



Research article

Hot air convective drying of hog plum fruit (*Spondias mombin*): effects of physical and edible-oil-aided chemical pretreatments on drying and quality characteristics

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ABSTRACT

This aim of this study was to evaluate the effects of pretreatments and temperature on the hot air drying characteristics of hog plum fruits. Hog plum fruits were pretreated with olive oil/K₂CO₃ or sunflower oil/K₂CO₃ at 28 °C and olive oil/NaOH cum blanching at 96 °C for 15s, hot water at 96 °C for 15s, and dried in a hot air drier at 50, 60, and 70 °C. Mathematical models were used to fit the data of drying and rehydration kinetics. Results showed that increase in temperature reduced drying time, increased effective diffusivity and shrinkage. Sunflower oil aided chemical pretreated sample had the shortest drying time (780 min) and highest effective diffusivity ($6.3 \times 10^{-8} \text{ m}^2/\text{s}$) at 60 °C, faster rehydration ability at 60 °C, highest retention rate for ascorbic acid (15 %), phenolic content (29 %), and antioxidant activity (12.3 %), while olive oil aided chemical (K₂CO₃) pretreated sample had the shortest drying time at 50 °C (990 min) and 70 °C (600 min), lowest shrinkage (48.5 %), slower rehydration capacity at 40 °C, and lowest colour change ($\Delta E = 11.5$). Modified Henderson and Pabis and Vega-Gálvez were superior to other fitting models in predicting the drying and rehydration kinetics. Sunflower oil/K₂CO₃ pretreatment could help improve the drying and quality characteristics of hog plum.

1. Introduction

Hog plum (*Spondias mombin* L.) also known as “yellow mombin” is an untamed fruit from a deciduous tree belonging to the family Anacardiaceae (Tiburski et al., 2011; Oladunjoye et al., 2021a). These fruit span across tropical areas of Asia, America, Brazil, and Africa, and it is currently pulling research attention in Nigeria (Oladunjoye and Eziam, 2020). Hog plum is a rich source of vitamins (A and C), minerals (potassium and copper), phenolic compounds, phytonutrients, terpenoids, carotenoids, organic acids, phytosterols and antioxidants (Oladunjoye et al., 2021b). The matured hog plum fruit can be eaten raw or processed to other value-added economic products like jams, canned fruit juice, syrups, sauces etc (Oladunjoye et al., 2021b). During the on-season a

huge percentage of this fruit wastes due to its high water content, high respiration rate and fast ripening process (Hasan et al., 2019). Therefore, it is important to employ a preservation technique to extend their availability and for further processing even during the off-season.

Drying is one of the most important preservation techniques for fresh fruits and vegetables (Defraeye et al., 2016; Ojediran et al., 2020). It causes reduction in water activity, thereby preserving the products against microbial and enzymatic activity, which causes physical and chemical changes (Horuz et al., 2017; Srikanth et al., 2019). Drying is also useful in reducing storage and transportation costs as a result of lower weight (Chen et al., 2020). Aside from the drying kinetic which is of importance to a food engineer, the rehydration kinetic and other quality indicators (shrinkage, antioxidant retention, texture, colour etc)

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are also of great importance, as it indicates the level of damage caused by the drying medium (Defraeye and Verboven, 2017). Mathematical modeling of drying process is a vital component of drying innovation, as it is useful in the designing of new or improved drying systems or even for the drying process control. Thin layer drying models have been widely adopted, they can be classified as empirical, theoretical, and semi-theoretical (Kaveh et al., 2018). At the present the drying of whole hog plum fruit have not been practiced. During the peak production season, a large quantity of this fruit is usually wasted due to its poor storability, making producer to sell them locally at a very low price. To reduce the wastage, get a reasonable price by the producer of this fruit, and for further processing preservation is necessary (Akther et al., 2020).

Hot air convective drying (HACD) is a process of moisture reduction via simultaneous heat, mass and momentum transfer (Pham et al., 2020). Heat is transferred to the food via the hot air stream. The inside of the product receives the energy from the surface through diffusion as a function of the product structure, temperature and moisture distribution in the product. The heat flux initiated in the product causes an increase in temperature and concurrent moisture evaporation (Castro et al., 2018). The heated convective air stream usually has low relative humidity thereby enhancing drying process of the product (Chandramohan, 2020). HACD technology has been constantly used for fruits and vegetables, probably because of its relatively low cost (Zielinska and Michalska, 2016). Due to waxy-coated skin of hog plum, HACD alone is limited, as it is characterized with longer drying time, poor water mass transfer, slow drying rate, and low product quality (Staniszewska et al., 2020). Researchers have focused on the application of various pretreatments methods to fruits and vegetables prior to drying to augment the deficiencies associated with the use of HACD alone (Tao et al., 2018).

Vásquez-Parra et al. (2013) evaluated the use of both CP and hot water (96 °C) dipping prior to the HACD of Cape gooseberry fruits at 60 °C. Olive oil (9.48 %) + potassium carbonate (4.74 %) pretreatment showed the highest drying rate, highest retention of ascorbic acid, highest rehydration capacity although it had the greatest colour change. Kaveh et al. (2020) recorded that the use of dipping in ascorbic acid solution, hot water blanching, microwave blanching, and sonication for hot air dried blackberry fruits generally shortened the drying time, lowered specific energy consumption, shrinkage, and colour change, although microwave blanching had the best performance. Brar et al. (2020) reported that chemical dipping solutions (ascorbic acid, citric acid and potassium Metabisulfite (KMS) for 1 min at 40 °C) had significant reduction in drying time, effective moisture diffusivity was higher, while total phenolics and antioxidant activity was found to be controlled by drying temperature alone. Dehghannya et al. (2017) discovered that hot air dried Mirabelle plum treated with combined sonication in osmotic solution at higher concentration had a better desirable colour and reduced shrinkage when compared with the control sample. Rojas et al. (2020) reported that ethanol pretreatment before convective drying and ultrasound-assisted convective drying of apple increased the moisture mass transfer rate, reduced shrinkage and produced sample with greater rehydration capacity. Increase in drying temperature during HACD of chokeberries was found to reduce the phenolic compounds, antioxidant activity, and colour (Samoticha et al., 2016). Junqueira et al. (2017) discovered that CP (alkaline solution of ethyl oleate) of cape gooseberry fruits had the shortest drying time, highest retention of ascorbic acid, highest rehydration potential, improved texture and least shrinkage as compared to PP (fast freezing with liquid nitrogen and slow freezing followed by thawing). Other literature are; Kaveh et al. (2021), effect of different drying methods on quality of green peas, Soydan and Doymaz (2021), effects of different pretreatments type (ascorbic acid, citric acid, blanching, and potassium carbonate) on the drying kinetic of apple slice, Taghinezhad et al. (2021), effects of blanching, ultrasound, and microwave pretreatments on turnip slices dried in a hybrid convective-infrared dryer, and Abbaspour-Gilandeh et al. (2021), effect of ultrasound pretreatment on the drying kinetic, energy consumption and bioactive compounds of hawthorn fruits dried in a combined hot air, microwave

and infrared dryer. Authors found out that the application of physical pretreatment (PP) and chemical pretreatment (CP) to waxy-skin fruit improved the drying rate, inactivate enzymes, reduced drying time and quality depletion (Vásquez-Parra et al., 2013; Deng et al., 2017). Also, Vásquez-Parra et al. (2013) are the only researchers who have applied edible-oil-aided CP for drying of fruit (gooseberries), this pretreatment type has not been used in the drying process of hog plum. Furthermore, the drying temperature effect was not considered. To the best of the authors' knowledge there has not been any report on HACD of hog plum fruits or on the HACD of hog plum fruit treated with edible-oil aided CP and hot water blanching.

Therefore, the objectives of this research was to study the effects of edible-oil-aided CP and PP on the drying characteristics, rehydration kinetic, shrinkage, colour, ascorbic acid, total phenolic content, and total antioxidant capacity of hog plum fruits. Mathematical modeling for both the drying kinetic and rehydration kinetic was performed. The effects of the drying temperature, edible oil cum chemical solutions type, concentration, and dipping time were also evaluated.

2. Materials and method

2.1. Chemicals and reagents

Distilled water was obtained through Merit water still (Stone, Staffordshire, ST15 OSA, UK). Olive oil, sunflower flower oil, potassium carbonate, and sulphuric acid were purchased from Sigma-Aldrich (Germany). Sodium hydroxide was acquired from Carlo-Erba (Spain). Ammonium hydroxide, Concentrated Amyl alcohol, and Ammonium Molybdate solution were purchased from Loba Chemie PUT limited, Mumbai 400005 (India). Folin Ciocalteu was purchased from Sigma-Aldrich Chemie (Switzerland). Sodium phosphate was purchased from Oxford laboratory unit (India). Ascorbic acid (Kermel Ascorbic acid). All chemicals and reagents used were of analytical grade.

