

Modification of Parabolic Shaped Solar Dryer for Enhanced Performance in Preservation of Agricultural Produce

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Abstract

Postharvest losses of fruits and vegetables remain high in Nigeria due to continued reliance on traditional sun drying and limited access to electricity-powered dryers. This study presents the modification and performance evaluation of the parabolic-shaped solar dryer (PSSD) integrated with a secondary heat source and an improved airflow system, designed to address the limitations of conventional dryers in maintaining optimal drying conditions during nighttime and cloudy weather. The modified dryer was compared with an existing, non-modified unit under no-load and load conditions, using 190 kg of tomatoes as test material. Temperature, relative humidity, drying rate, colour change and moisture content were monitored during evaluation. Under both conditions, the modified dryer achieved higher internal temperatures and lower relative humidity compared to the non-modified dryer and ambient air, resulting in improved drying efficiency and overall performance. Drying curves exhibited an initial warming-up phase followed by a falling-rate period, with a peak drying rate of 36.6 kg/day observed in the modified dryer. A safe final moisture content of 12.3% was achieved in 96 hours, compared with 120 hours and 13.9% (dry basis) in the non-modified dryer. Colour analysis revealed a decrease in L (Lightness), a* (Redness), and b* (yellowness) for both systems; however, overall colour difference (ΔE) was consistently lower in the modified dryer (≈ 18.9) than in the non-modified dryer (≈ 23.2), indicating superior colour retention. The modification enhanced thermal performance, drying efficiency, and quality preservation, demonstrating its potential to reduce postharvest losses in tomatoes and promote sustainable drying technologies for smallholder farmers.*

Keywords:

Solar drying, Tomato preservation, Moisture content, Colour, Postharvest technology

Introduction

Drying is a preservation technique used to enhance the value of agricultural products or transform them into storable or marketable items (Ohijeagbon et al., 2016). It has been practised since ancient times. Drying extends shelf life, minimises storage and packaging space, reduces weight for transportation and handling, and improves the market value of agricultural produce. Sun drying is still widely practised in most parts of Nigeria. This method involves spreading the crop on bare ground, mountain tops, paved roadsides, and sometimes on raised platforms. However, the products are not protected from dust, debris, ultraviolet rays and pests.

Crop drying systems that utilise mechanical or electrical heating are suitable for drying agricultural products. However, the high initial and running costs, as well as the unreliable national grid, make them impractical as an alternative, especially in rural areas. Solar energy is rapidly gaining acceptance for diverse applications in agriculture, including drying (Akinola & Fapetu, 2006). The use of solar energy is another affordable, cost-effective and readily available alternative in this part of the world. Simple solar dryers, in which heated air rises naturally through the product by convection, have been proposed for rural areas (Basunia & Abe, 2001). These dryers

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eliminate dependence on electricity and fossil fuels, which are scarce commodities in rural areas of developing countries like Nigeria. The Nigerian Stored Product Research Institute has, over the years, developed various types of solar-powered dryers, including hybrid, tray, cabinet, tent, mobile, and parabolic-shaped solar dryers (PSSD). PSSD consists of a curved transparent ultraviolet screen that concentrates sunlight into a drying chamber, thus utilising solar radiation as the primary source of heat (Figure 1). Two sizes, with effective drying areas of 45 and 16 m², have been deployed in more than 30 states across the country. The dryer has been found to effectively dry crops such as cassava mash, cassava chips, yam chips, sliced tomatoes, chilli peppers, and paddy rice (Oyewole et al., 2016; Ade et al., 2018; Ogunsua et al., 2020; Akomolafe et al., 2021).

Feedback from users of the PSSD across Nigeria has shown that in the northern region, produce is cooked due to a low rate of moisture removal from the dryer. In contrast, in the southern region, the dryer's performance is reduced during the peak period of the rainy season due to prolonged cloud cover. Another major challenge of the PSSD is the inability to maintain optimal drying conditions at nighttime, resulting in extended drying time and potential quality degradation. To address these challenges, this study focused on modifying the PSSD with a secondary heat source and an enhanced airflow circulation mechanism. This innovation ensures continuous drying during periods of cloudy weather conditions or after sunset, thereby also improving drying efficiency and product quality.

