison showed that drying cost of solar maize dryer proves to be more economical as compared to open sun drying. The literature reviewed showed that cost of drying maize in open sun was 0.0197 \$/kg, while solar assisted dryer was 0.0123 \$/kg. The breakeven analysis for the dryer payback period is shown in Fig. 7 by the intersection of two lines. The point shows that the payback period of the maize dryer is 970 h. The dryer will run free of cost after the payback period. Table 5. Shows the economic analysis of solar maize dryer in American dollars (\$).

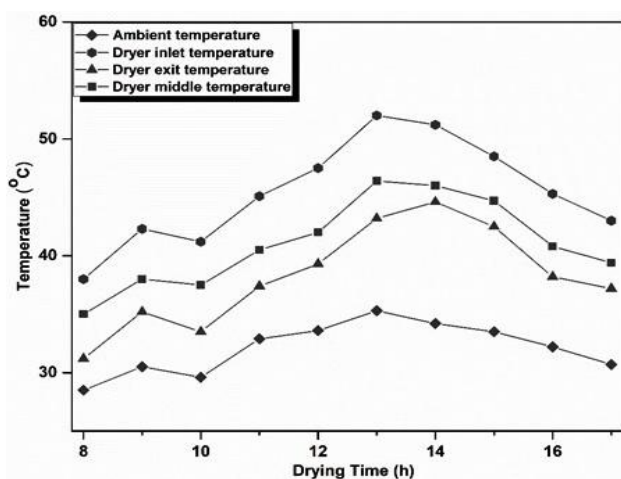


Figure.3. Variation of mean ambient and dryer inlet, middle and outlet temperature during experiments

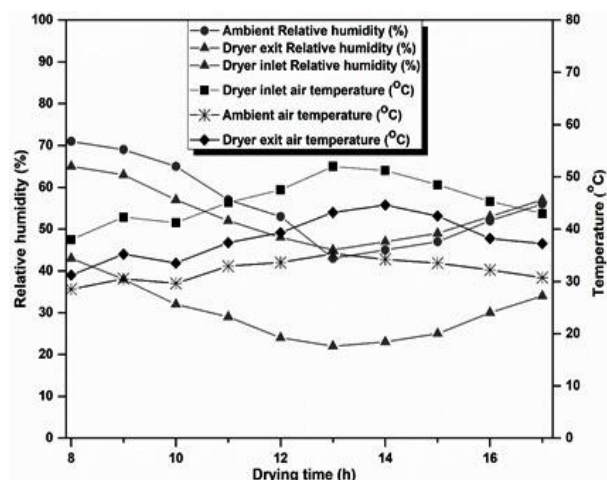


Figure. 4. Variation of mean drying temperature and relative humidity of solar assisted maize dryer. Dryer Efficiency

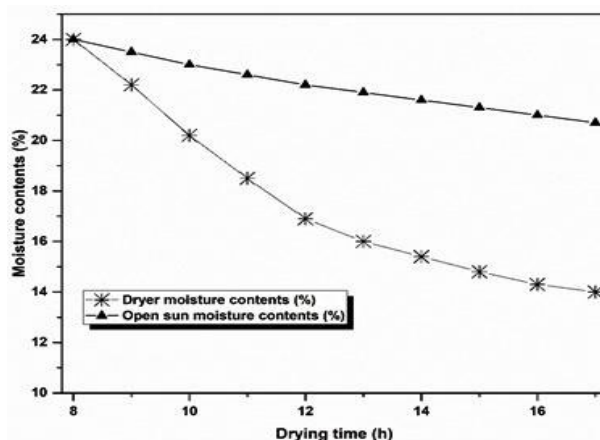


Figure 5. Comparison of moisture loss in open sun and maize dryer

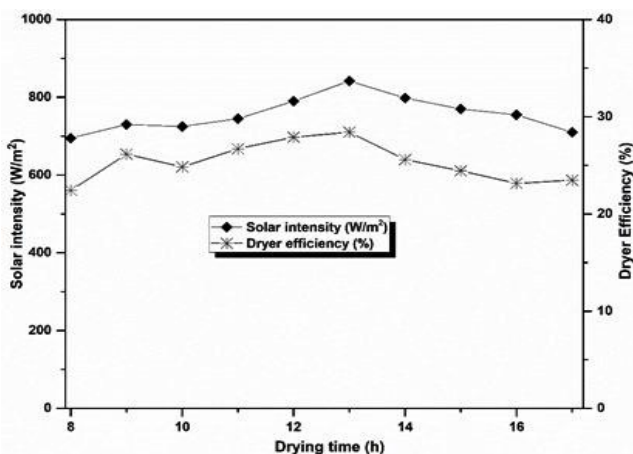


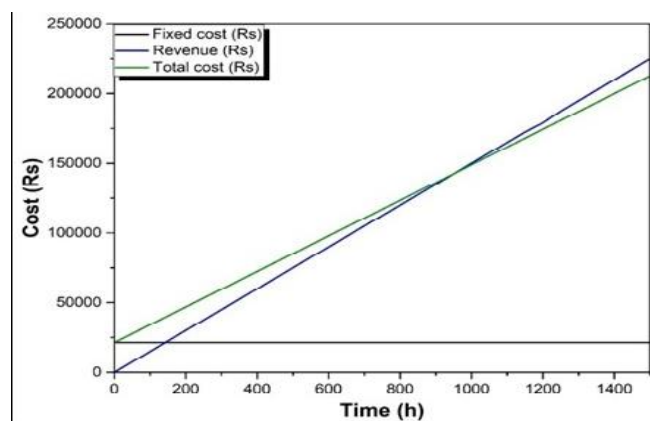
Figure 6. Shows dryer efficiency vs solar radiation during typical experimental days

Table 4. Quality analysis of maize dried in solar assisted maize dryer.

Quality parameters	Percent Contents (%)
Fats	3.86-3.89
Carbohydrate	76.86-76.89
Protein	6.89-6.91
Fiber	7.26-7.29

Table 5. Worksheet of calculated economic analysis parameters of solar assisted maize dryer.

Cost	Parameters	Values (\$)
Capital cost	Depreciation	35.52
	Interest on avg. investment	17.36
	Insurance	8.88
	Repairs	11.84
	Total fixed cost	73.61
	Total capital cost	0.0040\$/kg
	Variable cost	Energy cost per unit dried
Per unit labor cost		0.0035\$/kg
Total drying cost		0.0123\$/kg

**Figure 7. Break even analysis of solar assisted maize dryer**

Conclusion: The experiments for drying of maize in maize dryer were conducted during the month of October 2017 for evaluating the performance of the dryer. The full-scale tests of 100 kg maize grain were conducted in the solar maize dryer. The initial moisture contents of 24% (on average basis) were reduced to 14% in 9 hours that was lesser than open sun drying that took 4 days to dry up to the same final moisture content. The difference between drying time of both drying methods was because of high temperature and low relative humidity prevailed inside solar assisted maize. The percent (%) fats, carbohydrates, proteins and fiber ranged between 3.86-3.89, 76.86-76.89, 6.89-6.91 and 7.26-7.29% respectively. The performance and quality analysis of the dryer revealed that solar assisted maize dryer helpful for

small scale farmers to reduce post-harvest losses and quality oriented maize products.

Acknowledgements: The authors would like to thank for financial support by office of Research, Innovation and Commercialization (ORIC) and Department of Farm Machinery & Power, University of Agriculture Faisalabad, Pakistan.

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