2.2. Samples source

Fresh hog plums (*Spondias mombin* L.) were obtained in August 2020 from the premise of Obafemi Awolowo University, Ile-Ife, Osun state, Nigeria with coordinates; 7.5177°N and 4.5263°E. After harvest, the fruits were kept frozen (-18 ± 1 °C). About 2 h to the commencement of any pretreatments operation, the quantity of frozen fruits to be used were thawed and warmed up at normal room temperature, rinsed with distilled water and dried using a paper towel. The initial moisture content of the harvested hog plum fruit was 74.09 ± 0.2 % (w.b). Some physical properties of the hog plum determined were; mass (8.7 ± 0.3 g), diameter (20.98 ± 0.35 mm), length (33.88 ± 0.34 mm), and sphericity (0.69).

2.3. Pretreatments

The pretreatment used was as suggested by Vásquez-Parra et al. (2013) for gooseberry fruits. At the commencement of each pretreatment condition, fresh solution was prepared. Fruit to dipping solution ratio used was 1:3 (g/g) for all cases. The pretreatments used evaluate edible oil type and concentration, chemical type, dipping time and hot water blanching. All EOC pretreatments were carried out at normal room temperature (28 °C). Stirring was carried out using a laboratory stirrer set at 288 rpm (UC151 Stirrer, Stuart, UK). Hot water blanching at 96 °C for 15 s was carried out with the help of a laboratory water bath (ELE International, Bedfordshire LU7 4WG, UK). The pretreatments were; P1 (control: fresh samples without any treatment), P2 (Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min), P3 (Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min), P4 (Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min), P5 (Blanching in distilled water at 96 °C for 15s), P6 (Olive oil (4.74%)+NaOH (1.5 %) and stir for 60 min + blanching in distilled water at 96 °C for 15s), and P7 (Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min). Pretreated samples were dried with an

absorbent paper before the commencement of the drying operation. Each treatment was carried out in triplicate.

2.4. Drying procedure

Hog plum fruits were dried in a hot air oven (Memmert UF75, Memmert GmbH + Co. KG, 91126 Schwabach, Germany) at 50, 60, and 70 °C with an air velocity of 1.3 m/s (Figure 1). Parameters like temperature, air velocity, and air-flap position can be regulated. The heated air in the dryer can be mixed with fresh air from the environment via the adjustable air flap control, which was kept at 50 % throughout the experiments (Okonkwo et al., 2021). The various drying parameters can be electronically controlled using the knob. At the start of any drying operation, the dryer was allowed to run on zero loads for 1 h to help equilibrate the dryer environmental condition. The relative humidity and ambient air temperature of the drying environment were varied between 55-67 % and 27-30 °C respectively during all experiments. Drying procedure as suggested by Vásquez-Parra et al. (2013) was used. About 100 g of the treated hog plum fruit were spread on a single tray in the oven (585 × 944 × 514 mm) at each set condition. In the first 30 min of drying, the samples were weighed at 6 min interval; 10 min for the next 90 min of drying, 15 min for the next 2 h, and 30 min interval afterward till 3 equal consecutive values were obtained. The weighing balance (AND GR-200, Japan, accuracy ±0.0001 g, readability of 0.1 mg and maximum capacity 210 g) was placed very close to the oven, and weighing period of 15 s was maintained. All experiments were conducted in triplicate.

2.5. Drying characteristics

The effect of the EOC and physical pretreatments on the drying characteristics of hog plum was evaluated by measuring the following parameters.

2.5.1. Moisture ratio

The moisture ratio during drying of the hog plum fruits at any time; t was calculated using Eq. (1) (Kumari et al., 2020; Kroehnke et al., 2021).

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

where: MR is the moisture ratio, M_t is the moisture content at any given time during the drying process (g water/g dry matter), M_o is the initial moisture of the fruit (g water/g dry matter), and M_e is the equilibrium moisture content (g water/g dry matter). The equilibrium moisture content was determined according to Wang et al. (2019), by drying about 100 g of the hog plum fruit in a hot air oven at 105 °C until a constant weight. Means of three (3) replicates was used.

The moisture content at any time, t was determined using Eq. (2).

$$M_t = \frac{W - D}{D} \tag{2}$$

where: W is the total mass at any time t (g), and D is the dry sample mass (g).

2.5.2. Drying rate

The drying rate of the fruit was evaluated using Eq. (3) (Horuz et al., 2017).

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t} \tag{3}$$

where: Δt is the change in time (min), DR is the drying rate (g/g.min), $M_{t+\Delta t}$ is the moisture content at t+ Δt (g water/g dry matter).

2.5.3. Mathematical modeling of drying kinetic

The drying kinetic of the process is the moisture ratio as a function of time. The experimental data of the drying process was modeled with thirteen (13) frequently used thin layer drying models (Table 1). The ability of each model to fit the experimental data was evaluated using coefficient of correlation (R^2), root mean square error (RMSE), and sum of square error (SSE) as in Eqs. (4), (5), and (6). The model having the highest value of R^2 , lowest value for RMSE and SSE was taken as the best

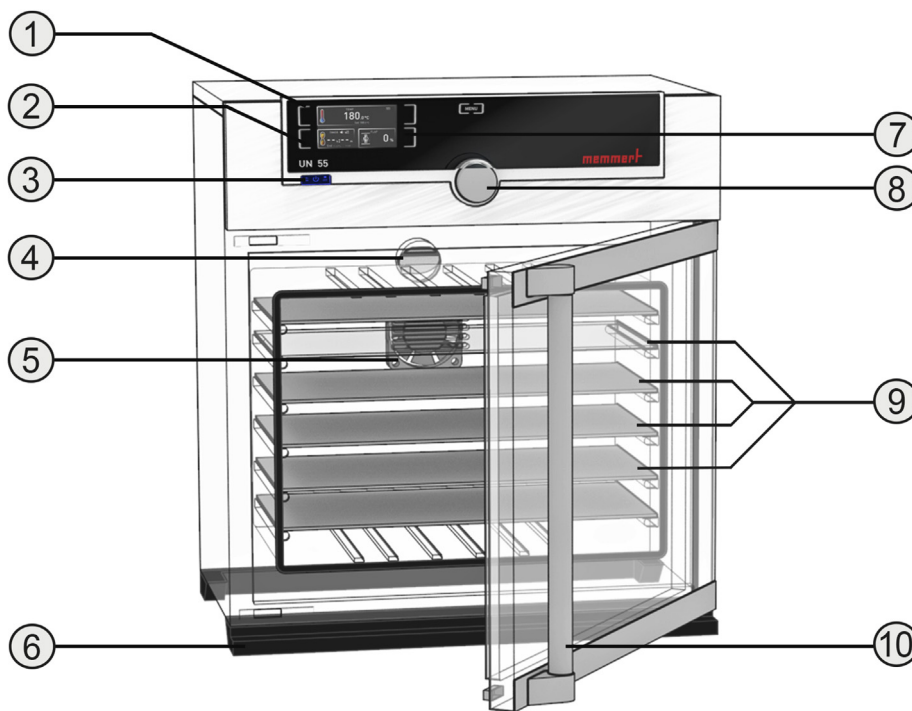


Figure 1. Schematic view of the hot air oven: 1-Temperature display, 2-fan speed display, 3-ON/OFF button, 4-Air flap, 5-axial fan, 6-base stand, 7-air flap display, 8-control knob (for temperature, fan speed, and air flap levels), 9-drying trays, 10- oven door (Okonkwo et al., 2021). Reproduced with permission from John Wiley and Sons.

Table 1. Mathematical models applied to the drying and rehydration curves of *Spondias mombin*.

Models	Equations	References
Mathematical models applied to the drying curves		
Newton	$MR = \exp(-kt)$	Junqueira et al. (2017)
Page	$MR = \exp(-kt^n)$	Junqueira et al. (2017)
Henderson & Pabis	$MR = a \exp(-kt^n)$	Pashazadeh et al. (2020)
Logarithmic	$MR = a \exp(-kt^n) + c$	Aral and Beşe (2016)
Two term	$MR = a \exp(-kt) + b \exp(-gt)$	Aral and Beşe (2016)
Two term exponential	$MR = a \exp(-kt) + (1+a) \exp(-kat)$	Pashazadeh et al. (2020)
Wang & Singh	$MR = 1 + at + bt^2$	do Nascimento Silveira Dorneles et al. (2019)
Approximation of diffusion	$MR = a \exp(-kt) + (1-a) \exp(-kbt)$	Pashazadeh et al. (2020)
Verma	$MR = a \exp(-kt) + (1-a) \exp(-gt)$	Pashazadeh et al. (2020)
Modified Henderson & Pabis	$MR = a \exp(-kt) + b \exp(-gt) + c \exp(-ht)$	do Nascimento Silveira Dorneles et al. (2019)
Logistic	$MR = a / (1 + b \exp(kt))$	Pashazadeh et al. (2020)
Midilli et al.	$MR = a \exp(-kt^n) + bt$	Aral and Beşe (2016)
Aghbashlo	$MR = \exp(-kt / (1 + gt))$	do Nascimento Silveira Dorneles et al. (2019)
Mathematical models applied to the rehydration curves		
Peleg	$RR = \left(\frac{1}{(X_e - X_o)} \right) \times \left(\frac{t}{(a + bt)} \right)$	Pashazadeh et al. (2020)
First order kinetic	$RR = 1 - \exp(-at)$	Ghellam and Koca (2020)
Exponential	$RR = 1 - \exp(at^c)$	Pashazadeh et al. (2020)
Weibull	$RR = 1 - \exp\left(-\left(\frac{t}{b}\right)^a\right)$	Pashazadeh et al. (2020)
Vega-Gálvez	$RR = a \exp\left(\frac{-b}{(1+t)^c}\right)$	Ghellam and Koca (2020)