Materials and Methods

Description of the dryer

The modified dryer has a structural dimension of 6.5 x 4.2 x 2.0 m (L x W x H), an insulated black floor for heat storage and prevention of heat sink. The parabolic shaped structural frame is made of galvanised steel pipes. The frame was covered with a polycarbonate cover that screens out ultraviolet (UV) rays and features air vents. The drying chamber consists of two drying racks, each with two layers, made of mild steel angle iron, and 20 trays measuring 0.8 x 0.5 m (L x W), constructed from square pipe, angle bar, and wire mesh. Two extractors were positioned at regular intervals on the top of the dryer to increase the rate of moisture-laden air removal from the dryer and prevent localised heating. There are four adjustable inlet vents, and an access door was provided at one end of the structure. The drying platform was integrated with an

insulated heat conduit for the movement of heated air into the dryer (Figure 1). The dryer was equipped at the sides with two secondary heat sources powered by biomass (briquettes). The secondary heat source is equipped with a combustion chamber, a heat exchanger, and a blower. Heat generated inside the combustion chamber is channeled into the dryer with the aid of the blower through the insulated heat conduit located under the drying platform (Figures 1-4). Two 350-Watt solar panels, a (12V 100 Amp) battery and a 40A MPPT charge controller were installed to power the (12V) DC blower.

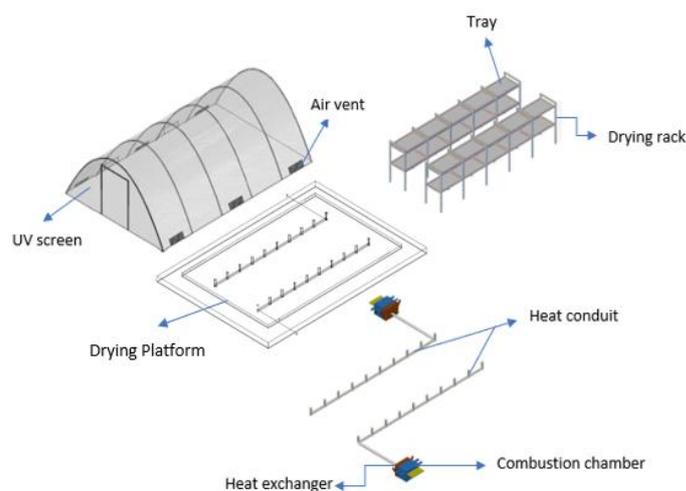


Figure 1: Exploded view of the PSSD

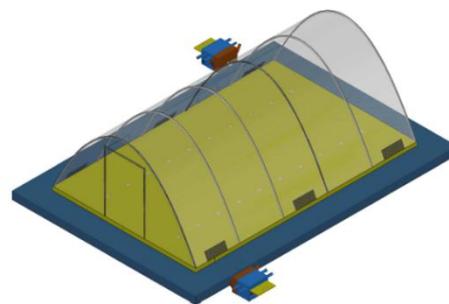


Figure 2: Isometric view of the PSSD

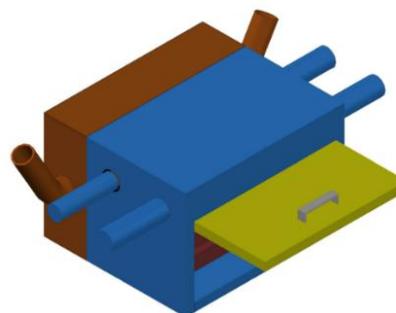


Figure 3: Isometric view of the biomass powered heat

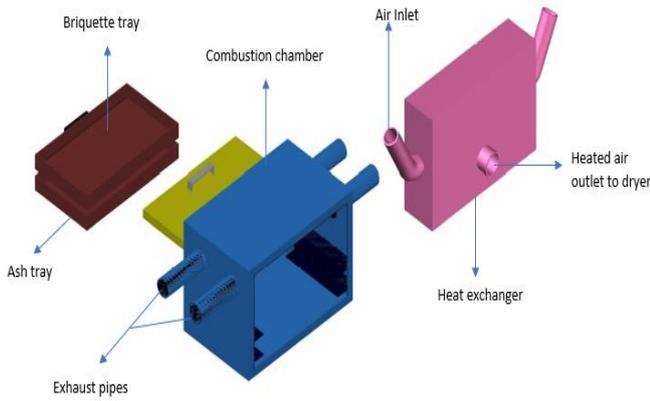


Figure 4: Exploded view of the biomass powered heat source

Construction of the Modified PSSD

The biomass-powered secondary heat source is shown in Figure 5. The dryer platform was constructed and incorporated with the heat conduit channel, as shown in Figure 6. The solar components and blower were also installed, as shown in Figure 7. The completed, fabricated, and modified parabolic-shaped solar dryer is shown in Figure 8.



