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Alternative Preservation Techniques to Address the Challenges of Postharvest Losses of Fruits: Osmotically Pretreatment on Colour Retention of Selected Fruits During Drying

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ABSTRACT

Post-harvest losses of fruits remain a major challenge in developing countries, especially in tropical regions, where high temperatures speed up deterioration. This study compared conventional solar drying and osmotic dehydration pretreatment for preserving the colour quality of apples, pin eapples, and tomatoes under the climatic conditions of BirninKebbi, Nigeria. Fruits were subjected to either direct solar drying or osmotic pretreatment followed by solar drying. Digital image analysis using ImageJ software was used to quantify colour changes through red, green and blue (RGB) pixel intensities during storage. Results indicated superior colour retention in osmotically treated samples, especially apples and pineapples. Analysis of variance showed significant differences in colour characteristics among treatment groups ($F(6,35)=3.43$, $p=0.009$). Regression analysis additionally showed that drying method markedly predicted colour quality ($\beta=0.172$, $p=0.024$). The results show that osmotic dehydration is a practical, low-cost technology able to reduce post-harvest losses while maintaining fruit market quality in resource-constrained environments.

Keywords: Osmotic dehydration; Solar drying; Fruit preservation; ImageJ; Digital image analysis; Colour retention; Post-harvest losses; Nigeria

INTRODUCTION

Fruit consumption plays a major role in human nutrition by providing vitamins, minerals, dietary fibre, and antioxidants. Fruits and vegetables are essential for proper human growth and development, as they are a major source of vitamins and antioxidants that naturally fight germs and infections. (Yao, Chen and Fan, 2023). Nigeria lies around the equator, which gives it a good climate for the growing of fruits and vegetables. In a tropical society such as Nigeria, the consumption of fruits and vegetables helps build the population's immunity, particularly children's, consequently reducing infant mortality rates. Fruits and vegetables similarly play a vital role in maintaining the health of senior citizens, who need them for the nourishment of their bones and vital organs (Tewari et al., 2017). This is because fruits and vegetables are rich in vitamins, minerals and antioxidants that help to fight diseases and infections. (Yao, Chen and Fan, 2023). Every region in Nigeria has major fruits that are abundant at different seasons in the year. In a nation with a high poverty rate and high inflation, the availability of fruits is a major factor in improving health. Moreover, the fruits are more abundant in the rural areas where the standard of living is lower, and income generation is low. Because of differences in environmental conditions during these seasons, some of the fruits become scarce. However, they are in abundance during their season, necessitating their preservation.

Moreover, fruits are highly perishable commodities, and substantial losses occur between harvest and consumption. The Food and Agriculture Organisation estimates that significant proportions of fruits and vegetables produced globally are lost before reaching consumers (Ambuko et al., 2025; Dou, 2024). In sub-Saharan Africa, inadequate preservation technologies, poor transportation infrastructure, and limited cold-chain facilities further aggravate these losses (Mawoneke et al., 2025; Makule et al., 2022). Hence, every effort to reduce these losses will go a long way toward minimising global hunger and poverty (Porat et al., 2018).

Colour is among the most important quality attributes influencing consumer purchasing decisions on fruits. Consumers frequently associate bright and natural colours with freshness, nutritional value and safety. Consequently, colour degradation during storage and drying can reduce product acceptability and market value. Most consumers base their initial quality assessment on physical appearance, such as colour, size, shape, and the absence of defects (Bhargava & Bansal, 2021; Dobrzanski&Rybczyński, 2018). The external colour has also been used to assess fruit ripeness (Julhia et al., 2019).

Solar drying remains one of the most accessible storage approaches in rural Africa because it requires minimal infrastructure and energy input. Nevertheless, prolonged exposure to sunlight and oxygen frequently causes pigment degradation and browning (Qian et al. 2024; Enaru et al., 2021). Osmotic dehydration is a beneficial pretreatment technology that partially extracts moisture from food materials by immersing them in hypertonic solutions (Sarker et al., 2025). The process reduces water activity, limits oxidative damage and improves retention of sensory and nutritional properties (Asghari et al., 2024; Akbarian et al., 2014).