MR = moisture ratio, RR = rehydration ratio, t = time, and a, b, c, g, h and k are constants of the models.

model for modeling the drying kinetic of hog plum (Ojediran et al., 2020; Pashazadeh et al., 2020).

$$R^2 = \frac{\sum_{i=1}^N (y_i - x_i)^2}{\sum_{i=1}^N (y_i - x_i)^2} \tag{4}$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - y_i)^2} \tag{5}$$

$$SSE = \sum_{i=1}^N (x_i - y_i)^2 \tag{6}$$

where: x_i and y_i are observed and predicted moisture ratio and N is the number of observations.

2.5.4. Effective moisture diffusivity

The effective moisture diffusivity is an important drying and rehydration kinetic parameter which describes the moisture transport from the samples to the environment in the falling rate period and vice versa (Aral and Beşe, 2016; Demiray and Tulek, 2017). It is generally governed by Fick's second law of diffusion. Fick's second law for sphere is given in Eq. (7).

$$\frac{\partial M}{\partial t} = D_{eff} \frac{\partial^2 M}{\partial r^2}, \frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \tag{7}$$

Solving Eq. (7), it is assumed that for drying there is uniform initial moisture distribution, negligible shrinkage, constant moisture diffusivity, and constant temperature (Zielinska and Michalska, 2016). While for rehydration, the assumptions are; uniform initial moisture content in the dried samples, the shape is retained during rehydration, moisture saturation of the dried solid sample is achieved when submerged, negligible external resistance to heat and mass transfer, constant effective diffusion coefficient (Demiray and Tulek, 2017). Therefore, Eq. (7) becomes Eq. (8) (unsteady state moisture transfer for sphere).

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{6}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{n^2} \exp\left(-\frac{n^2 \pi^2 D_{eff} t}{r^2}\right) \tag{8}$$

For long drying periods the first time of the series is usually considered making Eq. (8) to be further reduced to Eq. (9) and Eq. (10) (Brar et al., 2020).

$$MR = \frac{M_t}{M_o} = \frac{6}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{r^2}\right) \tag{9}$$

$$\ln MR = \ln\left(\frac{6}{\pi^2}\right) - \ln\left(\frac{\pi^2 D_{eff} t}{r^2}\right) \tag{10}$$

where: D_{eff} is the effective moisture diffusivity (m^2/s), r is the radius of the fresh (0.011m) and dried fruit (0.0087m), t is time (min). The radius of the hog plum fruit was calculated as half of the diameter of the fruit measured with vernier caliper. Means of 20 randomly selected samples was used. From the plot of $\ln MR$ against time, t , the effective moisture diffusivity was calculated using the method of slopes. A plot of $\ln MR$ versus time gives a straight line curve with slope, K_L as in Eq. (11).

$$K_L = \frac{D_{eff} \pi^2}{r^2} \tag{11}$$

2.5.5. Activation energy

The activation energy required for moisture transport from the samples to the surrounding was calculated using the Arrhenius equation as presented in Eq. (12). It shows the correlation between effective moisture diffusivity and temperature (Srikanth et al., 2019; Ojediran et al., 2020).

$$D_{eff} = D_o \exp\left(-\frac{E_a}{RT}\right) \tag{12}$$

where: E_a is the activation energy (kJ/mol), R is the universal gas constant (8.3 kJ/mol), T is the absolute temperature (K), and D_o is the

Arrhenius equation pre-exponential factor (m²/s). $\ln D_{\text{eff}}$ was plotted against the inverse of the absolute temperature to determine the activation energy.

2.6. Quality parameters

Effects of drying temperatures, EOC and physical pretreatments on the following quality parameters were evaluated.

2.6.1. Shrinkage

Shrinkage describes the percentage volume reduction occurring during the drying process as a result of moisture evaporation from the structure of the sample (Janowicz and Lenart, 2015; Aral and Beşe, 2016). Shrinkage (S) was evaluated using Eqs. (13), (14), (15), and (16).

$$S = \left(1 - \frac{V_f}{V_o}\right) \times 100 \quad (13)$$

where: V_f and V_o is the volume of dried and fresh hog plum fruits respectively

$$V_f = \frac{4}{3}\pi \left(\frac{D_f}{2}\right)^3 \quad (14)$$

$$V_o = \frac{4}{3}\pi \left(\frac{D_o}{2}\right)^3 \quad (15)$$

$$D = (L \times b \times t)^{1/3} \quad (16)$$

where: D_f and D_o are the geometric mean diameter for dried and fresh hog plum fruits respectively. L , b , and t are the length, width and thickness dimensions of the fresh or dried fruit (mm), D_f and D_o were calculated from Eq. (16). Geometric mean diameter was used because hog plum is assumed to be spheroid in shape. The l , b , and t component of the fresh and dried fruit were measured with a vernier caliper, and a mean of 10 replicates was used.

2.6.2. Rehydration kinetic

The rehydration experiment was carried out at 28, 40, and 60 °C. Dried hog plum fruit at 70 °C was used so as to evaluate the extent at which the HACD has on the structure of the fruit. The method used was according to Pashazadeh et al. (2020) and Srikanth et al. (2019). About 5g of the dried hog plum fruits were immersed in 250 ml beaker containing 200 ml distilled water heated to the desired temperature in a laboratory water bath (ELE International, Bedfordshire LU7 4WG, UK). During the rehydration process the samples were removed at 30 min intervals, drained over a mesh, blotted with a paper towel to remove the surface water and then weighed. The rehydration lasted for 10 h, which was the time to reach equilibrium. The moisture absorbed at any time; t and the rehydration ratio was calculated using Eqs. (17) and (18).

$$M_a = \frac{W_t - W_d}{W_d} \quad (17)$$

$$RR = \frac{M_a - M_o}{M_e - M_o} \quad (18)$$

where: W_t and W_d is the sample weight at any time and the initial dry weight (g) respectively, M_a is the absorbed moisture at any time (d.b), RR is the rehydration ratio, M_e is the moisture content at the end of the rehydration process, M_o is the moisture content before rehydration.

2.6.2.1. Mathematical modeling of rehydration kinetic. In modeling the rehydration kinetic, five (5) frequently used mathematical models were

used (Table 1). The rehydration kinetic is the rehydration ratio as a function of time. The best model describing rehydration behavior was selected based on the highest R^2 , lowest RMSE and SSE values (Ghellam and Koca, 2020). The values for R^2 , RMSE and SSE were calculated using Eqs. (4), (5), and (6).

2.6.3. Colour

Colour parameters of fresh hog plum and hog plum dried at 70 °C for the different pretreatments type were measured using a colorimeter (Minolta Chroma, Model CR-400, Osaka, Japan) based on CIELab method. The results obtained was expressed in L^* (lightness; white-100, black-0), a^* (red-positive and green-negative), and b^* (yellow-positive and blue-negative) colour system. The total colour change (ΔE) was calculated afterwards using Eq. (19) (Wang et al., 2019; Pham et al., 2020; Kaveh et al., 2021), the reference value was the fresh fruit. Measurement for each sample was carried out in six (6) replicates, and the mean and standard deviation calculated afterwards.

$$\Delta E = \sqrt{(L_o - L^*)^2 + (a_o - a^*)^2 + (b_o - b^*)^2} \quad (19)$$

where: L_o , a_o , and b_o are measurement of the hog plum fruits dried at 70 °C for the different pretreatment type, L^* , a^* and b^* are colour measurements of the fresh fruits.

2.6.4. Ascorbic acid

The ascorbic acid content (AA) of the fresh and dried hog plum fruits at 70 °C was determined by titrimetric method with 2,6-dichlorophenol indophenols reagent as stated by Moo-Huchin et al. (2014) but with some few modifications. 0.5g of oxalic acid was dissolved in 100 ml of distilled water. Afterward 0.05g of ascorbic acid was mixed with 50 ml of 0.5 % oxalic acid solution. 2,6-dichlorophenol indophenols (0.0029 g) was dissolved in 100 ml of water. 10ml of the oxalic acid solution was weighed into 0.5 ml of the sample and homogenized to produce the extract. 9ml of the 2,6-dichlorophenol indophenols solution was added to 1ml of the extract in three test tubes (triplicate), and read at 515 nm using the UV/Vis-spectrophotometer. The results were expressed in mg/100g.