Figure 6a, 6b, 6c: filling, casting and framing of drying platform incorporated with heat conduit channel



Figure 5a, 5b: Back and front views of biomass-powered heat source



Figure 7a, 7b, 7c: Solar panel, charge controller and battery to power blower



Figure 8a, 8b, 8c: front, back and inside of the completed, fabricated, modified parabolic-shaped solar dryer

Performance evaluation

No load evaluation of the dryer

No load evaluation was conducted on the dryer to determine its performance. The temperature and relative humidity of the modified dryer were monitored for two days and two nights. The blower connected to the heat exchanger was switched on throughout the no-load evaluation period. At the same time, the combustion chamber was only fired at night (7:00 pm - 7:00 am) to compensate for the unavailability of solar energy during this time. The recorded daytime and nighttime temperature and relative humidity values were analysed and compared with those of the conventional PSSD and the ambient environment.

Load evaluation of the dryer with tomato

Load evaluation of the modified PSSD was performed using tomato as the test material. One hundred ninety (190) kg of ripe tomatoes (Sokoto Variety) were purchased from Mandate Market and transported to the Nigerian Stored Product Research Institute, Ilorin. The

tomatoes were sorted and cleaned with water and allowed to drain. The cleaned tomatoes were sliced into a thickness of 10 mm and loaded into trays inside the modified PSSD (PSSD1) and the existing PSSD (PSSD2) for comparison evaluation. Six portions were also spread along the roadside to serve as controls. The weight of the samples was taken twice daily at 12-hour intervals until the product reached a safe moisture content. The quality parameters monitored included weight loss, moisture content, and microbial load. The blower attached to the heat exchanger of the modified PSSD was switched on throughout the drying period, while the combustion chamber was only fired at night (7:00 pm- 7:00 am).

Temperature and relative humidity monitoring

The temperature and relative humidity of the solar dryers and ambient air (control) were monitored using Standard ST-170 data loggers and a Kestrel weather station.

Weight loss and drying rate determination

Labelled trays from the various layers in both dryers, as well as the control, were weighed daily for monitoring weight loss. The process was carried out and monitored daily using an electronic weighing balance with a sensitivity of 0.001 (Camry ACS-30-JE11). The values obtained were used to determine the drying rate (Equation 1) (Suherman et al., 2018) and to plot the drying curves.

$$DR = \frac{M_o - M_t}{d_t} \quad (1)$$

where;

M_o is the initial weight of the sample (kg), M_t is the weight of the dried sample at time t (kg)

$M_o - M_t$ is weight loss (kg), dt is the drying time (day).

Colour analysis

Colour was measured using the Fru WG 10Q portable digital handheld colourimeter. Ten slices of tomato were selected and labelled for non-destructive colour change sampling at every 24-hour interval. The CIE L^* (lightness), a^* (red-green), and b^* (yellow-blue) values were recorded. The overall colour change (ΔE^*) was calculated using equation 2 (CIE, 1976).

$$\Delta E^* = \sqrt{(L^* - L^*_{ref})^2 + (a^* - a^*_{ref})^2 + (b^* - b^*_{ref})^2} \quad (2)$$

where;

L^*_{ref} , a^*_{ref} , and b^*_{ref} denote the colour coordinates of the fresh sample at time zero.

Results and Discussion

No load evaluation result

The temperature and relative humidity of the air inside PSSD1 and PSSD2 are shown in Figure 9. The average daytime temperature and relative humidity inside PSSD1, PSSD2 and ambient air were 54.5, 52.9, 32.4 °C and 24.1, 26.4, 44.8 % respectively, while the average nighttime temperature and relative humidity inside PSSD1, PSSD2 and ambient air were 30.3, 26.3, 27.1 °C and 52.4, 61.5, 32.4 % respectively. The results showed that PSSD1 was able to achieve a 3.7 °C temperature increase and a 9.1% relative humidity decrease at night in PSSD2.

