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Comparative Study of the Drying Rate, Drying Kinetics and Sensory Evaluation of Mango Chips Using a Cabinet Tray Dryer and a Solar Dryer

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ABSTRACT

The need to reduce post-harvest losses, coupled with the increasing demand for dried fruits especially mango chips, necessitates the development and evaluation of efficient drying technologies. This study evaluated the performance of Nigerian Stored Products Research Institute (NSPRI) multi-crop dryer and NSPRI Parabolic Shaped Solar Dryer (PSSD) for drying mango chips under tropical conditions. Fresh mango slices were dried at temperatures ranging between 32.44 - 60.49 °C; 42.88 – 58.05 °C, for both the cabinet tray dryer (multi-crop dryer) and solar dryer (PSSD) respectively. The drying rate and kinetics, sensory attributes of the dried samples were assessed. Furthermore, mathematical modeling of the drying kinetics was conducted using commonly used thin-layer models, and the goodness of fit was evaluated using the coefficient of determination (R^2) and root mean square error (RMSE). Results indicated that the initial moisture contents of the fresh mango were 419.08% d.b., while the final moisture content using both the cabinet tray dryer and solar dryer was 7.98±2.93% after 11 h, and 15.12% ± 4.77% (d.b.) after 12 h respectively. Also, there was a 45.74% increase in temperature in the solar dryer compared to the ambient conditions, 17.27% decrease in RH inside the solar dryer compared to the ambient conditions, a 58.14% reduction of solar radiation in solar dryer compared to the ambient and a 51.67% reduction in air movement inside the solar dryer compared to the ambient. Drying rate of samples using cabinet tray dryer and solar dryer were 0.0884±0.0044, 0.0495±0.0025 kg/h, respectively. Cabinet tray dryer exhibited a significantly higher drying rate ($p<0.05$) and shorter drying duration compared to the solar dryer. However, while the solar dryer demonstrated advantages in terms of energy savings; and better retention of product quality, the cabinet tray dryer achieved faster drying performance due to optimized air circulation and temperature control.

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Introduction

Mango is an economically important crop in Nigeria, with production of mango, mangosteen, and guava reaching approximately 940,000 metric tonnes in 2022 (Helgi, 2022). Although, this is a significant quantity, Nigeria still falls short of its potential, often producing just under one million tonnes annually (Essiet, 2024). Mango cultivation supports livelihoods for many small-scale farmers and plays a role in local food security (FRN, 2021). Existing processing capability, such as Benfruit Plant in Benue State with ~26,500 metric tonnes/year capacity, shows growing infrastructure for value addition (Wikipedia, 2025). However, post-harvest losses remain high due to the perishable nature of mangoes, inadequate storage, and under-utilization of value-added processing (yakubu, 2024). Enhancing drying, improving packaging, and developing processing industries (for production of chips, juices, and purees) present substantial economic opportunity for Nigeria.

The Mango (*Mangifera indica*) is an extremely nourishing and economically viable tropical fruit, generally consumed either fresh or in processed forms. However, its high moisture content (water level in the material that is above the recommended or safe range for storage or processing, which can affect product stability and drying efficiency) makes it highly perishable, leading to substantial post-harvest losses, particularly in developing countries where cold storage and transport infrastructure are limited (Akoy & Ismail, 2020). Drying is one of the most effective methods used for prolonging the shelf life of agricultural crops by reducing its moisture content, thus inhibiting microbial activity and enzymatic degradation (Raji & Olanrewaju, 2015; Akoy & Ismail, 2020).

Drying of agricultural crops can be done using diverse types of dryers which includes; Cabinet tray dryer such as the Nigerian Stored Products Research Institute, NSPRI multi-crop dryer, and solar dryer. The cabinet tray dryer is a convective hot air dryer usually used for drying agricultural materials in small to medium-scale operations (Raji and Olanrewaju, 2015). The controlled temperature and airflow conditions in cabinet tray dryers offer consistent drying performance and help preserve product quality, and nutrient retention (Muthuvairavan et al., 2023). Solar drying is a generally adopted, energy-efficient, and environmentally friendly method of preserving crops, particularly in regions with high solar radiation such as sub-Saharan Africa. The efficiency of solar drying systems relies on several factors, which includes dryer design, ambient environmental conditions, and thermal properties of the product being dried (Ajao et al., 2024a).

Understanding the drying behaviour of mango is essential for optimizing drying conditions, improving energy efficiency, and preserving product quality, which is typically achieved by studying drying kinetics (Oyewole et al., 2024a). Drying kinetics are influenced by temperature, air velocity, humidity, and thickness (Oyewole et al., 2024b). Mathematical modeling plays a key role in analyzing and predicting drying behavior, allowing for the optimization of dryer design and operational parameters. Thin-layer drying models are used to simulate drying curves, and also shed light on the fundamental heat and mass transfer mechanisms involved (Raji and Olanrewaju, 2016; Gebre & Tesfaye, 2024). Heat energy facilitates internal moisture diffusion to the surface, from where it evaporates into the drying air. The effectiveness of this process significantly influences drying rate and energy efficiency.

