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Performance evaluation of NSPRI parabolic solar dryer for drying of bell pepper

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Abstract

Parabolic solar dryer developed by Nigerian Stored Products Research Institute was used to dry bell pepper. The drying rate, color changes and drying kinetics using some empirical modelling equations were determined. Open sun drying method was used as a control. Drying rate (2.11 kg/day) of the parabolic solar dryer was significantly higher than that of the sun drying (1.92 kg/day). Bell peppers dried under parabolic dryer retained their color better than those peppers under sun drying. Page model is the most suitable model to describe the drying kinetics of the bell pepper under solar drying. The drying constant k (0.607) of the parabolic dryer is significantly higher than that of the sun drying (0.321) indicating higher mass transfer in the parabolic solar dryer.

Keywords: Bell pepper; Parabolic dryer; Drying rate; Modelling

1. Introduction

Despite the nutritional contribution of food (regardless of its plant or animal origin), much of it will not be consumed by humans or animals and will be discarded as waste (Viaggi 2018). Thus, the prevention of food loss and waste promotes a favorable impact on the environment and food security of the world population, contributing to economic development (Malorgio and Marangon 2021). Besides prevention, the revalorization of these food wastes is a technologically viable strategy, using them as bioactive ingredients to generate new, potentially functional or nutraceutical products (Brunori et al. 2013). Worldwide, food losses and waste mainly occur in fresh fruits and vegetables (>40%), and are mainly associated with poor handling and storage during post-harvest (Sawatdeenarunat et al. 2016) which can be a raw source of bioactive compounds. The bell pepper (*capsicum genus*) belongs to the *Solanaceae* family, Solanoicleae subfamily, Solaneae tribe. Chili (Capsicum), along with corn, beans, and squash, is one of the oldest cultivated plants in America (Sawatdeenarunat et al. 2016). There are five commercially cultivated species of chili (*C. chinense, C. annuum, C. pubescens, C. baccatum, and C. frutescens*) and around 25 wild and semi cultivated species (Budzianowski 2017). Peppers (C. annuum L.) are classified as hot or sweet; they are grown in subtropical climate regions throughout the world, including Northern Nigeria (Smith et al. 2020). The production of bell peppers has increased considerably in recent years; however, the annual losses of this crop are estimated to be 40% (Scoma et al. 2016). Bell peppers can be of different colors (red, green, orange, and yellow) depending on their ripening stages and capacity to synthesize chlorophylls or carotenoids. Besides having an exotic flavor, bell peppers are an important source of vitamins (provitamin A, E, and C) and various bioactive compounds (phenolic compounds and carotenoids) that are beneficial for the health of consumers (Samtiya et al. 2021). Additionally, scientific evidence shows that bioactive compounds extracted from bell peppers have anti-inflammatory, antidiabetic, antimicrobial, and immunomodulatory effects, among others (Coman et al. 2020). To ensure shelf stability of this nutritive and healthy pepper, most farmers in the Northern Nigeria dry the peppers under sun. Drying is the ancient and best method to conserve the nutrition values and enhance the self – life of the food product which provides that the light weight for shipping and storage

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(Smith et al. 2020). Natural sun drying is the usual conventional process used in most tropical and sub – tropical countries. This method is not hygienic and produces very poor quality products due to contamination with surrounding factors (Samtiya et al. 2021). It is highly weather dependent uncontrolled drying also takes very long time period for drying process. However, solar dryers are the best substitute to overcome the above problems and produce standard quality products for exportation. From literature, different types of drying methods are used to dehydrate and preserve the seasonal agricultural products (Umayal et al. 2017). In the literature, several numerical models are proposed to distinguish the kinetics of various food samples such as apple, carrot and apricot (Lamnatou et al. 2012); parsley leaves (Kavak 2011); okra (Wankhade et al. 2013); dika nuts and kernels (Aregbesola et al. 2015), red chilli pepper (Ilknur 2012), banana, mango and cassava (Kamenan et al. 2009), mango and cluster beans (Umayal and Subramanian 2017). But, only a few works are focused on drying kinetics of Bell pepper using parabolic shaped solar dryer. Therefore, this present study is undertaken to inquire the drying characteristics of bell pepper in parabolic shaped solar dryer which is compared with natural sun drying.