Drying temperature and relative humidity of the tomato

The average daytime and nighttime temperature and relative humidity of air inside PSSD1, PSSD2 and ambient air are shown in Figure 10. The average daytime temperature and relative humidity inside PSSD1, PSSD2 and ambient air were 53.3, 52.9, 34.5 °C and 27.6, 25.9, 61.5 % respectively, while the average nighttime temperature and relative humidity inside the PSSD1, PSSD2 and ambient air were 30.3, 27.4, 28.9 °C and 54.8, 60.9, 44.7 % respectively..

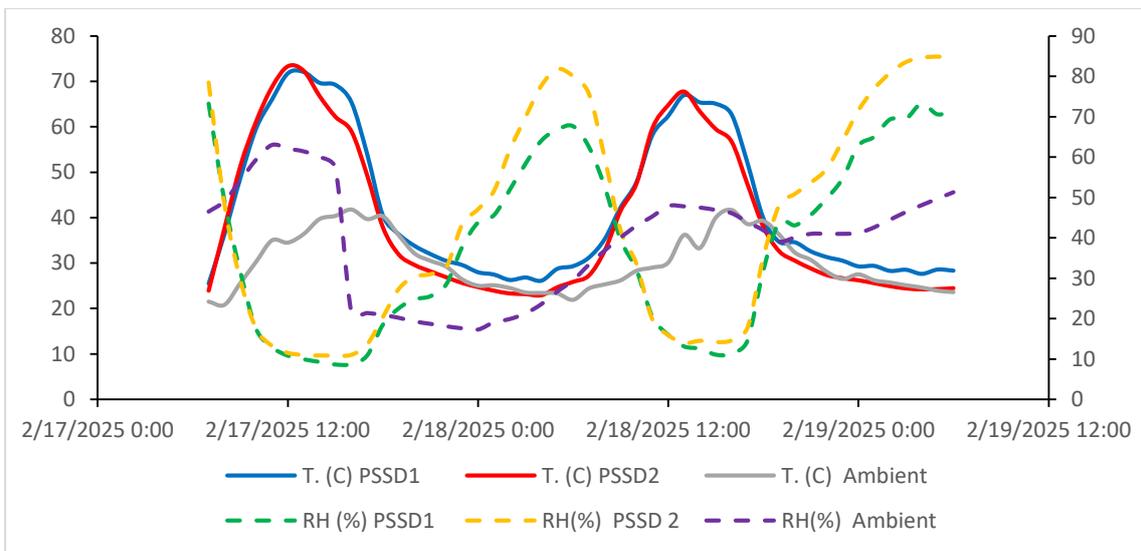


Figure 9: Temperature and Relative humidity variation inside the modified PSSD and PSSD.