Convective dryers like the NSPRI Multi-Crop Dryer, forced air circulation enhances convective heat transfer, while in passive systems such as the Parabolic Shaped Solar Dryer (PSSD), natural convection governs the drying dynamics (Muthuvairavan et al., 2023). Hence, understanding the heat transfer processes in different dryer is crucial for comparative performance evaluation. Kumar et al. (2022) conducted a computational simulation of mango pulp drying using refractance window drying, highlighting the significance of uniform heat and mass transfer distribution for product quality and energy conservation. Similarly, Gebre and Tesfaye (2024) from previous studies investigated the drying behavior of mango seeds at different temperatures using mathematical models and reported how pretreatments and air temperature significantly affect drying kinetics and final product characteristics. These studies highlight the relevance of modeling in accurately capturing the complex dynamics of fruit drying processes. Furthermore, the selection of appropriate drying kinetics models is essential for accurately describing and predicting the drying behaviour of agricultural materials. In this study, eight commonly used thin-layer drying models were applied to experimental data from mango chips dried in both the cabinet tray dryer and solar dryer.

In addition, sensory evaluation of dried mango chips is crucial for determining consumer acceptability. Research has shown that drying methods and pre-treatment significantly affect these sensory qualities, with chips dried using optimized hot air or solar methods (Arthey & Dennis, 1996; Owureku-Asare et al., 2017). Building on this background, this present study aimed to comparatively analyze the drying rate, drying kinetics, and sensory evaluation of mango chips produced using a cabinet tray dryer and a solar dryer. The innovation of this work lies in linking thermal performance (through drying rate and kinetics modeling) with product quality (through sensory evaluation), thereby providing practical guidance on the suitability of these two dryers for small- to medium-scale mango processing.

Materials and Methods

Materials

Procurement of Mangoes

Fresh, mature ripe mangoes (*Mangifera indica*) were sourced from Ogbomosho, Oyo State, Nigeria, a town known for its seasonal production of high-quality mangoes. Afterwards, they were transported to Nigerian Stored Products Research Institute (NSPRI) Ibadan Zonal Office. Mangoes were selected based on uniform ripeness, firmness, and absence of defects, in line with the selection criteria described by Owureku-Asare et al. (2017).

Brief description of Cabinet Tray Dryer (NSPRI multi-crop dryer): Principle of Operation

The cabinet tray dryer used in this study (NSPRI Multi-crop dryer) was designed and fabricated at the Nigerian Stored Products Research Institute, Ilorin, Nigeria. The dryer is shown in Figure 1a and operate with the principle of forced convective heat and mass transfer. It is a gas-powered dryer that uses forced convection to transfer thermal energy from a heated air stream to the surface of the moist material to be dried, thereby, causing evaporation of moisture, which is then carried away by the airflow. Its components include the drying chamber, drying trays, heating elements, combustion chamber, control system and vents. The cabinet tray dryer used in this study had internal dimensions of approximately 1200 mm × 600 mm (length × width), designed to accommodate trays of 1150 mm × 550 mm each, stacked vertically within the drying chamber. The working principle involves the loading phase where the wet food material is evenly and thinly spread across the trays and the trays are thereafter loaded into the cabinet in vertical arrangement for optimized airflow; the heating and circulation phase where the heating system raises the temperature of the ambient air, thereby producing hot air through the drying chamber for improved convective heat transfer; the drying phase where sensible heat is transferred from the hot air to the material to be dried, latent heat of vapourization is absorbed by moisture, causing phase change from liquid to vapour and this is removed via the vents; finally is the unloading phase, drying continues to the desired moisture content, either to safe moisture content or equilibrium moisture content, afterwards, dried products are unloaded and the dryer may be prepared for the next batch. Although, locally fabricated at NSPRI for multi-crop applications, it operates on the same principle as conventional cabinet tray dryers.

Brief Description of NSPRI Parabolic Shaped Solar Dryer, PSSD

The NSPRI PSSD that has been installed in NSPRI Ibadan Zonal Office was used for this study and is presented in Figure 1b. It is a solar drying technology developed by Nigerian Stored Products Research Institute to improve the drying of agricultural produce. It is designed to reduce post-harvest losses and enhance food preservation, especially for smallholder farmers. The dryer is a stationary structure with key features like transparent UV screen cover, parabolic metallic frames, black floor, drying racks and trays, air inlet vents and exit (aspirators). The transparent UV screen covering material supported by the metallic frames provides an enclosure and also transmits solar radiation heat from the sun into the drying chamber. The black floor stores the heat from the sun and is insulated to prevent heat loss to the ground due to conduction. The dryer has 28 trays arranged in two layers on two sets of mobile racks positioned on rail tracks. There are six inlet vents screened with galvanized wire mesh (net) to prevent insects from gaining access into the dryer. The dryer has dimensions of 6.5 × 4.2 × 2.4 m with an effective drying area of 17.85 m^2. The parabolic shape design focuses and concentrates solar radiation, increasing the efficiency of heat capture. It is solar-powered as it uses natural sunlight, making it environmentally friendly and cost-effective. The drying chamber is enclosed to protect produce from dust, insects, and sudden rainfall and the ventilation system ensures proper airflow for uniform and faster drying. Compared to the conventional open sun drying, it is faster with more uniform drying. In addition, it produces better product quality by minimizing contamination and spoilage, leading to cleaner and better-preserved products. It requires no fuel or electricity thereby reducing operational costs. It helps to reduce post-harvest losses, preserving more food for consumption and sale. It uses include for drying fruits, vegetables, grains, fish, and other perishable produce.