2. Material and methods

2.1. Sample Preparation

Freshly harvested bell peppers were procured from a farm in Kano State. The peppers were sorted, washed using clean tap water and drained. The bell peppers were arranged on the drying trays in the parabolic shaped solar dryer. The dryer was closed for drying process. Samples were taking every 3 days to determine the weight loss and colour changes. Bell peppers were also dried openly under sun as control. It took 21 days to dry bell peppers to 9% moisture content in the parabolic solar dryer.

2.2. Determination of color changes

The color changes were measured using Lander Color meter, model: CM200S with serial number N974978. Color is a vital quality characteristic in dehydrated banana to nearly every consumer. It serves as an indicator of the intrinsic good qualities (Doymaz et al. 2006). The relationship of color with consumer acceptability is common and inevitable (Doymaz et al. 2006). It has been reported that drying operation changes the surface characteristics of foods and hence alters their reflectivity and color (Fellows 2009). The color of food products is a very important quality parameter. L (lightness), a (redness) and b (yellowness) color values of the bell pepper were determined every 3 days. Total color change was calculated as follows:

$$\Delta E = \sqrt{(L_d^* - L_f^*) + (a_d^* - a_f^*) + (b_d^* - b_f^*)} \qquad (1)$$

Figure 1 Lander Color meter, model: CM200S with serial number N974978

2.3. Determination of weight loss

The weight changes in bell pepper were measured every 3 days using digital weighing scale.

Figure 2 Camry digital weighing balance, model: EK3230, Max: 5kg/11Ib

2.4. Drying kinetics of the bell pepper using NSPRI parabolic shaped dryer

In studying the kinetics, the weight reduction in the samples during the drying process was monitored by gravimetric method, where the tray and bell pepper were weighed together every 3 days on a digital weighing balance with a resolution of 0.001 g. Weighing continued until the variation in weight of bell pepper was constant. From the experimental data, the values for moisture ratio (Equation 1) were calculated.

$$MR = \frac{X^* - X_e^*}{X_i^* - X_e^*} \quad \text{.......... (2)}$$

Where;
MR = Moisture ratio, dimensionless;
X^* = Water content of the product (%, d.b.);
X^*_i = Initial water content of the product (%, d.b.);
X^*_e = Equilibrium water content (%, d.b.).

To study the drying kinetics, the experimental data were adjusted by the mathematical models of Page model and Henderson & Pabis model as a function of the effective drying time.

2.4.1. Page model equation

The page model equation can be expressed as:

$$MR = e^{(-kt^n)} \quad \text{.......... (3)}$$

2.4.2. Henderson and Pabis

Henderson and Pabis model can be expressed as:

$$MR = ae^{(-kt)} \quad \text{.......... (4)}$$

Where;
t = drying time (day);
k = drying constant;
a, n = coefficients of the models.

The Sigma Plot 14.0 software was used in fitting the mathematical models to the experimental data through non-linear regression analysis. For the significance of the regression coefficients by t-test, a 5% level of significance was adopted.

In selecting the best models to represent the drying kinetics of the fruit, the magnitude of the coefficient of determination adjusted by the model (R^2) and mean squared error (MSE).

2.4.3. Mean Squared Error

The mean squared error was determined using the expression given as:

$$MSE = \sqrt{\frac{\sum (MR_{exp} - MR_{pred})^2}{DF}} \quad (5)$$

3. Results and discussion

3.1. Temperature and Relative humidity

The temperature and the relative humidity of the dryer throughout the drying period were ranged between (35 – 52 °C) and (46 – 65 %) respectively as compared to open sun drying which ranged between (30 – 43 °C) and (48 – 72 %) respectively. Thermo-hygrometer was used to take the temperature and relative humidity measurement. From the temperature and relative humidity data, it can be observed that the parabolic shaped solar dryer was able to accumulate slightly higher temperature as compared to the outside temperature observed. This is expected to aid the drying rate of the dryer.