2.6.5. Total phenolic content

The total phenolic content (TPC) of the fresh and dried hog plum fruits at 70 °C was determined by the Folin-Ciocalteu method (Tao et al., 2018). The sample extract was prepared by dissolving 1 g of the sample in 10 ml of 80 % ethanol. The reaction mixture contains 1ml of the sample extract, 2.5 ml of 10 % Folin-Ciocalteu's reagent, and 2 ml of 7.5 % NaHCO_3 . The mixture was allowed to stand for 30 min, before absorbance was read using the UV/Vis-spectrophotometer at 610 nm on dry basis. The reaction mixture for each sample extract was prepared in triplicate. The same procedure was repeated for the standard solution of gallic acid and the calibration curve was constructed based on measured absorbance, the phenolic concentration was measured in mg/100g from the calibration curve. The calibration equation and R^2 value was $0.007x + 0.0413$ and 0.9784 respectively.

2.6.6. Total antioxidant activity

The total antioxidant activity (TAA) of the fresh and dried hog plum fruits at 70 °C was determined by the Phosphomolybdenum method (Esua et al., 2016). 0.84g sodium phosphate and 1.24 g ammonium molybdate was dissolved in 8.2 ml of conc. sulphuric acid contained in 250 ml flask. 0.5 ml of the sample extract was homogenized with 4.5 ml of the above solution, and incubated for 90 min at 90 °C. The blank solution used was 2 ml of the reagent solution. The mixture was allowed to cool at room temperature and the absorbance read on the UV/Vis-spectrophotometer at 695 nm dry basis. The calibration curve equation and R^2 value were; $y = 0.0103x - 0.1296$ and 0.9182 respectively.

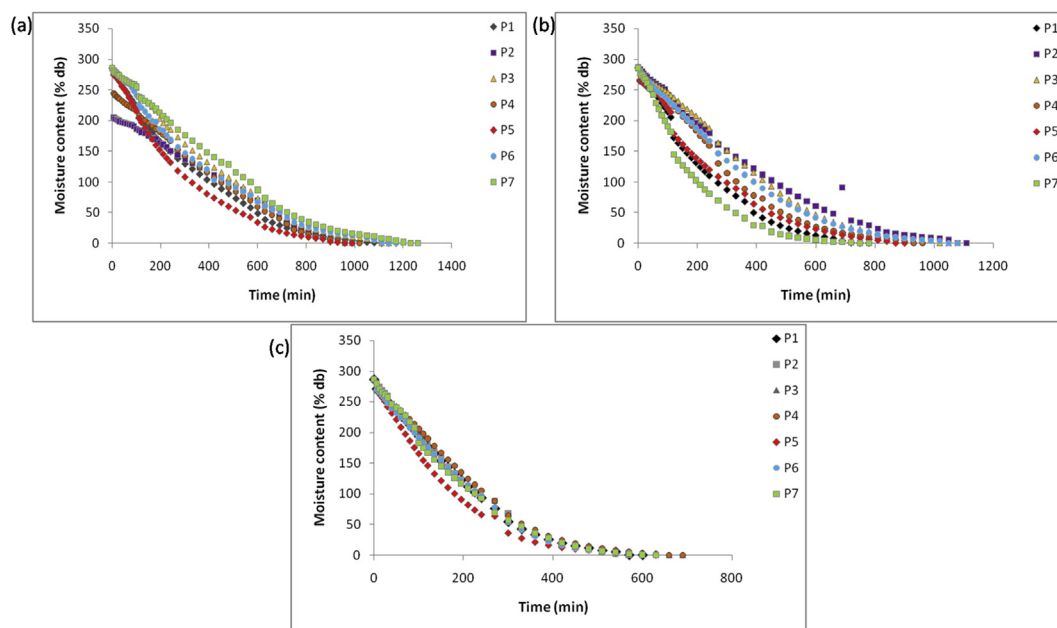


Figure 2. Moisture content versus drying time at different drying temperatures; (a) 50 °C, (b) 60 °C, and (c) 70 °C [P1: Control (No treatment); P2: Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min; P3: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min; P4: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min; P5: blanching in distilled water at 96 °C for 15s; P6: Olive oil (4.74%)+NaOH (1.5 %) and stir for 60min + blanching in distilled water at 96 °C for 15s; P7: Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min].

2.7. Statistical analysis

The experimental data obtained from the HACD of the fruits were analyzed with Microsoft office excel (version 2007). Graphs was plotted with both Microsoft office excel (version 2007) and Minitab 17 statistical software. Matlab R2017a was used for the mathematical modeling of both drying kinetic and rehydration kinetic. R², RMSE and SSE was use to select the best model. One-way analysis of variance (ANOVA) was performed with SPSS (IBM SPSS statistic 22, New York, USA) to study the effect of pretreatments on the quality parameters of the fruits. Duncan's tests were used to evaluate the significant differences at $p < 0.05$ between the samples.

3. Results and discussion

3.1. Drying curve and kinetic modeling

The drying curve of hog plum fruit at 50, 60, and 70 °C are presented in Figure 2 (a-c). Figure 2 (a-c) showed that the moisture content of both pretreated and untreated hog plum fruits reduced continuously with time at all drying conditions. The shortest drying time for samples dried at 50 °C was pretreatment P2 and P5 (990 min), 60 °C pretreatment P7 and control (780 min), and at 70 °C pretreatment P2 and control (600 min). This shows that pretreatment type used was only found to reduce the drying time for samples dried at 50 °C; afterwards the drying temperature was more dominant in control of the drying time. This might be because at higher temperature there is more moisture diffusion through the pores and capillaries of the samples. Aral and Beşe (2016) reported that the drying time of hawthorn fruit was significantly controlled by temperature compared to other drying parameters. The reduction in drying time experienced with chemical dipping was also reported by Junqueira et al. (2017) for gooseberries, Önal et al. (2019) for apple slice, Wang et al. (2019) for scallion, Brar et al. (2020) for yellow European plums, and Kaveh et al. (2020) for blackberries. There was a significant difference in the moisture content across the pretreatments types during drying at 60 °C as compared to 50 and 70 °C. Pretreatment P7 (sunflower aided CP)

had significant higher moisture reduction than olive oil aided chemical dipping (P2–P4 and P6) at 60 °C. This might be because of the low density of sunflower oil (0.919 kg/l) as compared to olive (0.929 kg/l). Oil concentration was found not to significantly affect the moisture content curve during drying. Lesser dipping time of 20 min (P4) showed faster moisture reduction per time as compared to 60 min (P3) at 60 °C, but was not significant for samples dried at 50 and 70 °C. High temperature short time water blanching alone (P5) showed a significant increase in the water loss as compared to physical cum edible oil aided CP (P6). Vásquez-Parra et al. (2013) who used similar pretreatment for HACD of gooseberries revealed that the edible oil type, dipping time, PP alone versus physical cum CP had no significant difference on the final moisture content while oil concentration significantly reduced the final moisture content. The differences observed might be as a result of differences in the fruit structure, waxy cuticle layer and characteristics. The drying curves progressed in the falling rate period, signifying that drying of hog plum fruit was solely by internal moisture diffusion and there is non-bound water present on the fruit surface (Fig. 2a-c). Similar observation was made by Aral and Beşe (2016) for hawthorn fruit, Zielinska and Michalska (2016) for blueberries and Horuz et al. (2017) for sour cherries. Increase in drying temperature increased the drying rate, although after 60 °C there was no much difference. Similar result was reported by Darıcı and Şen (2015) for kiwi, as drying rate increased at higher drying temperatures. Drying rate decreased from pretreatment P7 followed by P3, P6 and P4, P2, P1 and P5 at 50 °C, while at 60 °C, P2 and P3, followed by P6 and P4, P5, P1, and P7, whereas at 70 °C there was no significant difference, except that pretreatment P6 had the lowest drying rate. The higher drying rate recorded for sunflower oil aided CP, olive oil aided chemical pretreatment was reported by Vásquez-Parra et al. (2013) for Cape gooseberry fruit. Junqueira et al. (2017) also highlighted that CP with ethyl oleate increased drying rate of Cape gooseberry fruit.

The drying kinetic modeling result is presented in Table 2. As seen from the modeling performance indices; R², RMSE, and SSE, the drying models (Modified Henderson and Pabis, Logarithmic, Aghbashlo, Midilli et al., and Wang and Singh) predicted maximally most of the drying characteristics of the hog plum fruit at the different temperatures.

Table 2. Statistical results of mathematical models fitted to experimental drying and rehydration curves of *Spondias mombin*.