Methods

Preparation of Dried Mango Chips

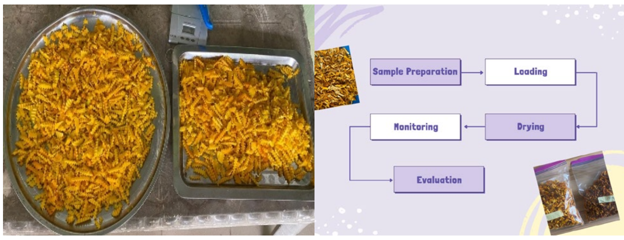
The mangoes were sorted to remove damaged or over ripe fruits, afterwards, they were washed using potable water to eliminate debris and impurities, following the procedure outlined by Dadzie and Orchard (1997). The cleaned mangoes were manually peeled using stainless steel knives and hand-sliced into uniform pieces approximately 30 mm thick to ensure even drying, as shown in Figure 2a and recommended by Emelike and Ebere (2016); Oyewole et al., (2023). Figure 2b shows the flowchart for the preparation of the dried mango chips.

Drying Experiment

The experiment was done on 30th April, 2024 in the premises of NSPRI Ibadan Zonal Office (N 7˚ 23' 36"; E 3˚ 52' 42") located at Onireke, Ibadan, Nigeria. The sliced mango samples were arranged in thin layers on trays and dried using both the cabinet tray dryer and solar dryer (Figure 3a and 3b respectively), until the moisture content reached safe moisture content, based on drying protocols described by Emelike & Ebere (2016) and Arthey & Ashurst (1996). The initial moisture contents of mango samples were estimated by placing samples in a laboratory oven at 105 °C for about 6 – 7 h as required by ASABE S352.1 standards, (ASABE, 2021) and AOAC standards (AOAC, 2020). Each drying experiment was monitored by weighing the samples every thirty minutes for the first three hours, and every sixty minutes thereafter until the end of the drying, using a digital weighing balance (±0.01 g accuracy). Meteorological parameters such as Temperature, Relative Humidity, Solar radiation and Air Velocity were monitored for mango chips dried in the NSPRI PSSD. Devices used included: Temperature Temtop Datalogger [TemLog 20H (Accuracy: T - ±0.5°C; R.H. - ±3 %)]; Relative humidity Temtop Datalogger [TemLog 20H (Accuracy: T - ±0.5°C; R.H. - ±3 %)]; Air velocity Testo 410-1 air velocity meter (Resolution – 0.1 m/s; accuracy - ±1 m/s); Solar radiation DT-1307 solarimeter (Resolution – 1 W/m 2 ; max. –1999 w/m^2 ; accuracy - ±10 W/m^2).

(a) (b)

Figure 1a. NSPRI multi-crop dryer, b: NSPRI PSSD



(a) (b)

Figure 2a. Sliced mango chips before drying
b. Flowchart for the preparation of mango chips

(a) (b)

Figure 3. Interior views of the dryers showing thinly spread sliced mango chips
a: NSPRI multi-crop dryer; b: NSPRI PSSD

Table 1. Mathematical models applied to the drying curves of dried mango chips

S/N	Model Name	Model	Sources
1	Newton/Lewis	$MR = \exp(-kt)$	(Liu and Bakker-Arkema, 2001)
2	Modified Page	$MR = \exp(-(kt)^n)$	(Agbossou et al., 2016)
3	Logarithmic	$MR = a\exp(-kt) + c$	(Yaldiz et al., 2001)
4	Two-term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	(Zielińska and Markowski, 2010)
5	Henderson and Pabis	$MR = a\exp(-kt)$	(Karathanos and Belessiotis, 1999)
6	Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-kt)$	(Amendola and Queiroz, 2007)
7	Midilli et al.	$MR = a\exp(-kt^n) + bt$	(Midilli et al., 2002)
8	Wang and Singh	$MR = 1 + at + bt^2$	(Wang and Singh, 1978)

Determination of Moisture Content and Drying Rate of the Dryers

The Drying Rates (DR) of samples dried using the two dryers was calculated using the following equation according to Akpinar et al. (2003); Ajao et al. (2025) as shown in equation 1:

$$Drying\ rate = \frac{W_t - W_{t+\Delta t}}{\Delta t} \quad (1)$$

Where: W_t is weight of the sample (kg) at time t, $W_{t+\Delta t}$ is weight of the sample at time, $t + \Delta t$, and Δt is time interval (h).

The moisture ratio (MR) at each time point was calculated according to Ertekin & Firat (2017); Ajao et al. (2024b) using the formula in equation 2:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (2)$$

Where: M_t is moisture content at time t, M_0 is initial moisture content, M_e is equilibrium moisture content.

Selection of Drying Kinetics Models

The selection of appropriate drying kinetics models is vital for accurate description and prediction of drying behaviour of agricultural materials. Thin-layer drying models are empirical or semi-theoretical equations that have been developed to simulate the relationship between moisture ratio and drying time under specific conditions. These models help in understanding the drying mechanism, optimizing drying parameters, and designing efficient drying systems (Midilli et al., 2002; Ajao et al., 2024b). Eight thin-layer drying models as shown in Table 1 were used to determine the best fit to experimental data for drying of mango chips using both cabinet tray dryer and solar dryer. These models have been commonly used in literature by several other researchers for drying of agricultural crops (Akpinar et al., 2003; Ertekin & Firat, 2017).

Model Fitting and Performance Evaluation of Models

The experimental data of dried mango chips which is the result of relationship of moisture ratio and time were fitted into the eight drying models using the iterative approach of non-linear regression analysis. The accuracy and performance of the eight models were evaluated based on statistical parameters which includes: Coefficient of determination (R^2) and this indicates how well a model explains the variability in the data. The values closer to 1 indicate a better fit; and Root Mean Square Error (RMSE) which measures the average magnitude of the errors between predicted and experimental values. The values tending towards zero indicate a better fit. Thus, the best model was selected based on the highest (R^2) and lowest RMSE values (Doymaz, 2004).