Although osmotic dehydration has been extensively investigated in Asia, Europe and South America, limited information exists regarding its performance under Nigerian environmental conditions. Therefore, this study evaluated the effects of osmotic dehydration on the colour preservation of selected fruits using digital image processing techniques.

MATERIALS AND METHOD

The study was conducted in Birnin Kebbi, Northwestern Nigeria, between June and November 2025. The city lies at a longitude of 4.1975˚ E and latitude 12.4539˚ N. The area experiences a tropical climate characterized by high ambient temperature (30-42 $^{\circ}c$ during the dry season), relatively low humidity during the dry period, and annual rainfall concentrated between June and September (Abubakar, 2025). These climatic conditions make solar drying a practical and economaical method for food preservation.

Experimental Materials

Fresh apples, pineapples, and tomatoes of uniform maturity, colour, and size were purchased from local market in Birnin Kebbi. Damaged, bruised, diseased, or overripe fruits were excluded to ensure sample uniformity. Granulated sucrose, food-grade sodium chloride (NaCl), and potable water were used for preparing the osmotic solutions.

Equipment used

Solar dryer, digital weighing balance, stainless steel knife, plastic containers for osmotic treatment, computer installed with image j software for image processing, smartphone camera for image, IBM SPSS statistics software for statistical analysis.

Experimental Design

The experiment was arrange as a 3x2 factorial design consisting of three fruit types (apple, pineapple, and tomato) and two drying methods (direct solar drying and osmotic pretreatment followed by solar drying).

Each treatment was conducted in triplicate (n=3), giving six treatment combinations with three independent replicates per treatment. Fruits were randomly assigned to each treatment group to minimize experimental bias.

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Experimental Treatment

Apple – Direct solar drying

Apple – osmotic pretreatment + solar drying

Pineapple- Direct solar drying

Pineapple- osmotic pretreatment + solar drying

Tomato –Direct solar drying

Tomato- osmotic pretreatment + solar drying

Sample Preparation

The fruits were thoroughly washed with clean water to remove dirt and foreign materials. Apples and pineapples were peeled before slicing, whereas tomatoes were washed and sliced without peeling. All the fruits were cut into slices of approximately 5 mm thickness using a stainless-steel knife to ensure uniform drying.

Osmotic Pretreatment

Apple and pineapple slices were immersed in a 50% (w/v) sucrose solution prepared by dissolving 100 g of granulated sugar in 100 mL of water. A fruit-to- solution ratio of 1:2 (w/v) was maintained to ensure adequate mass transfer throughout the osmotic process. The samples were soaked for 4 hours at ambient laboratory temperature. After osmotic treatment, excess solution was drained, and the fruit surfaces were gently blotted with absorbent paper before drying

Solar Drying Procedure

Control samples were dried directly in the solar dryer without pretreatment, while treated samples were dried immediately after osmotic dehydration. The fruits were arranged in a single layer on drying trays to avoid overlapping. Drying was carried out under natural solar radiation until the samples reached a stable weight, indicating sufficient moisture removal. Average ambient temperature and relative humidity were monitored using a digital thermo-hygrometer throughout the drying period.

Storage and Image Acquisition

The dried fruit samples were stored in clean, airtight transparent containers at room temperature throughout the five-month storage period. Digital photographs were captured immediately after drying and subsequently at one- week intervals under standardized conditions. To minimize variations in illumination, all photographs were taken using the same smartphone camera under identical lighting conditions, at a fixed camera-to-sample distance and constant camera settings. A white background was used during image acquisition to improve colour consistency.

Image Processing and Colour Measurement

Digital images were analysed using imageJ software. Each Image was separated into its red (R), green (G), and blue (B) colour channel using the spilt channel function. Mean pixel intensity values for each RGB channel was extracted for every sample. Higher RGB values indicated better colour preservation during storage. The average RGB values obtained from the three experimental replicates were used for subsequent statistical analyses.