Treatment conditions	Models	R ²	RMSE	SSE					
Statistical results of mathematical models fitted to experimental drying curves									
50 °C									
P1	Logarithmic	0.99810	0.01565	0.01224					
P2	Midilli et al.	0.9960	0.01704	0.01277					
P3	Logarithmic	0.99890	0.01221	0.00730					
P4	Logarithmic	0.99500	0.02270	0.02319					
P5	Midilli et al.	0.99920	0.01035	0.00471					
P6	Logarithmic	0.99860	0.01334	0.00889					
P7	Aghbashlo	0.99880	0.01255	0.00867					
60 °C									
P1	Modified Henderson & Pabis	0.99600	0.02315	0.01875					
P2	Logarithmic	0.99550	0.02429	0.02832					
P3	Modified Henderson & Pabis	0.99960	0.007258	0.00232					
P4	Modified Henderson & Pabis	0.99950	0.008724	0.00312					
P5	Modified Henderson & Pabis	0.99630	0.02225	0.01931					
P6	Modified Henderson & Pabis	0.99970	0.006221	0.00174					
P7	Modified Henderson & Pabis	0.99770	0.01827	0.11610					
70 °C									
P1	Aghbashlo	0.99890	0.01148	0.00435					
P2	Modified Henderson & Pabis	0.99880	0.01272	0.00518					
P3	Aghbashlo	0.99910	0.01046	0.00361					
P4	Modified Henderson & Pabis	0.99940	0.00921	0.00271					
P5	Logarithmic	0.99830	0.01501	0.00766					
P6	Logarithmic	0.99900	0.01134	0.00411					
P7	Wang & Singh	0.99780	0.01623	0.00896					
Statistical results of mathematical models fitted to experimental rehydration curves									
Rehydration temperature (°C)	Models	R ²	SSE	RMSE	Models	R ²	SSE	RMSE	
P1 (control)					P2 (olive oil (9.48%) + K₂CO₃ (4.74%) and stir for 60 min)				
28	Peleg	0.99690	0.00310	0.02105	Peleg	0.99390	0.00634	0.03010	
	First order kinetic	0.99040	0.00952	0.03086	First order kinetic	0.97400	0.02703	0.05199	
	Exponential	0.99050	0.00938	0.03227	Exponential	0.97920	0.02161	0.04901	
	Weibull	0.99040	0.00952	0.03253	Weibull	0.9740	0.02703	0.05480	
	Vega-Gálvez	0.99790	0.00212	0.01630	Vega-Gálvez	0.99680	0.00334	0.02043	
40	Peleg	0.97560	0.02234	0.05650	Peleg	0.99650	0.00388	0.02355	
	First order kinetic	0.96370	0.03326	0.05767	First order kinetic	0.98350	0.01840	0.04289	
	Exponential	0.95640	0.04002	0.06668	Exponential	0.99000	0.01121	0.03529	
	Weibull	0.96370	0.03326	0.06079	Weibull	0.98350	0.01840	0.04521	
	Vega-Gálvez	0.99000	0.00917	0.03385	Vega-Gálvez	0.99610	0.00440	0.02344	
60	Peleg	0.99150	0.00821	0.03425	Peleg	0.97290	0.03430	0.07000	
	First order kinetic	0.99300	0.00674	0.02596	First order kinetic	0.96810	0.04035	0.06352	
	Exponential	0.99430	0.00549	0.02470	Exponential	0.99190	0.01026	0.03377	
	Weibull	0.99300	0.00674	0.02736	Weibull	0.96810	0.04035	0.06696	
	Vega-Gálvez	0.99200	0.00775	0.03113	Vega-Gálvez	0.98550	0.01840	0.04795	
P3 (olive oil (0.47%) + K₂CO₃ (4.74%) and stir for 60 min)					P4 (olive oil (0.47%) + K₂CO₃ (4.74%) and stir for 20 min)				
28	Peleg	0.95210	0.06026	0.09278	Peleg	0.99730	0.00298	0.02062	
	First order kinetic	0.94540	0.06872	0.08290	First order kinetic	0.97720	0.02504	0.05004	
	Exponential	0.97170	0.03565	0.06293	Exponential	0.99160	0.00928	0.03212	
	Weibull	0.94540	0.06872	0.08738	Weibull	0.97720	0.02504	0.05274	
	Vega-Gálvez	0.96860	0.03949	0.07026	Vega-Gálvez	0.99740	0.00288	0.01898	
40	Peleg	0.99050	0.01112	0.03985	Peleg	0.99210	0.00840	0.03463	
	First order kinetic	0.97430	0.03000	0.05477	First order kinetic	9.97620	0.02538	0.05037	
	Exponential	0.98090	0.02222	0.04969	Exponential	0.98580	0.01517	0.04105	
	Weibull	0.97430	0.03000	0.05773	Weibull	0.97620	0.02538	0.05310	
	Vega-Gálvez	0.98940	0.01234	0.03928	Vega-Gálvez	0.99150	0.00905	0.03363	
60	Peleg	0.99810	0.00206	0.01715	Peleg	0.96770	0.04045	0.07601	
	First order kinetic	0.98420	0.01685	0.04105	First order kinetic	0.91910	0.10130	0.10070	
	Exponential	0.99090	0.00973	0.03289	Exponential	0.96760	0.04062	0.06718	
	Weibull	0.98420	0.01685	0.04327	Weibull	0.91910	0.10130	0.10610	
	Vega-Gálvez	0.99760	0.00255	0.01785	Vega-Gálvez	0.96680	0.04159	0.07210	

(continued on next page)

Table 2 (continued)

Statistical results of mathematical models fitted to experimental rehydration curves								
Rehydration temperature (°C)	Models	R ²	SSE	RMSE	Models	R ²	SSE	RMSE
P5 (Blanching in distilled water at 96 °C for 15s)					P6 (olive oil (4.74%) + NaOH (1.5 %) and stir for 60 min + blanching in distilled water at 96 °C for 15s)			
28	Peleg	0.99780	0.00239	0.01848	Peleg	0.98380	0.02078	0.05448
	First order kinetic	0.96700	0.03647	0.06039	First order kinetic	0.93550	0.08280	0.09100
	Exponential	0.99150	0.00937	0.03226	Exponential	0.99050	0.01216	0.03676
	Weibull	0.96700	0.03647	0.06366	Weibull	0.93550	0.08280	0.09592
	Vega-Gálvez	0.99770	0.00256	0.01787	Vega-Gálvez	0.98980	0.01314	0.04053
40	Peleg	0.99360	0.00708	0.03180	Peleg	0.99430	0.00634	0.03009
	First order kinetic	0.97630	0.02634	0.05132	First order kinetic	0.98700	0.01435	0.03789
	Exponential	0.98460	0.01708	0.04356	Exponential	0.99330	0.00738	0.02864
	Weibull	0.97630	0.02634	0.05409	Weibull	0.99270	0.00811	0.03003
	Vega-Gálvez	0.99270	0.00812	0.03186	Vega-Gálvez	0.99390	0.00679	0.02913
60	Peleg	0.91330	0.07727	0.10510	Peleg	0.99100	0.00886	0.03558
	First order kinetic	0.87640	0.11010	0.10490	First order kinetic	0.99290	0.00702	0.02650
	Exponential	0.90950	0.08065	0.09466	Exponential	0.99290	0.00699	0.02787
	Weibull	0.87640	0.11010	0.11060	Weibull	0.99290	0.00702	0.02793
	Vega-Gálvez	0.91610	0.07480	0.09670	Vega-Gálvez	0.99330	0.00660	0.02873
P7 (Sunflower oil (9.48%) + K₂CO₃ (4.74 %) and stir for 60 min)								
28	Peleg	0.98210	0.02138	0.05527				
	First order kinetic	0.97290	0.03230	0.05683				
	Exponential	0.98450	0.01850	0.04534				
	Weibull	0.99320	0.00815	0.03010				
	Vega-Gálvez	0.98520	0.01766	0.04698				
40	Peleg	0.99060	0.01055	0.03883				
	First order kinetic	0.95170	0.05412	0.07356				
	Exponential	0.99190	0.00905	0.03171				
	Weibull	0.95170	0.05412	0.07754				
	Vega-Gálvez	0.99430	0.00639	0.02825				
60	Peleg	0.99660	0.00346	0.02224				
	First order kinetic	0.99590	0.00416	0.02039				
	Exponential	0.99660	0.00351	0.01974				
	Weibull	0.99590	0.00416	0.02149				
	Vega-Gálvez	0.99890	0.00109	0.01165				

P1 = no blanching, P2 = blanching in olive oil (9.48%) + K₂CO₃ (4.74%) and stir for 60 min, P3 = blanching in olive oil (0.47%) + K₂CO₃ (4.74%) and stir for 60 min, P4 = blanching in olive oil (0.47%) + K₂CO₃ (4.74%) and stir for 20 min, P5 = blanching in distilled water at 96 °C for 15s, P6 = blanching in olive oil (4.74%) + NaOH (1.5 %) and stir for 60min + blanching in distilled water at 96 °C for 15s, P7 = blanching in sunflower oil (9.48%) + K₂CO₃ (4.74 %) and stir for 60 min, R² = coefficient of determination, SSE = sum of square errors, RMSE = root mean square error.