Sensory Evaluation of Dried Mango Chips Using Hedonic Scale

A total of twenty (20) untrained panelists, comprising staff and students of the Nigerian Stored Products Research Institute, Ibadan Zonal Office, were selected for the sensory evaluation. The panel included both male and female participants, aged between 18-50 years, representing a mix of students and staff. Panelists were screened for allergies and instructed not to consume any strongly flavoured foods or beverages at least one hour before the evaluation as recommended by Stone et al. (2012). The evaluation was conducted in a well-ventilated, and quiet laboratory. The sensory evaluation was conducted in a single session. Each panelist was presented with two samples (one dried with the cabinet tray dryer and the other with the solar dryer) for evaluation. Furthermore, each panelist received coded samples of the dried mango chips in randomized order to minimize bias. Water was provided for palate cleansing between samples (Meilgaard et al., 2016). In addition to specific sensory attributes such as appearance, aroma, texture, taste, panelists were also asked to rate the overall acceptability, which represents their general impression of the product after considering all evaluated attributes. A 9-point hedonic scale was used to rate each attribute, where: 1 = Dislike extremely; 2 = Dislike very much; 3 = Dislike moderately; 4 = Dislike slightly; 5 = Neither like nor dislike; 6 = Like slightly; 7 = Like moderately; 8 = Like very much; and 9 = Like extremely. This scale is commonly used in consumer sensory testing (Lawless & Heymann, 2010).

Data Analysis

Drying data were processed in Microsoft Excel, Version 2016, to compute moisture content (dry basis), drying rates, and preliminary model parameters. Nonlinear regression analysis and statistical evaluation of the drying models (R^2, RMSE) were performed using IBM SPSS Statistics (Version 21.0, IBM, New York, USA). Furthermore, the sensory scores obtained from the panelists were collated and subjected also to statistical analysis. For each attribute (colour, aroma, texture, taste, and overall acceptability), the mean and standard deviation (Mean ± SD) were calculated separately for mango chips dried in the cabinet tray dryer and solar dryer. An independent samples t-test was performed to determine whether there were significant differences in sensory attributes between the two drying methods. The level of significance was set at $p<0.05$.

Results and Discussion

The initial and final moisture contents of mango chips

The product dried in this study was Mango chips, and moisture contents are expressed on a dry basis (d.b.). Literature reports that fruit chips and similar dried products are generally dried to a safe storage moisture of below 10% d.b., with some chip products (e.g., banana chips, dehydrated potato flake) typically in the range of 5-9% d.b. for optimum quality and shelf stability (Sakhale et al., 2009).

In the present study, the initial moisture contents of the fresh mango chips sample was 419.08%db, while the final moisture content of dried mango chips varied significantly depending on the type of dryer used. The final moisture content using both the cabinet tray dryer and solar dryer was 7.98±2.93%, and 15.12% ± 4.77% (db) respectively, and is presented in Table 2. The cabinet tray dryer achieved a much lower and more consistent final moisture content compared to the solar dryer**.** The moisture content of 7.98% db falls well within the recommended safe range (<10% db) for dried fruit products, which ensures microbial stability and shelf life (Fellows, 2009). The lower standard deviation (±2.93%) further indicates uniform drying and effective moisture removal. However, the PSSD gave higher average final moisture content of 15.12% db, with a standard deviation of **±**4.77%**.**

Although, the solar dryer substantially reduced the moisture content, the product would require further drying or complementary preservation to reach the safe storage standard for mango chips. This variation was due to environmental fluctuations especially because the experiment was carried out during the rainy season which caused high humidity, and low sunlight radiation which is inherent in solar drying systems (Forson et al., 2007; Amer et al., 2010; Oyewole et al., 2023; Ajao et al., 2024a). The cabinet tray dryer, being mechanically controlled, guarantees more precise temperature and airflow regulation, resulting in more consistent drying results. Its performance aligns with studies by Gabas et al. (2009) and Sharma et al. (2009), who observed final moisture contents between 8 - 12% db for hot-air-dried mango slices. The observed fluctuation of chamber temperature between 50 and 60 °C is due to the operational design of the cabinet tray dryer, which relies on manual control (switching the heat source on and off or adjusting intensity) rather than an automatic thermostat or PID regulation. Such fluctuations are therefore expected and reflect the practical, field-oriented nature of the dryer. Despite this, the average drying temperature (51.43°C) remained within the recommended range for mango chip drying, and consistent drying behaviour was observed. Nonetheless, incorporating an automated temperature control mechanism in future designs would help minimize variability and further improve product quality.

Furthermore, the solar dryer, though capable of reducing moisture content of fruits to acceptable ranges for short-term or semi-dry preservation, exhibits greater variability. Its average Final moisture content (15.12% db) is on the borderline of safe storage conditions, depending on packaging and relative humidity. The solar dryer relies on fluctuating solar radiation and ambient conditions, which likely contributed to higher variability (± 4.77%) and incomplete drying. This wide range suggests that, while solar drying substantially reduces moisture content, it may not consistently achieve the low levels required for long-term storage of mango chips particularly during rainy season without supplementary drying or design modifications. According to Akoy et al. (2013), moisture sorption studies of dried mango slices indicate that maintaining moisture content at approximately 15% d.b. or less is important for microbiological stability. Similarly, Goyal et al. (2006) reported that mango chips dried to 8-12% d.b. retained acceptable texture, colour, and sensory attributes when appropriate packaging was applied. In another comparative study, Ur-Rehman and Awan (2012) observed that dehydration of fruits often target final moisture contents close to 15% as a practical upper limit for safe storage. The solar dryer relies on fluctuating solar radiation and ambient conditions, which likely contributed to the higher variability among replicates and occasional incomplete drying. This wide variation suggests that, while solar drying substantially reduces moisture content, it may not consistently achieve the low levels required for long-term storage of mango chips, particularly during the raining season without supplementary drying or design modification. Therefore, the results emphasize the trade-off between consistency and control (cabinet drying) versus cost-effectiveness and renewable energy use (solar drying). Hence, to improve reliability, the following maybe considered: Reduction of mango slice thickness, optimizing tray positioning and airflow, or supplementing solar drying with post-drying techniques especially during periods of rainy season.