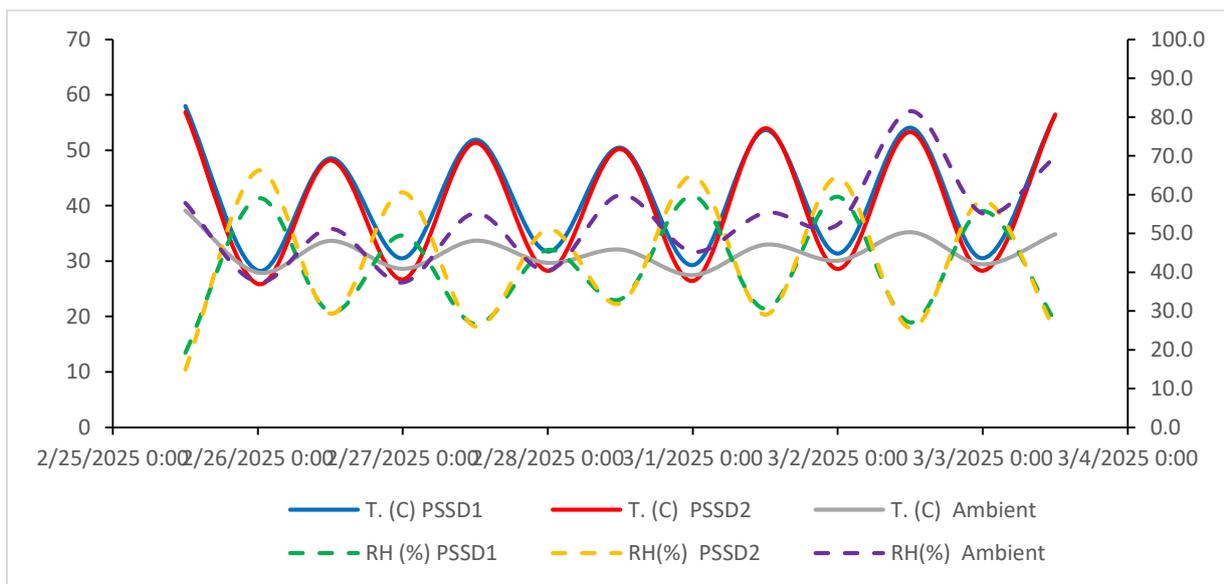


Figure 10: Daytime and nighttime temperature and relative humidity variation inside the modified PSSD, PSSD and ambient.

Daytime temperature increases of 18.8 °C and a relative humidity decrease of 35.6% were observed in PSSD1 compared to ambient air. The modified PSSD was able to achieve a 2.9 °C and 1.4 °C nighttime

temperature increase over the PSSD1 and ambient air, respectively. The results also showed that a higher average nighttime relative humidity was observed in solar dryers compared to ambient conditions. PSSD1

achieved a 6.1% decrease in nighttime relative humidity compared to PSSD2. Higher drying temperature and lower relative humidity enhance drying potential, leading to more efficient moisture removal and reduced drying time (Yusufe et al., 2017; Owureku-Asare et al., 2017)

Drying rate of tomato

The drying curves for tomato inside PSSD1 and PSSD2 are shown in Figure 11. The curves exhibited a warming-up period and a falling rate period for the solar dryers. The warming-up period for the dryers was within the first two days of drying (which refers to the initial phase where the product absorbs heat from the

surrounding environment but loses very little moisture. The primary focus during this time is to raise the temperature of the produce and its internal moisture to the wet-bulb temperature of the drying air, followed by the falling rate period. Higher drying rates were observed in PSSD1 during the warming-up period compared to PSSD2, indicating a higher rate of moisture removal in the modified dryer. The highest drying rate of 36.6 kg/day was observed on the second day of drying in PSSD1. PSSD1 was able to dry tomatoes to a safe moisture content at 60 hours of drying, while PSSD2 was able to dry to a safe moisture content at 72 hours of drying.

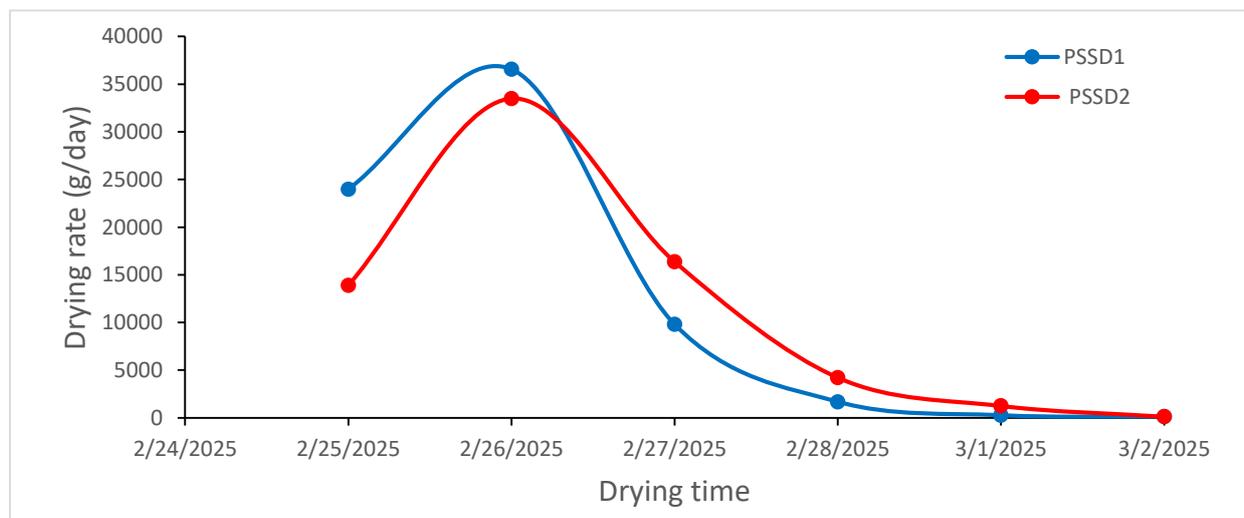


Figure 11: Drying rate versus drying time curve of tomato

This could be attributed to the higher temperature and lower relative humidity in the modified PSSD at night, which ensures continuous drying throughout the drying period. These results are consistent with previous findings that report faster drying and improved moisture removal efficiency in solar dryers with enhanced thermal performance and humidity control (Ekechukwu & Norton, 1999; El-Sebaai & Shalaby, 2012; Kituu et al., 2010).