3.2. Weight Changes of the Bell Pepper

The results from the weight loss of bell pepper during drying period compared with open sun drying were described using Figure 3. It can be observed from the figure that the rate at which the bell pepper loss its weight (2.11 kg/day) in parabolic shaped dryer is higher than the rate at which it loses its weight (1.92 kg/day). This could be due to the fact that there was higher temperature accumulation in the parabolic solar dryer than open drying and it is a known fact that the higher the temperature the higher the drying rate.

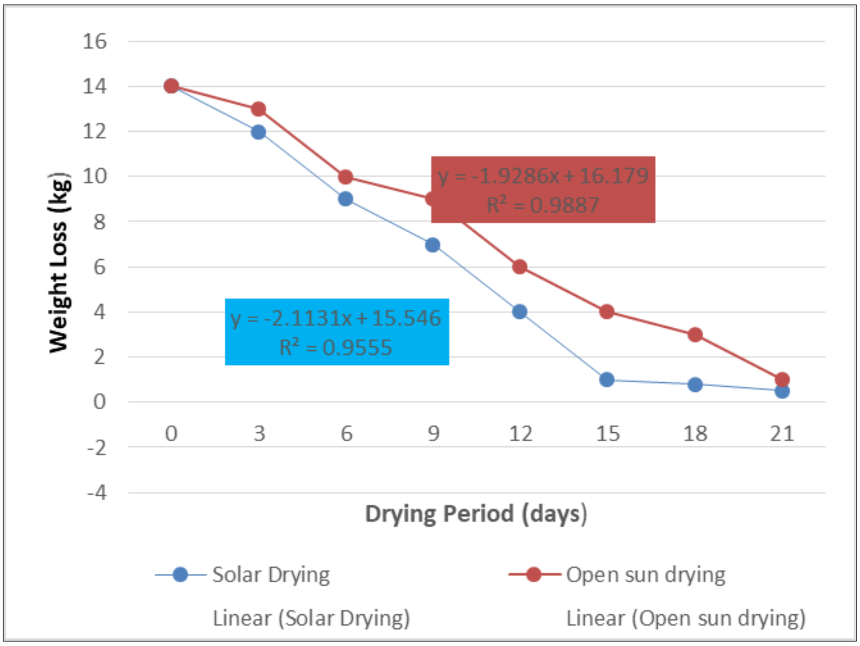

Figure 3 Drying rate of Bell Pepper Using Solar Dryer

3.3. Color Changes of the Bell Pepper

Color is a vital quality characteristic in dehydrated fruits and vegetables to mostly every consumer. It serves as an indicator of the intrinsic good qualities (Doymaz et al. 2006). The relationship of color with consumer acceptability is common and inevitable (Doymaz et al. 2006). It has been reported that drying operation changes the surface characteristics of foods and hence alters their reflectivity and color (Fellows 2009). The results of the color changes in the bell pepper during drying period were described in Figure 4. It can be observed from the figure that the rate of color loss (4.501unit/day) in bell pepper during dried with parabolic solar dryer is noticeably lower than those dried in open sun drying (7.45 unit/day). This finding could be due to the fact that the bell peppers dried in open sun drying were more exposed to light as compared with those in the parabolic solar dryer. Also, the highest temperature observed in the parabolic solar dryer was not too much to have led to color degradation. Existing research had reported that pigment degradation of fruits and vegetable could result from exposure to high temperature (above 60 °C), light and moisture (kamaldeen et al, 2021).