Result of drying environment data

The drying environment was characterized by monitoring temperature, relative humidity, solar radiation, and air velocity within the drying chamber and ambient. The result of the drying environmental data during the drying period is shown in Figure 4. Over the drying period, the solar dryer maintained an average temperature of 51.85 °C, while the ambient environment had an average of 35.60 °C (Figure 4a). This represents a 45.74% increase in temperature compared to the ambient conditions. This substantial and sustained increase demonstrates a significant thermal performance advantage and suggests that the solar dryer system effectively absorbs and retains heat from the sun, hence minimizing heat loss for better efficiency of the dryer. Also, the solar dryer maintained an average relative humidity of 45.90%, while the ambient environment had a higher RH of 55.49% (Figure 4b). This represents a 17.27% decrease in RH inside the solar dryer compared to the ambient conditions. The significant difference in average humidity values establishes the fact that the solar dryer effectively reduces and controls humidity. Furthermore, the average maximum solar radiation within the solar dryer was 481.44 W/m², while the ambient environment had a much higher average of 1150.19 W/m² (Figure 4c). The 58.14% reduction indicates that the solar dryer significantly filters solar radiation. This reduction is due to the effect of the transparent UV screen in the solar dryer. Hence, this confirms the effectiveness of the solar dryer in limiting exposure of products to be dried to solar energy thereby retaining more nutrients. Finally, the average air flow in the solar dryer is 0.58 m/s, while in the ambient, is 1.20 m/s (Figure 4d). This represents a 51.67% reduction in air movement inside the solar dryer. This helps to stabilize temperature and relative humidity.

Table 2. Initial and final moisture contents, and drying rate of mango chips dried using the cabinet tray dryer and solar dryer

Sample ID	Average Moisture Content (%, db)		Drying rate (kg/h)	
	Cabinet tray dryer	Solar dryer	Cabinet tray dryer	Solar dryer
Fresh Mango Chips	419.08	419.08	-	-
Dried Mango Chips	7.98±2.93	15.12±4.77	0.0884±0.0044	0.0495±0.0025

Values are expressed as mean ± standard deviation of triplicate determination. Means with the same letters along the same row are not significantly different ($p<0.05$)