Nevertheless, modified henderson and pabis with highest R² = 0.9997, lowest RMSE = 0.006221, and SSE = 0.001741 outperformed other models more frequently. This observation was not consistent with Pashazadeh et al. (2020) for *Rosa pimpinellifolia* fruit; they reported Midilli et al. as the best model. This variance might be because of differences in fruit structure and pretreatment applied.

3.2. Effective moisture diffusivity

The effective moisture diffusivity values are shown in Figure 3a. Higher drying temperatures exhibited high moisture diffusivity. This was because higher temperature increased the vapor pressure in the hog plum fruit, causing faster moisture movement from the inside to the surface of the fruit where it is eventually evaporated. Similar behavior was reported by Aral and Beşe (2016) for hawthorn fruit dried in a hot air dryer, Zielinska and Michalska (2016) for blueberries, and Kaveh et al. (2020) for blackberries. The effective moisture diffusivity ranged between 2.37

× 10⁻⁸ to 7.11 × 10⁻⁸ m²/s. Kaveh et al. (2020) reported an effective moisture diffusivity range of 3.10 × 10⁻⁹ to 1 × 10⁻⁸ m²/s for blackberry fruits. Pretreatment P5 (hot water blanching) increased the effective moisture diffusivity by 20 % at 50 °C, while P7 (sunflower oil aided CP) increased the effective moisture diffusivity by 13 % at 60 °C, whereas at 70 °C the pretreated samples had lower effective moisture diffusivity as compared to the control sample. The increase in effective diffusivity of sunflower oil aided chemical (potassium carbonate) pretreatment at 60 °C may be due to the modification of the waxy cuticle on the fruit surface, leading to a synergistic increase in water transport through the samples. The high temperature-short time blanching results in loss of turgidity and causes the increase in water permeability through the plant tissue as a result of damage of the membrane structure. Similar increase in effective diffusivity with such treatments was reported by Vásquez-Parra et al. (2013) for Cape gooseberry fruits. Kaveh et al. (2020) reported that ascorbic acid pretreated blackberry fruits showed higher effective diffusivity.

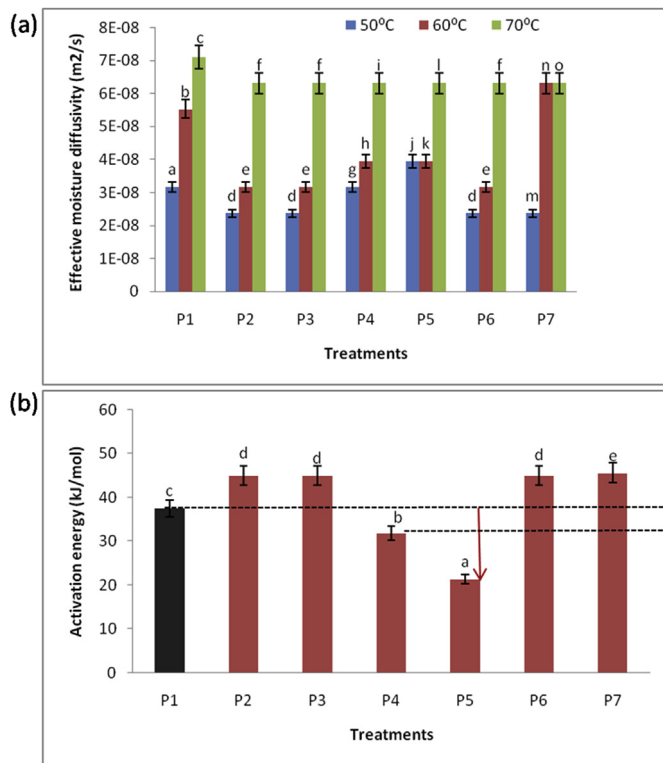


Figure 3. Graph of; (a) Effective moisture diffusivity (b) Activation energy [P1: Control (No treatment); P2: Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min; P3: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min; P4: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min; P5: blanching in distilled water at 96 °C for 15s, P6: Olive oil (4.74%)+NaOH (1.5 %) and stir for 60min + blanching in distilled water at 96 °C for 15s; P7: Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min]. Different letters on the bars indicates significant difference (p < 0.05).

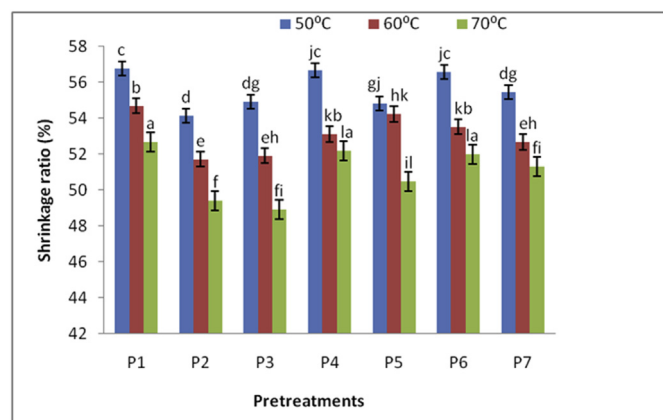


Figure 4. Shrinkage at different drying temperatures and treatments [P1: Control (No treatment); P2: Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min; P3: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min; P4: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min; P5: blanching in distilled water at 96 °C for 15s, P6: Olive oil (4.74%)+NaOH (1.5 %) and stir for 60min + blanching in distilled water at 96 °C for 15s; P7: Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min]. Different letters on the bars indicates significant difference (p < 0.05).

3.3. Activation energy

The activation energy graph is shown in Figure 3b. Activation energy is the energy require for moisture diffusion through the pores and

capillaries of the samples during drying. It also shows the sensitivity of samples to temperature. As can be seen only pretreatments P5 and P4 reduced the activation energy by 45 and 16 % respectively, other pretreatments showed higher activation energy as compared to the untreated samples. Srikanth et al. (2019) reported higher activation energy of elephant foot yam pretreated with potassium metabisulphite (KMS) and combination of KMS and citric acid. The minimum and maximum activation energy was 21–45 kJ/mol respectively. Kaveh et al. (2020) reported a lower activation energy range of 13.61–26.08 kJ/mol for pretreated blackberries.

3.4. Shrinkage

As can be seen in Figure 4, shrinkage increased with decreasing drying temperature. This observation can be due to the slow drying rate realized at low temperatures and the uniformity in moisture distribution inside the fruit. Prolonged drying causes huge damages to the pores of food materials, thereby leading to greater shrinkage. At higher drying temperatures the drying rate is high, leading to mechanical stabilization of the sample surface, limiting shrinkage. Similar observation was reported by Aral and Beşe (2016) for hawthorn fruit in a convective dryer. The pretreatments applied were found to significantly decrease the shrinkage, signifying that the pretreatment had a positive effect on preservation of structure of the dried samples. This was in agreement with Junqueira et al. (2017), as CP (ethyl oleate dipping) reduced shrinkage of gooseberry fruit, Kaveh et al. (2020) for ascorbic acid pretreated blackberries, and Önal et al. (2019) for CP apple slice. The lowest shrinkage at 50 and 60 °C was for samples with pretreatment P2 (54 and 51.5 %), while at 70 °C it was for samples with pretreatment P3 (48.5 %), although P2 (49 %) also performed comparatively. However, the highest shrinkage at all drying conditions was the untreated samples. This observation might be due to the faster drying rate recorded for pretreatment P2 and P3. The fresh and dried hog plum fruits are shown in Figure 5.

3.5. Rehydration curve and kinetic modeling

Rehydration describes extent to which the structure of a sample is affected or injured during drying and treatments. It is an irreversible process use in moistening dry samples. The rehydration rate or water absorption rate is highly important during the recondition of dried materials, as it affects sensory evaluation and reconditions time (Horuz et al., 2017). Pretreated dried hog plum fruits at 70 °C were rehydrated at three different temperatures of 28 (normal room temperature), 40, and 60 °C. The rehydration curves are presented in Figure 6 (a-c). Similar inclination was noticed amongst the rehydration curves for the different pretreatment and rehydration temperatures. During the early rehydration stage, quick water absorption by the samples was noticed, followed by a drop in water absorption rate and a constant rehydration capacity afterwards. These three stages are usually experienced during the rehydration of food materials (Wang et al., 2019; Srikanth et al., 2019; Pashazadeh et al., 2020). The drop in water absorption rate at the second stage is due to the reduction in mass transfer rate and closeness to the equilibrium point of the sample (Pashazadeh et al., 2020). Increase in the rehydration temperature increased the rehydration capacity of the fruit. Although there was no significant increase experienced between temperature of 28 °C and 40 °C. High water temperature has been reported to stimulate faster water absorption in dried samples (Srikanth et al., 2019; Pashazadeh et al., 2020). This might be due to increased moisture diffusion experienced at high temperature; also high temperature causes expansion in sample tissue and capillaries, which improves the hydrophilic characteristics. The effect of pretreatment on the rehydration capacity of the dried fruit varied for different water temperature used. Generally pretreatment increased the water absorption capacity for the different rehydration temperature considered across the hydration time. Wang et al. (2019) reported similar trend, as chemical pretreatment