Statistical Analysis

All statistical analyses were performed using IBM SPSS statistics at a 95% confidence level (α= 0.05). descriptive statistics (mean and standard deviation) were calculated for each treatment group. A one- way

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analysis of variance (ANOVA) was used to determined whether significant differences existed among the drying treatments and fruit types with respect to RGB colour intensity.

Simple linear regression analysis was performed to evaluate the influence of drying method on colour preservation. The regression model was expressed as:

$$Y = \beta_{0} + \beta_{1} \times + \varepsilon$$

Where

Y= mean RBG colour intensity

X =Drying method (0= direct solar drying ; 1= osmotic pretreatment)

β_0= regression intercept

β_1= regression coefficient

ε= random error term

RESULTS AND DISCUSSION

Table 1 summarises the mean pigment values for both solar drying and the osmotically pretreated process throughout the study period.

Table 1: Mean value of RGB for solar-dried and the osmotically pretreated apple, pineapple and tomatoes.

Fruit		RGB (mean)					
		Red		Green		Blue	
		Type of drying		Type of drying		Type of drying	
		Natural	Osmosis	Natural	Osmosis	Natural	Osmosis
		Mean	Mean	Mean	Mean	Mean	Mean
Fruit	Apple	172.72	190.26	121.45	146.68	85.36	108.16
	Pineapple	91.37	140.86	74.95	114.94	62.14	61.86
	Tomato	133.21	125.70	72.37	74.00	44.37	65.88

The regression model in Table 2 explained approximately 30.6% of the variation in colour intensity, confirming that the drying method substantially influenced colour preservation.

Table 2: Regression model summary of the drying method predicting the colour

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.553[a]	.306	.295	46.48248

a. Predictors: (Constant), RGB, Type of drying
b. Dependent Variable: Mean

This evidence indicates that osmotic dehydration can effectively sustain visual quality throughout extended storage.

Mean Value of RGB for Solar-Dried and the Osmotically Pretreated Apple, Pineapple and Tomatoes.

Figure 1 shows the difference in the mean of the RGB between the solar-dried and the osmotically pretreated fruits in the first week. Mean RGB values demonstrated improved colour retention among osmotically treated fruits. Apples exhibited higher red, green and blue values after osmotic pretreatment. Pineapples showed

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substantial increases in the red and green channels, whereas tomatoes showed improvements mainly in the green and blue channels.