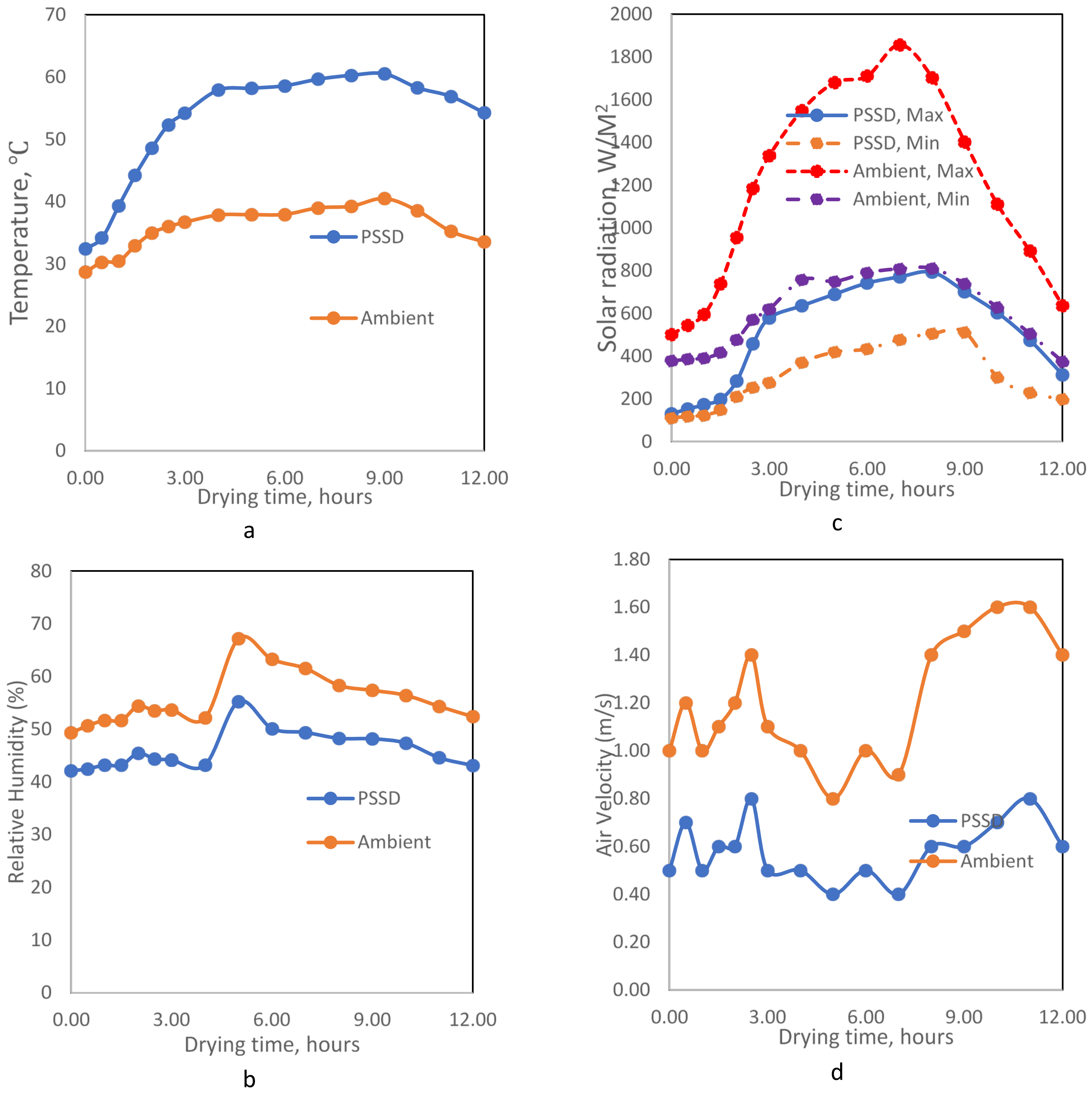


Figure 4a. Temperature reading during the drying period, b. Relative humidity reading during the drying period, c. Solar radiation reading during the drying period, d. Air velocity reading during the drying period
Note: Values represent single measurements; error bars are not applicable

Furthermore, it supports the fact that the solar dryer is designed to minimize external airflow disturbances, contributing to a more stable and controlled microclimate. This is consistent with other studies from Ekechukwu and Norton (1999); Oyewole et al. (2023); Ajao et al. (2024a). For instance, a study conducted in Sikkin, India, reported maximum temperatures inside the solar dryer of 66.5 and 59.5 °C at 14:00 h, with minimum temperatures of 28.5 and 24.1 °C at 08:00 h. Solar radiation during the same period ranged from 94 W/m^2 (Seveda and Jhajharia, 2012).. Similarly, research on solar drying in Bangladesh indicated maximum drying temperatures of 66.97 °C, with average temperatures between 35.10 and 43.26 °C, and relative humidity levels around 20% (Morshed et al., 2018). These comparative data underscore the effectiveness of solar drying systems in achieving high temperatures and low humidity, which are conducive to efficient drying processes.

Temperature Readings During Drying of Mango Chips Using Cabinet Tray Dryer

The drying process was monitored for 11 h as shown in Figure 5, with temperature readings taken at intervals. The average drying temperature was 51.43 ºC, which falls within the optimal drying range of typically 50–60 °C for mango chips to ensure efficient moisture removal without compromising quality, texture, or colour (Kingsly et al., 2007; Sablani et al., 2008). A stable drying temperature within this range helps prevent case hardening, nutrient degradation, or surface discoloration, which are common issues when temperatures are too high (Jayaraman & Gupta, 1995). The readings suggest that the cabinet tray dryer maintained favourable conditions for effective dehydration, thereby ensuring high-quality dried mango chips.

Comparison of Drying Behaviour of Mango Chips Dried Using Cabinet Tray Dryer and Solar Dryer

Drying rate of samples using both dryers were 0.0884±0.0044 kg/h, 0.0495±0.0025 kg/h respectively as shown in Table 2. These values fall within the ranges reported in earlier studies: mango slices dried at controlled temperatures achieved rates of 0.04-0.09 kg/h (Akoy, 2020), solar dryers for fruits and vegetables typically show 0.03-0.08 kg/h (Bala, 2009), while dika nuts under Nigerian ambient conditions exhibited rates of 0.05-0.07 kg/h (Aregbesola et al., 2015). The higher rate observed with the cabinet tray dryer reflects its more controlled environment and elevated drying temperatures compared with the natural convection solar dryer, consistent with previous reviews of dryer performance (Ekechukwu & Norton, 1999).

This significant difference of drying rate values of both dryers confirms that cabinet dryer, which typically uses forced convection and controlled heating, is more efficient in moisture removal compared to the solar dryer that relies primarily on natural convection and solar radiation. These findings align with previous studies that have demonstrated the superior performance of mechanically-assisted dryers over passive systems (Olumekun et al., 2020; Akinoso & Owolarafe, 2018). While the solar dryer remains a cost-effective and environmentally friendly alternative, its lower drying rate may limit its effectiveness during periods of low solar intensity or high humidity.

Evaluation of models and drying kinetics

The drying kinetics of mango chips dried using cabinet tray dryer and solar dryer was evaluated using moisture-dependent parameters such as drying time, drying rate and moisture ratio. Thus, the experimental moisture ratio was fitted accordingly into the eight drying models and graphs generated are presented in Figures 6a and b respectively to illustrate the experimental drying behaviour of the mango chips.