Moisture content of dried tomato

Moisture content decreased markedly during solar drying, from an initial 95.4% (wet basis) to 12.3% in PSSD1 and 13.9% in PSSD2. Achieving final moisture levels of 12–14% is critical, as this falls within the range generally considered safe for microbial stability and the extended shelf life of dried tomato products (Doymaz, 2007). The slightly lower final moisture content in PSSD1 indicates more effective drying performance. Improved air circulation and temperature stability likely enhanced moisture transfer; by contrast, the higher residual moisture in PSSD2 suggests slower

drying rates. Overall, both dryers achieved substantial dehydration, but the modified dryer demonstrated superior moisture removal.

Colour analysis

Colourimetric evaluation of tomato slices during drying inside PSSD1 and PSSD2 is illustrated in Table 1 and Figures 12-15. In PSSD2, L^* (darkening) decreased from 49.1 to 31.5 at 72 h, while a^* (redness) and b^* (yellowness) dropped substantially to 11.3 and 8.7, respectively. ΔE exceeded 14 by 24 h and peaked above 23 by 72–96 h, indicating substantial perceptible differences from fresh tomato. By contrast, PSSD1 showed smaller reductions in a^* (15.4 → 14.2) and b^* (27.2 → 20.1), with ΔE stabilising around 18.5–18.9 at 72–96 h. Although darkening was also observed (L^* from 47.3 to 30.2), the overall chromatic changes were less extreme than in PSSD1. The gradual darkening and reduction in redness and yellowness are consistent with carotenoid degradation and tissue browning reported in previous drying studies (Demiray et al., 2017; Arslan & Özcan, 2011).

Table 1: L*, a*, b* and ΔE of dried tomato

Time (h)	PSSD1`				PSSD2			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
0	47.3	15.4	27.2	0.0	49.1	18.9	24.1	0.0
24	49.4	13.4	14.3	13.1	47.4	16.9	9.6	14.8
48	37.9	15.1	12.8	17.1	37.4	13.5	9.2	19.7
72	32.1	14.0	16.0	18.9	31.5	11.3	11.0	23.3
96	30.2	14.2	20.1	18.5	33.1	12.2	8.7	23.2