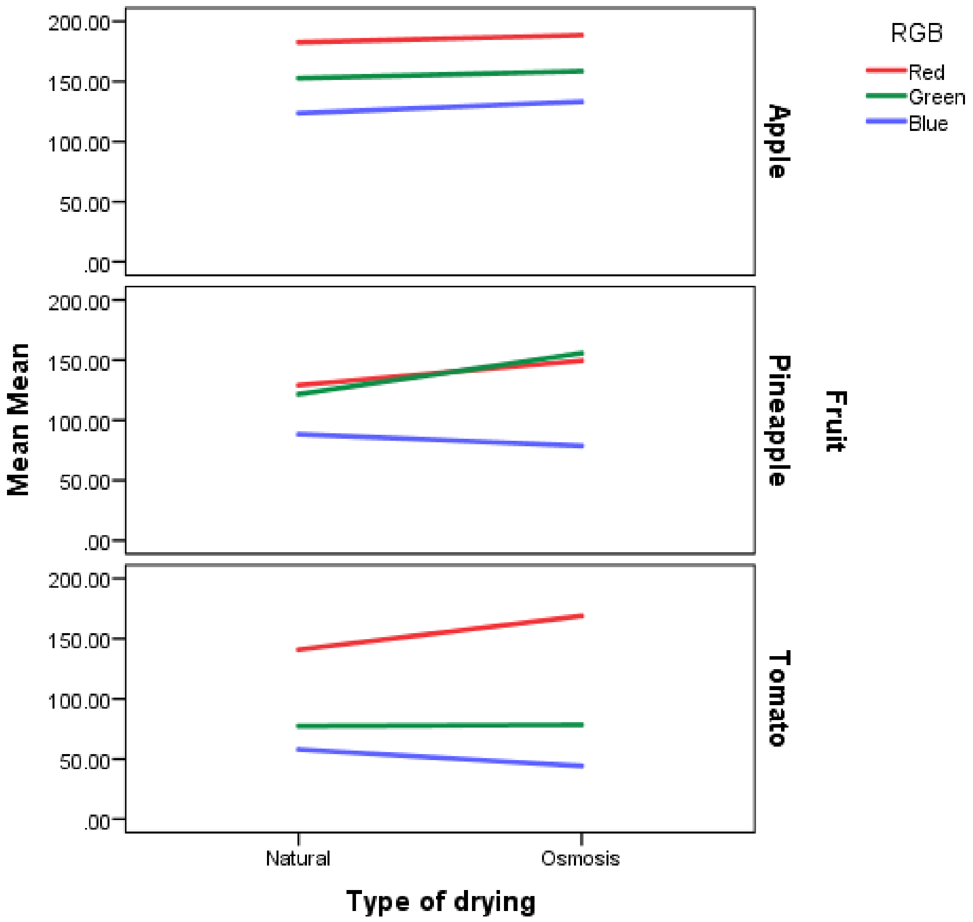

Figure 1: Shows changes in the RGB values for the three fruits during the first week.

The Mean difference in RGB values over a 5-month period.

Figure 2 shows the result for the entire 5 months of the research. The trend is more peculiar for apple in both figures than for pineapple and tomato. The superior colour retention observed in osmotically treated fruits agrees with previous findings that osmotic dehydration minimises enzymatic browning and pigment degradation. The study shows that osmotically pretreated fruits retain their brightness and lightness better than conventionally solar-dried fruits. Krokida and colleagues reported that osmotic pretreatment improves colour stability in dehydrated fruits by decreasing oxygen availability and limiting oxidation reactions. (Krokida et al., 2000; Krokida et al., 2001).

The primary agent of brightness is the sucrose solution in apples and pineapples (Leahu et al., 2020). The improved RGB values recorded for apples may be attributed to sucrose penetration into plant tissues, which stabilises cellular components and decreases enzymatic activity responsible for browning (Chauhan et al., 2011; Krokida et al., 2000). Similar observations have been reported in studies of apple, mango, and pear dehydration.

Pineapple presented remarkable improvements in red and green colour channels following osmotic treatment. The decrease in the blue for pineapple is not uncommon because a fructose solution may not have the same effect on all colours (Wojtys et al., 2025). Higher sucrose concentration and thicker slices can slightly reduce blue colouration (Akhtaruzzaman et al., 2022; Hanafi et al., 2021). Pineapple pigments and phenolic compounds are sensitive to degradation during conventional drying (Sarker et al., 2025). By lowering moisture content before solar drying, osmotic dehydration decreases thermal and oxidative stress, consequently preserving pigment integrity.

Tomato demonstrated a more detailed response. Although redness decreased slightly following salt-based osmotic treatment, green and blue intensities increased (Parvin et al., 2019). This observation may be associated with changes in carotenoid composition, particularly lycopene stability. Previous studies have reported that sodium chloride solutions may influence chroma and redness values during tomato dehydration. Despite this observation, osmosis-pre-treated tomato drying produces the best colour quality and retains more nutrients than the ordinary solar drying method (Heredia *et al*., 2007). As observed in this study, other studies also reported that the use of salt in osmotically preheated tomato reduces the measured redness due to a decrease in chroma (Ali et al., 2010). Salt is reported to be less favourable for redness due to its lower carotenoid reduction potential (Heredia et al., 2009). Osmosis pre-treatment of tomatoes usually facilitates drying because the salt sucks the water compared to naturally solar-dried (Escher *et al*., 2017). The osmosis drying also prevents flies and other insects from dropping on it, thereby making it more hygienic (Nabnean*etal*., 2016)

From a practical perspective, colour preservation has direct economic effects. Consumers commonly rely on appearance when evaluating food quality. Therefore, improved colour retention may increase market acceptability and profitability. The technology may be especially useful in rural communities where refrigeration facilities are scarce.