The result of the estimated parameters and statistical criteria for models used for mango chips dried using the cabinet tray dryer and solar dryer are presented in Table 3. The best model for the prediction of mango chips dried using the cabinet tray dryer based on R^2 value is Midilli et al. model with 0.9988, followed by Wang and Sing model with 0.9987. Both models gave the best prediction based on RMSE with values of 0.0120. The Midilli et al. model demonstrated the best overall performance, combining high predictive power (highest R^2) with minimal error (lowest RMSE) for the cabinet tray dryer. On the other hand, the best model for the prediction of mango chips dried using the solar dryer based on R^2 value is Midilli at al. model with 0.9915, followed by Modified Page model with 0.9889. However, the RMSE values of the two models are 0.0289 and 0.0418 respectively. Hence, for the solar dryer, the Midilli et al. model again outperforms others in both R^2 and RMSE values, confirming its suitability for mango chips drying. Several studies (Midilli et al., 2002; Akpinar et al., 2003; Ertekin & Firat, 2017; Ajao et al., 2024b) have reported similar drying behaviours in agricultural crops. Midilli et al. (2002) originally proposed the model to improve prediction accuracy in drying processes. It combines exponential and linear components, thus, yielding greater flexibility in curve fitting. Abasi et al. (2015) found the Midilli model superior in fitting drying data for carrot slices, reporting $R^2 > 0.99$ and RMSE < 0.02. Doymaz (2017) also observed that the Midilli model gave the best fit for drying kinetics of okra and tomato with highest R^2 and lowest RMSE compared to Newton and Page models. Furthermore, Simal et al. (2005) reported the effectiveness of the Midilli model for various fruits due to its ability to capture both initial fast drying and slower final stages (falling rate period). These findings are in agreement with the results obtained for the drying of mango chips using the cabinet tray dryer and solar dryer, where Midilli et al. model consistently show the best statistical fit for both dryers that were evaluated. Therefore, the consistent performance of the Midilli et al. model across both dryers indicates that it is a reliable predictor of moisture loss and it can be used to optimize drying parameters and enhance dryer design for improved energy efficiency and product quality.

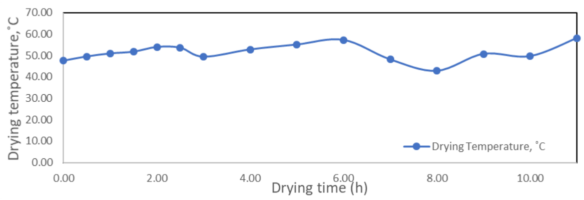
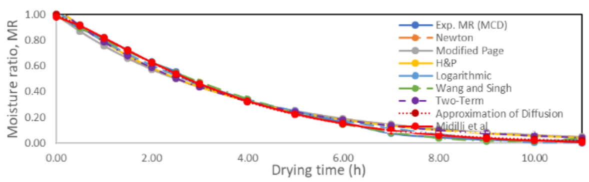
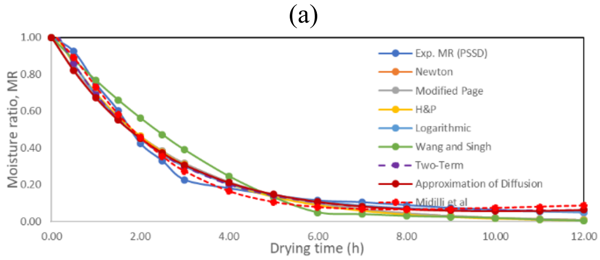


Figure 5. Drying temperature versus drying time curve for drying of mango chips



(a)



(b)

Figure 6a. Moisture Ratio Fittings of Dried Mango Chips using NSPRI Multi-crop Dryer
b. Moisture Ratio Fittings of Dried Mango Chips using NSPRI PSSD

Table 3. Estimated parameters and statistical criteria for thin-layer drying models applied to mango chips

Sample ID	EPSC	Models							
		1	2	3	4	5	6	7	8
Multi-crop Dryer	a			1.138	0.603	-12.35	1.059	0.984	-0.207
	k	0.276	0.235	0.232		0.526	0.294	0.182	
	n		1.176					1.291	
	k_o				0.294				
	b				0.455	0.945		-0.001	0.011
	c			-0.107					
	k_1				0.294				
	RMSE	0.0722	0.0448	0.0236	0.0382	0.0136	0.0382	0.012	0.0120
	R^2	0.9923	0.9922	0.9951	0.9895	0.9985	0.9895	0.9988	0.9987
NSPRI PSSD	a			1.023	0.020	0.403	1.051	1.026	-0.249
	k	0.384	1.844	0.471		0.405	0.408	0.351	
	n		0.208					1.265	
	k_o				-0.091				
	b				0.0150	0.992		0.007	0.015
	c			0.050					
	k_1				0.0450				
	RMSE	0.0498	0.0418	0.038	0.0380	0.0440	0.046	0.0289	0.0919
	R^2	0.9773	0.9889	0.9849	0.9853	0.9834	0.9810	0.9915	0.9277

EPSC: Estimated parameters and statistical criteria; 1: Newton/Lewis, 2: Modified Page; 3: Logarithmic; 4: Two-term; 5: Henderson and Pabis; 6: Approximation of diffusion; 7: Midilli et al.; 8: Wang and Singh

Sensory evaluation of mango chips dried using cabinet tray dryer and solar dryer

The sensory evaluation results provided important insights into the influence of drying methods on the quality perception of mango chips. The mean scores of the sensory attributes for mango chips dried using both cabinet tray dryer and solar dryer are presented in Table 4.

Colour

Panelists rated the solar-dried chips significantly higher (7.92 ± 0.67) compared to those dried in the cabinet tray dryer (6.17 ± 0.58) ($p<0.001$). This suggests superior colour retention in the PSSD. Although, the cabinet tray dryer is a closed convective dryer, greater colour loss was observed, likely due to temperature fluctuations resulting from its on-off heating control system, which exposed samples intermittently to high thermal loads. These fluctuations, combined with the forced convection airflow, may have accelerated pigment degradation through thermal and oxidative pathways (Karam et al., 2016).