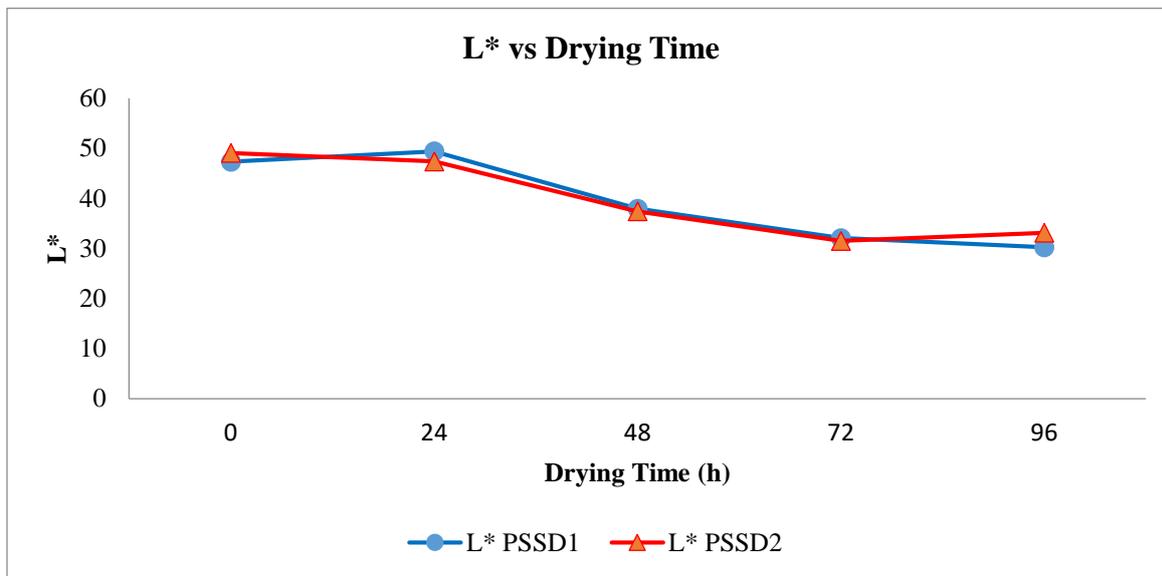


Figure 12: L* (darkening) vs Drying Time

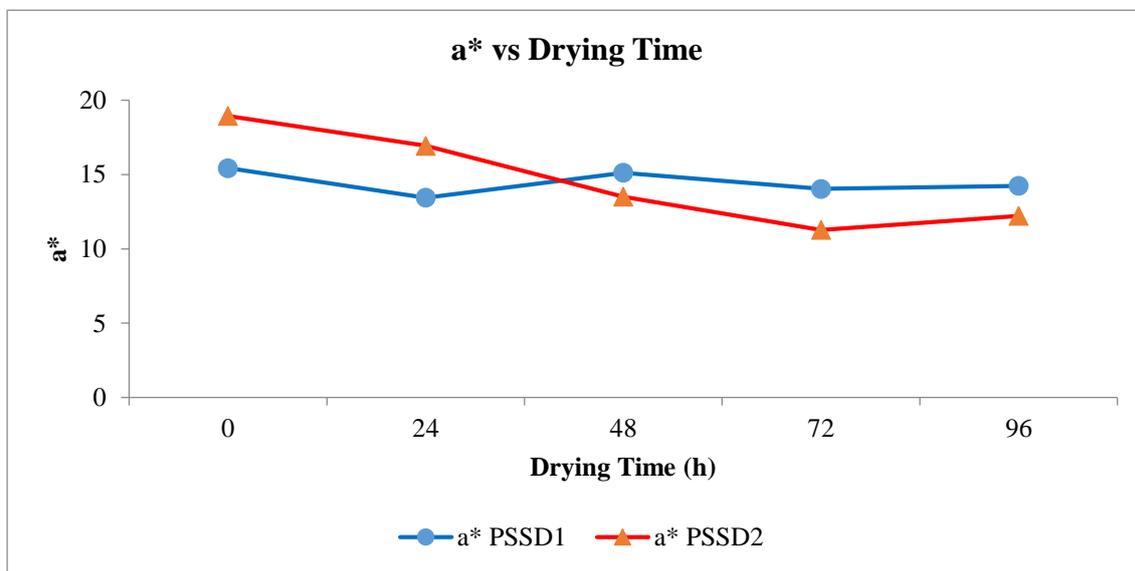


Figure 13: a* (redness) vs Drying Time

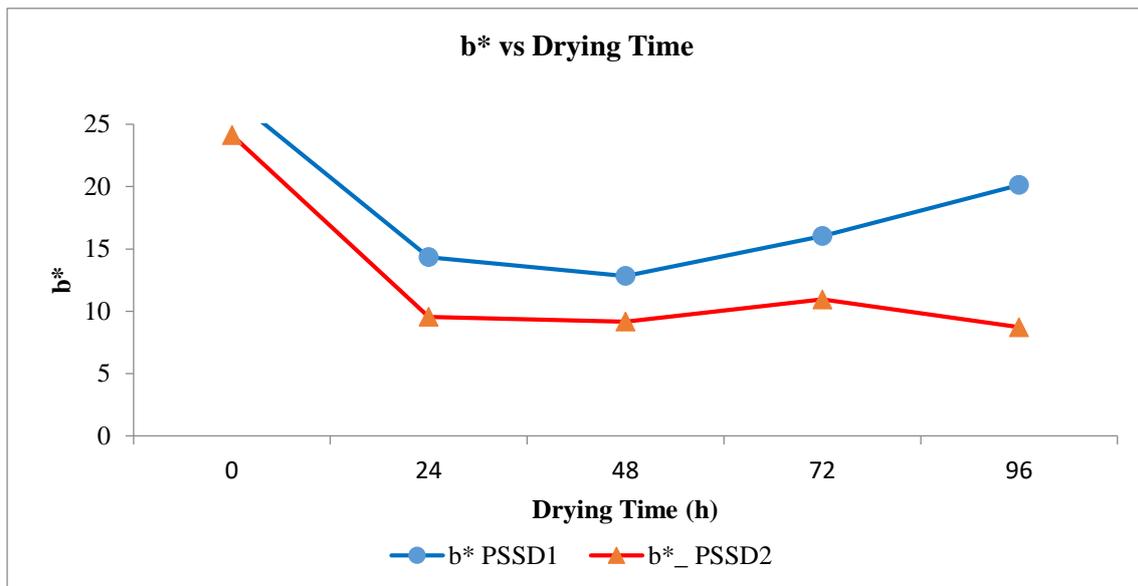


Figure 14: b* (yellowness) vs Drying Time

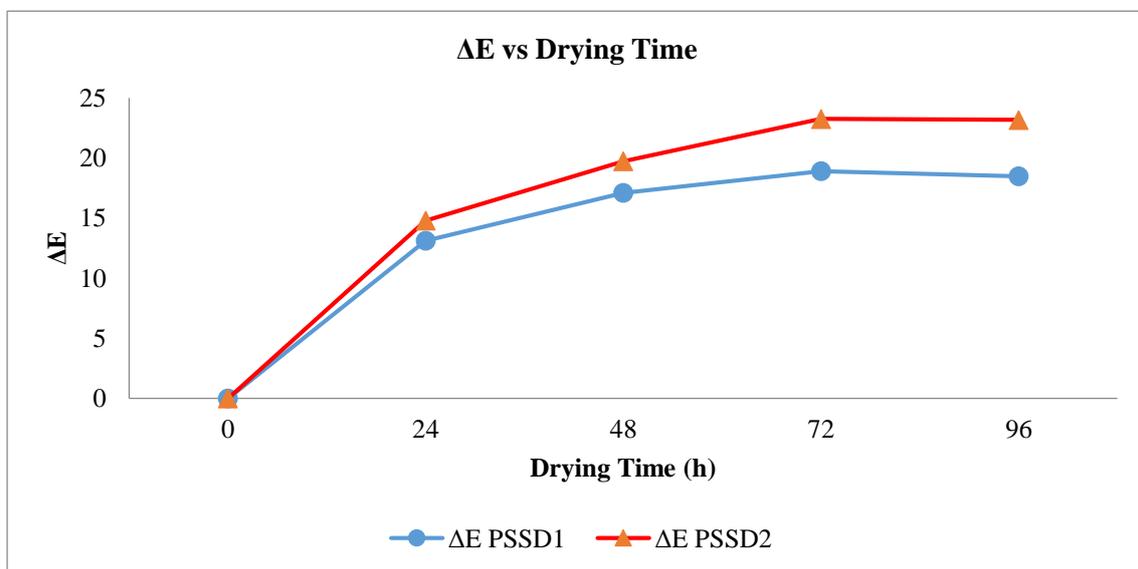


Figure 15: ΔE (colour change) vs Drying Time

The study showed that PSSD1 preserved tomato colour more effectively, especially for chromatic coordinates a^* and b^* . Although both dryers produced colour change (ΔE) values above the threshold of perceptibility (>6) after 24 h (Lindsey et al., 2007), PSSD1 consistently limited colour change by 4–5 units relative to PSSD2 in later drying stages. This suggests that design improvements in the modified dryer reduced pigment degradation, particularly for carotenoids such as lycopene and β -carotene, which are responsible for redness (a^*) and yellowness (b^*) values. Previous studies have shown that high drying temperatures and oxygen exposure accelerate carotenoid breakdown and colour loss (Demiray et al., 2017; Arslan & Özcan, 2011). The modified system likely offered more stable thermal and airflow

conditions, thereby slowing degradation and yielding better colour retention.

Conclusion

The study showed that the implemented design modifications significantly improved the drying conditions, reduced drying time, and enhanced product quality. The modified maintained a higher temperature during both daytime and nighttime, coupled with lower relative humidity, which facilitated continuous drying and the faster attainment of safe moisture levels. Drying rates were also superior in the modified unit, resulting in a 24-hour reduction in total drying duration compared to the existing dryer. Colour analysis confirmed that the modified dryer preserved redness and yellowness more effectively, with lower ΔE values indicating reduced perceptible colour changes. These

findings demonstrate that the modified solar dryer is more efficient in maintaining both the safety and visual quality of dried tomatoes. The adoption of such improved designs can significantly contribute to reducing postharvest losses and enhancing value addition in tomato processing.

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