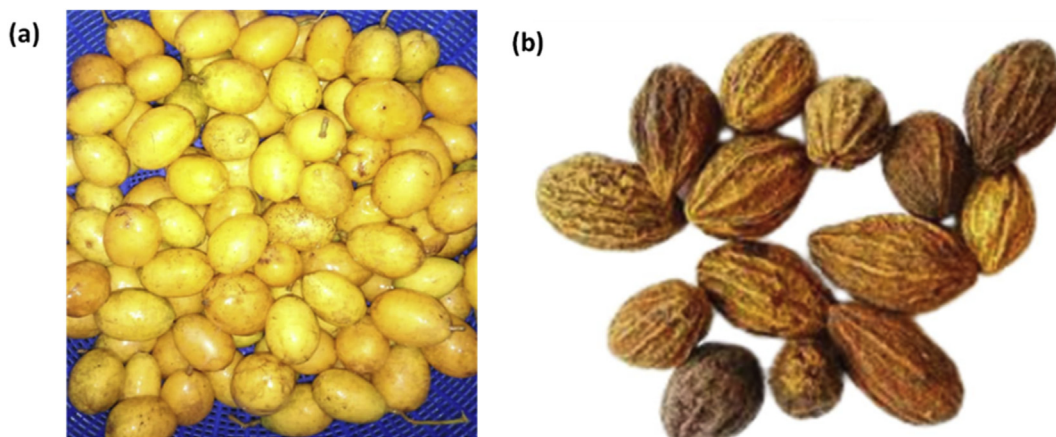


Figure 5. Hog plum fruits: (a) fresh, (b) dried samples.

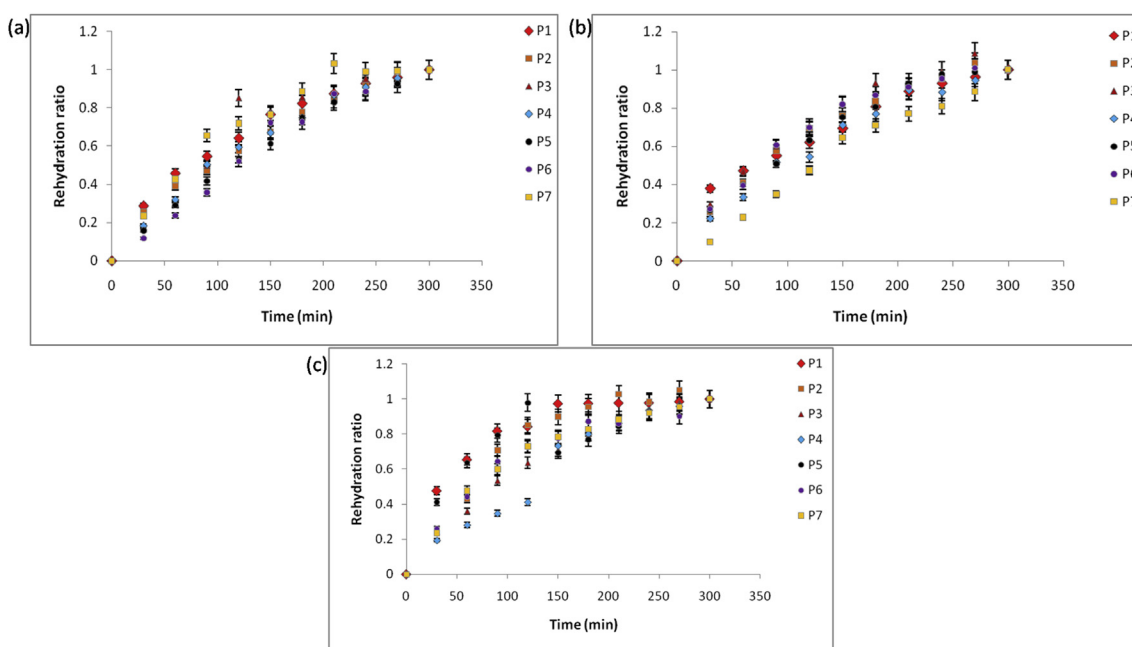


Figure 6. Rehydration ratio of Hog plum fruit dried at 70 °C and air velocity of 1.3 m/s versus time at different rehydration temperatures; (a) 28 °C, (b) 40 °C, and (c) 60 °C [P1: Control (No treatment); P2: Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min; P3: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min; P4: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min; P5: blanching in distilled water at 96 °C for 15s, P6: Olive oil (4.74%)+NaOH (1.5 %) and stir for 60min + blanching in distilled water at 96 °C for 15s; P7: Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min].

provided support to the cytoskeleton structure of scallion, the infiltrated chemical solutes prevents excessive shrinkage during drying which cause reduction in rehydration capacity. The highest rehydration ratio was found in fruits dried after pretreatment P7 for 28 °C, P3 for 40 °C, and P5 for 60 °C, while the lowest was found in P6 for 28 °C, P7 for 40 °C, and P4 for 60 °C. Nevertheless sample dried after pretreatment P5 (hot water blanching) for rehydration temperature 60 °C was observed to have a sharp decrease in its rehydration capacity after 130 min. This might be as a result of fissure and perforations in the waxy cuticle, thereby increasing porosity, drying rate and excessive shrinkage which hindered water retention capacity (Vásquez-Parra et al., 2013). The pretreatment effects were more significant at rehydration temperature 60 °C. Similar observation was made by Srikanth et al. (2019) for elephant foot yam. Edible-oil-aided CP (olive oil + sodium hydroxide) for 60 min before hot water blanching for 15 s (P6) was observed to increase the rehydration capacity as compared to hot water blanching alone. Increase dipping time increased the rehydration capacity as observed for P3 (60 min dipping) and P4 (20 min dipping). This signifies that more of the chemical solutes

infiltrates into the waxy cuticle of the fruit, thereby reducing excessive shrinkage caused during drying. High concentration of olive oil (9.48 %) in pretreatment P2 showed faster rehydration rate at temperatures 28 and 40 °C, but lower rehydration rate for 60 °C as compared to pretreatment P3 with low concentration of olive oil (0.47 %). This might be that the oil serves as a barrier to excessive moisture diffusion from the fruit pores, thereby reducing the rupture rate caused during drying. Effects of the oil type shows that samples pretreated with olive oil-aided chemical solution (P2) had better rehydration ratio as compared to sunflower-chemical solution (P7) pretreated sample. This might be as a result of difference in density of this oil, as olive oil is denser. So it closes the pores better than sunflower oil during drying. Similar trends were reported by Vásquez-Parra et al. (2013) for gooseberry fruit. The rehydration kinetic modeling result is presented in Table 2. As judged from modeling performance indices; R², RMSE, and SSE, the rehydration models (Peleg, Vega-Gálvez, Exponential, and weibull) depicted appropriately most of the rehydration behaviors' of the different pretreated dried fruit and at the different rehydration temperatures. Nevertheless,

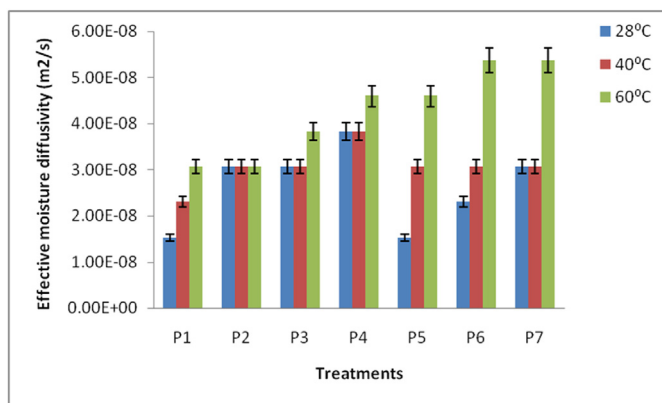


Figure 7. Effective moisture diffusivity during rehydration of hog plum fruit dried at 70 °C [P1: Control (No treatment); P2: Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min; P3: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min; P4: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min; P5: blanching in distilled water at 96 °C for 15s, P6: Olive oil (4.74%)+NaOH (1.5 %) and stir for 60min + blanching in distilled water at 96 °C for 15s; P7: Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min].

Vega-Gálvez (highest R² = 0.9989, lowest RMSE = 0.001086, and SSE = 0.01165) and Peleg (with highest R² = 0.9981, lowest RMSE = 0.00206, and SSE = 0.01715) outperformed other models more frequently. Similar observation was made by Pashazadeh et al. (2020) for *Rosa pimpinellifolia* fruit. The effective moisture diffusivity during rehydration ranged from 1.53–5.37 × 10⁻⁸ m²/s (Figure 7). Demiray and Tulek (2017) reported 1.37–1.48 × 10⁻⁹ m²/s for sun dried red pepper rehydrated at 25–45 °C and Maldonado et al. (2010), 1.24–1.6 × 10⁻¹⁰ m²/s for mango rehydrated at 25–40 °C. It was observed that increase in rehydration temperature increased the effective moisture diffusivity except for P2. Higher effective diffusivity at high temperature is expected due to the increase in moisture absorption rate. Demiray and Tulek (2017) reported similar observation for red pepper. At 28 and 40 °C, P4 (olive + K₂CO₃ and stir for 20 min) showed the highest effective moisture diffusivity (3.83 × 10⁻⁸ m²/s), while at 60 °C, P6 (olive + K₂CO₃ and stir for 60 min) and P7 (sunflower + K₂CO₃ and stir for 60 min) had the highest effective diffusivity (5.37 × 10⁻⁸ m²/s). This shows that the edible oil type did not significantly affects the rehydration process, and that rehydration temperature better controls the moisture diffusion.