The study further demonstrates the usefulness of digital image analysis as an affordable quality assessment tool. Unlike subjective visual inspection, computer-assisted colour measurement provides objective and reproducible information. The increasing availability of smartphones and open-source software makes such approaches attractive for researchers and small-scale food processors. The findings support wider efforts to reduce post-harvest losses and strengthen food security in developing countries. Adopting osmotic dehydration could improve shelf life, reduce waste, and enhance income for farmers and fruit processors.

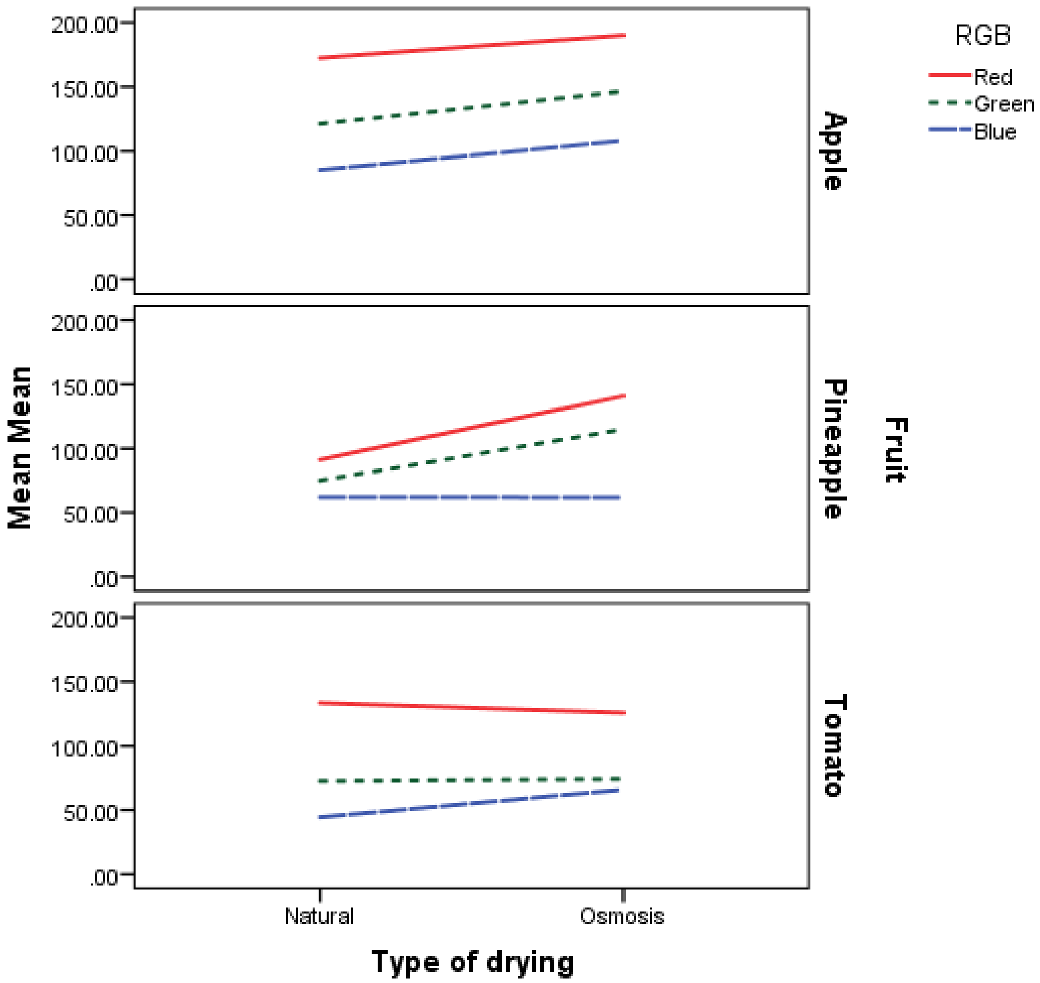

Figure 2: Shows the difference in RGB values over a 5-month period.