On the other hand, the solar dryer incorporated a UV screen that reduced photo-oxidative stress and stabilized drying conditions, thereby preserving carotenoids and other pigments. This observation is consistent with earlier reports that, moderate and stable drying conditions enhance colour preservation in dried fruits (Vega-Gálvez, 2009).

Aroma

There was no significant difference in aroma between the cabinet tray dryer (7.50 ± 0.52) and solar dryer (7.67 ± 0.49) samples ($p=0.430$). This suggests that drying method did not greatly affect volatile compounds responsible for aroma. Both systems appeared capable of maintaining acceptable aromatic quality, which aligns with previous studies showing that moderate drying temperatures can retain much of the natural aroma in mango products (Maskan, 2001).

Texture

The mean texture scores of the cabinet dryer (8.08 ± 0.51) and solar dryer (7.17 ± 0.39) chips were significantly different as cabinet tray dryer samples were rated significantly higher than those from solar dryer ($p=0.001$). This suggests that the drying conditions in the cabinet dryer have promoted firmer product structures, possibly due to high convective heat transfer leading to lower residual moisture. Firmer textures are often associated with better consumer acceptance of dried snack products. Furthermore, panelists generally perceived samples from the cabinet dryer as having desirable crispness and chewability. This may be attributed to the fact that the cabinet tray dryer reduced moisture content to comparable levels (Meilgaard, 2016).

Taste

Taste scores were also comparable between the cabinet tray dryer (7.67 ± 0.49) and solar dryer (7.50 ± 0.52) samples ($p = 0.430$). This indicates that the drying method did not significantly alter the perception of sweetness, acidity, or overall flavor profile of the mango chips. Since taste is influenced by sugars and organic acids, the similar outcomes suggest that neither dryer promoted excessive caramelization or degradation of flavor precursors (Abano & Ma, 2014).

Overall Acceptability

Despite the higher colour ratings for the solar dryer, overall acceptability was significantly higher for cabinet tray-dried chips (8.00 ± 0.60) compared to solar dried (7.42 ± 0.51) ($p = 0.019$). This outcome highlights that consumers evaluate products holistically, integrating multiple attributes beyond appearance. While colour is an important quality parameter, the combination of taste, aroma, and texture in the cabinet tray dryers likely contributed to their higher overall acceptance. Similar findings have been reported in sensory studies where overall acceptability was driven more by taste and texture than colour alone (Di & Crapiste, 2008, Osunleke et al., 2023).

Table 4. Results of sensory evaluation of mango chips dried using cabinet-tray dryer and solar dryer

Attribute	CD	SD	t-statistic	p-value	Interpretation
Colour	6.17 ± 0.58	7.92 ± 0.67	-6.863	<0.001***	Solar dryer significantly higher
Aroma	7.50 ± 0.52	7.67 ± 0.49	-0.804	0.430	No significant difference
Texture	8.08 ± 0.51	7.17 ± 0.39	4.919	<0.001***	Cabinet tray dryer significantly higher
Taste	7.67 ± 0.49	7.50 ± 0.52	0.804	0.430	No significant difference
Overall Acceptability	8.00 ± 0.60	7.42 ± 0.51	2.548	0.018*	Cabinet tray dryer significantly higher

CD: Cabinet-tray dryer (Mean ± SD); SD: Solar Dryer (Mean ± SD)

Conclusion

This comparative study evaluated the performance of the NSPRI Multi-Crop Dryer and the Parabolic Shaped Solar Dryer in producing thin-layer dried mango chips. The findings indicate that both dryers are effective in reducing moisture content to desirable levels within reasonable drying times. However, the cabinet tray dryer demonstrated superior drying performance in terms of final moisture content and drying rate, which may be linked to its more effective air circulation and temperature regulation. Whereas, solar dryer showed better retention of key quality attribute such as colour which is as a result of the effect of the UV Screen used in the construction of the solar dryer. These results suggest that the cabinet tray dryer is more suitable for producing high-quality dried mango chips with extended shelf life, while the solar dryer could be preferred when colour retention is of priority. Drying took place at the falling rate period. Midilli et al. model demonstrated the best overall performance, combining high predictive power (highest R²) with minimal error (lowest RMSE) for both dryers. Overall, the cabinet tray dryer achieved better drying outcomes compared to the solar dryer, particularly in terms of final moisture content and drying rate, owing to its more effective air circulation and temperature regulation. Future studies are recommended to include energy and exergy analyses to provide deeper insights into the energy utilization and overall efficiency of the dryers. Additionally, further investigations on product quality attributes such as nutrient retention, as well as the integration of smart sensor-based control systems, would enhance the comprehensiveness of performance evaluations.

Declarations

Ethical Approval Certificate

The experimental procedures of this study were approved by the Ethics Committee of the Nigerian Stored Products Research Institute, Ibadan Zonal Office.

Authors Contribution Statement

Taiwo Oluwatoyin AJAO: Data collection, formal analysis, drafting of manuscript and editing; Mariam Bukola AREMU: Conceptualization, methodology, review and editing; Omoniyi Samuel OYEWOLE: Data collection, investigation, review, supervision; Mariam Abiola, RAJI: Data collection, methodology, Omowunmi Olasunmbo ABEL: Data collection, methodology; M. K. ABDULBAKI: Data collection, methodology; Olubukola. A. OGUNDARE: Data collection, methodology; Samuel Taiwo POPOOLA: Data collection, methodology, formal analysis; Oluwatosin Abigael OJO: Data collection, methodology; V. O. ASAOYE: Data collection, methodology.

Conflict of Interest

The authors declare no conflict of interest.”

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