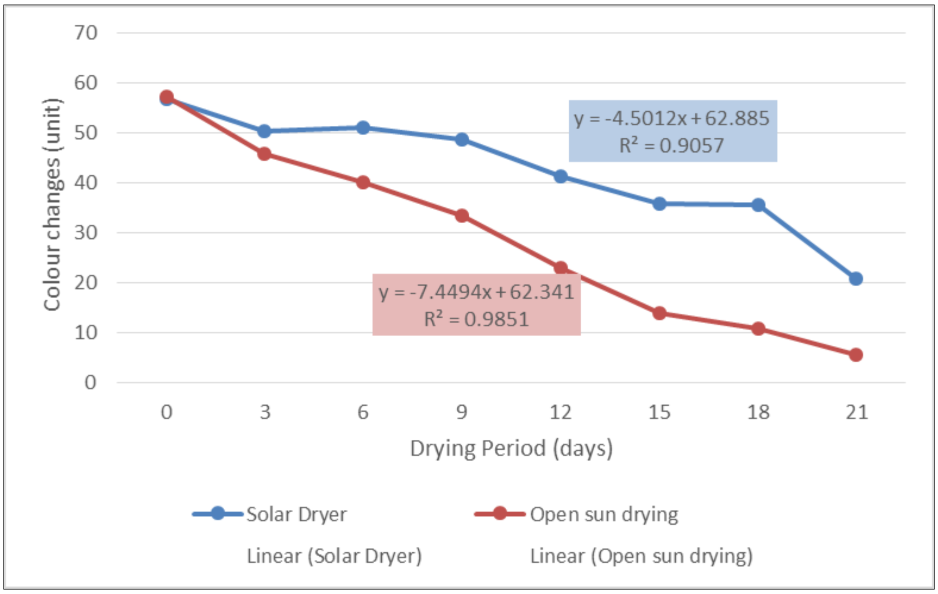

Figure 4 Color degradation of ball pepper during drying

3.4. Drying Kinetics of the bell pepper

The results obtained by the drying kinetics of the bell pepper in parabolic solar dryer and that of the open sun dryer were as shown (Table 1).

Table 1 Drying Kinetic models of the bell pepper

S/N	**Model**	**Drying Methods**			
		Parabolic Solar		**Sun Drying**	
		R2	**MSE**	**R2**	**MSE**
1	Page	0.902	0.013	0.891	0.081
2	Henderson and Pabis	0.882	0.102	0.852	0.112

It can be observed from the result that the values of the squared coefficient of regression R^2 for Page model is higher than that of the Henderson and pabis model while the mean squared error is noticeably lower for Page model than that of Henderson and Pabis. This condition holds for both parabolic solar dryer and that of the open sun drying. According to Silva *et al*. (2009), the lower the MSE value the better the representation of the model used. It can therefore be concluded that the Page model is the most suitable model to describe the drying kinetics of bell pepper using solar drying system. The page model equation can be used for simulation of the drying kinetics of the bell pepper in solar drying method.

3.5. Parameters of the Page Model

The parameters of the Page model fitted to the experimental data for the drying kinetics of the bell peppers are shown in Table 2.

Table 2 Parameters of the Page model

S/N	Drying Methods	Parameters	
		K	n
1	Parabolic solar dryer	0.607	0.286
2	Open sun drying	0.321	0.408

K = drying constant, n = model coefficient

It can be observed from the results that the parameters estimated by the Page model gave a higher value of the k constant and lower values of the n coefficient for the bell pepper dried in parabolic dryer than those dried in open sun drying. According to Duarte *et al*. (2012), Perez *et al*. (2013), Silva *et al*. (2015), and Siqueira, Resende and Chaves (2013), the k constant, known as the diffusion coefficient, represents the diffusivity of the process, while n reflects the internal resistance to drying. As such, these results confirm the behavior seen during the experiment, in which greater mass transfer was obtained with the bell pepper dried in parabolic solar dryer.

4. Conclusion

Parabolic solar dryer had higher drying rate than that of the open sun drying. The bell pepper dried using parabolic solar dryer retained color better than those under open sun drying. The Page model best represents the experimental data, and can be used to predict drying kinetics in a solar dryer for bell pepper.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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