ANOVA, and Regression Analyses

ANOVA results showed significant differences in colour changes during the 5-month drying period ($F(6, 35) = 3.43$, $p=0.009$). The boxplots in Figure 3 revealed that the colour differences between natural and osmotic drying became significant after the second week.The regression model in Table 2 explained approximately 30.6% of the variation in colour intensity, confirming that the drying method substantially influenced colour preservation.

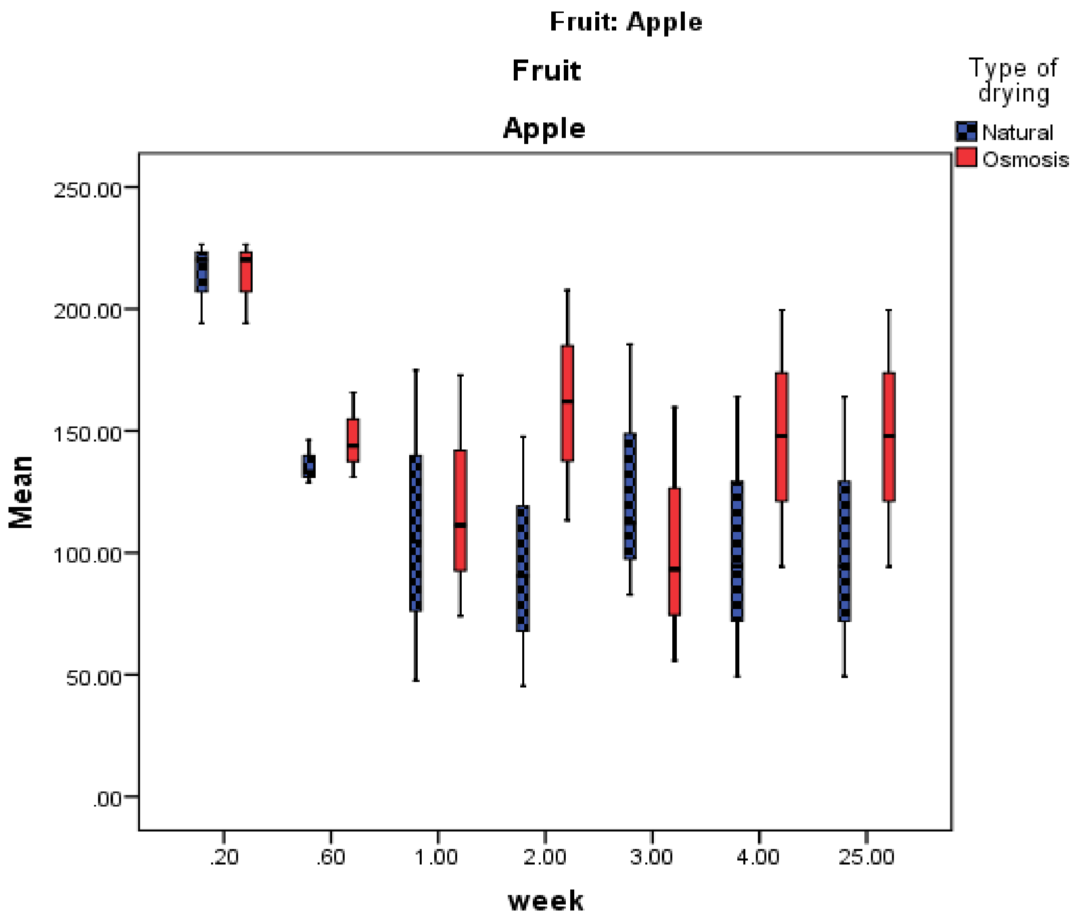

Figure 3: Boxplot for solar-dried and the osmotically pretreated fruit for the entire period.

CONCLUSION

Osmotic dehydration significantly improved colour retention relative to direct solar drying. Apples and pineapples benefited most from pretreatment, while tomatoes exhibited selective colour improvements. The technology provides a low-cost preservation strategy suitable for tropical environments in which access to refrigeration is limited. Future studies should evaluate nutrient retention, sensory acceptability, drying kinetics, moisture diffusivity and economic feasibility at a commercial scale.

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