3.6. Colour

Colour is one of the main parameters use in evaluating the quality index of food product (Aral and Beşe, 2016). The results for the effect of

pretreatments on colour parameters of dried hog plum fruit at 70 °C is presented in Table 3. HACD of the hog plum fruit led to a significant decrease (p < 0.05) in the lightness value (L*) from 55.52 to 24.87, signifying darker colour. This shows that the samples have contact with air, leading to a browning reaction (i.e. the activity of polyphenol oxidase (PPO) reaction over phenolic compound in the midst of air) or degradation of the pigment. Similar decrease in the lightness value was reported by Aral and Beşe (2016) for HACD of hawthorn fruit and Vásquez-Parra et al. (2013) for HACD of pretreated gooseberries. The untreated samples were found to be brighter than the pretreated samples after HACD at 70 °C. This was consistent with Wang et al. (2019), who reported that CP scallion had lower lightness value. Junqueira et al. (2017) also reported darker colour for Cape gooseberry treated with a chemical (ethyl oleate). Across the pretreatments applied, P6 (olive oil (4.74 %) + NaOH (1.5 %) for 60 min + hot water blanching at 96 °C for 15 s) had the highest lightness value (27.22). This shows that this treatment had the lowest degradation of the fruit pigment. Vásquez-Parra et al. (2013) in HAD of pretreated gooseberry fruit noticed that high temperature-short time pretreatment (96 °C for 15 s) deactivate PPO enzymatic activity, producing product with better carotenoid retention. The a* value of the fresh sample was significantly different (p < 0.05) from the dried samples. The fresh sample had a negative a* value (-6.93), signifying greenish colour. The application of pretreatments prior to drying increased the a* value when compared to the untreated, dried samples, except for pretreatment P6. Pretreatments P2 and P7 showed significant positive a* values (3.84 and 0.46), corresponding to reddish colour. This provides support to the claim that the pretreatment promotes browning reaction. Similar increase in a* value was reported by Vásquez-Parra et al. (2013) for edible oil aided chemical pretreated, dried gooseberry. Rani and Tripathy (2019) also reported that ultrasound and chemical pretreatment increased the a* value of hot air dried pineapple slice as compared to the fresh and control samples. The b* value of the fresh hog plum significantly (p < 0.05) reduced during drying. The b* value obtained for the untreated, dried sample was not significantly (p > 0.05) different from pretreatments P3–P7, except for P2 which recorded a higher value. The application of pretreatments P2–P7 indicates less yellowness caused by browning reaction. Similar observation was made by Vásquez-Parra et al. (2013) for edible oil aided CP, dried gooseberry and Junqueira et al. (2017) for ethyl oleate pretreated gooseberry. The ΔE of the untreated, dried fruit was significantly (p < 0.05) lower than only the pretreated sample P3. Nevertheless as seen in Table 3, other pretreatments had lower colour difference. This shows that the pretreatments especially P3 better preserved the carotenoid in the fruits. Wang et al. (2019) observed that ethanol pretreated scallion had significant lower ΔE compared to the control, dried scallion. Kaveh et al. (2020), ascorbic acid and hot water blanching pretreated, hot air dried blackberries had lower ΔE as compared to the directly dried samples.

Table 3. Effect of edible oil-aided chemical and physical pretreatments on the colour parameters of dried hog plum fruit at 70 °C.

Pretreatments	L*	a*	b*	ΔE	Ascorbic acid (mg/100g)	Total phenolic content (mg/100g)	Total antioxidant capacity (mg/100g)
Fresh	51.52 ^d ± 0.78	-6.93 ^a ± 0.23	20.71 ^c ± 0.34	-	204.25 ^c ± 0.81	264.75 ^c ± 0.58	854.01 ^f ± 0.35
P1	28.05 ^c ± 0.09	-1.00 ^b ± 0.03	2.22 ^a ± 0.02	14.92 ^d ± 0.09	7.23 ^b ± 0.67	72.95 ^c ± 0.70	104.65 ^e ± 0.36
P2	24.86 ^a ± 0.83	3.84 ^d ± 0.43	6.21 ^b ± 0.48	13.13 ^c ± 1.03	15.67 ^c ± 0.44	67.44 ^b ± 0.65	64.13 ^a ± 0.76
P3	24.97 ^a ± 0.26	-0.24 ^{bc} ± 0.06	2.20 ^a ± 0.06	11.81 ^b ± 0.27	5.07 ^a ± 0.51	72.99 ^c ± 0.63	73.68 ^b ± 0.48
P4	25.89 ^{ab} ± 0.12	-0.37 ^{bc} ± 0.04	2.38 ^a ± 0.01	12.75 ^c ± 0.13	6.50 ^b ± 0.46	73.90 ^{cd} ± 0.73	75.12 ^b ± 0.70
P5	25.90 ^{ab} ± 0.19	-0.66 ^{bc} ± 0.03	2.25 ^a ± 0.01	12.76 ^c ± 0.19	7.57 ^b ± 0.21	74.80 ^{cd} ± 0.54	79.06 ^c ± 0.78
P6	27.22 ^{bc} ± 0.78	-1.07 ^b ± 0.12	1.83 ^a ± 0.01	14.09 ^c ± 0.78	15.40 ^c ± 0.56	63.28 ^a ± 0.65	81.60 ^c ± 0.97
P7	25.81 ^{ab} ± 0.54	0.46 ^c ± 0.20	3.17 ^a ± 0.13	12.74 ^c ± 0.53	30.33 ^d ± 0.76	77.12 ^d ± 0.63	101.13 ^d ± 0.49

Note: within the column, means with different letters are significantly different at p < 0.05. P1: Control (No treatment); P2: Olive oil (9.48%)+K₂CO₃ (4.74%) and stir for 60 min; P3: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 60 min; P4: Olive oil (0.47%)+K₂CO₃ (4.74%) and stir for 20 min; P5: blanching in distilled water at 96 °C for 15s, P6: Olive oil (4.74%)+NaOH (1.5 %) and stir for 60 min + blanching in distilled water at 96 °C for 15s; P7: Sunflower oil (9.48%)+K₂CO₃ (4.74 %) and stir for 60 min.

3.7. Ascorbic acid

The AA results on the effect of pretreatments applied during HACD of hog plum are as shown in Table 3. In general, the pretreated dried hog plum samples showed significantly ($p < 0.05$) low AA than the fresh sample, signifying that the drying caused large degradation of AA. Davey et al. (2000) stated AA is a very delicate vitamin which is easily damaged by heat, light, moisture, and oxygen. Horuz et al. (2017) and Wang et al. (2019) also noticed a decrease in AA after drying for sour cherries and scallion respectively. The AA of the fresh, untreated, and pretreated samples followed the order: Fresh > P7 > P2 > P6 > P5 > P1 > P3 (control). Pretreated samples P7, P2, and P6 had higher retention rate for AA after drying compared to P5, P3 and P1 (untreated sample). Pretreatment P7 (sunflower aided CP) outperformed P2 and P6 (olive oil aided CP), probably because of the high content of vitamin E (tocopherol) in sunflower (634.4 mg/kg) as against olive oil (216.8 mg/kg) (Vásquez-Parra et al., 2013). Rizvi et al. (2014) reported that there is a probable cooperative interaction between vitamin C and vitamin E. Vitamin E during regeneration is found to give free radicals to vitamin C and the oil protects the vitamin from oxidation during drying. Vásquez-Parra et al. (2013) reported similar result for edible oil aided chemical dipping prior to drying of gooseberry. Junqueira et al. (2017) also discovered that chemical dipping with ethyl oleate solution preserved the AA of gooseberry. It was found that pretreatments containing hot water blanching (P5 and P6) caused additional losses in the AA due to the thermo-sensitivity of ascorbic vitamin. Similar observation was made by Vásquez-Parra et al. (2013) for high temperature pretreated gooseberry.

3.8. Total phenolic content

The TPC of fresh hog plum was found to be 264.75 mg/100g (Table 3). This was close to the value (260.21 mg GAE/100g) reported by Tiburski et al. (2011) for fresh yellow mombin fruits. HACD significantly ($p < 0.05$) reduced the TPC of the fresh samples from 264.75 mg/100g to as low as 63.28 mg/100g, i.e. about 76 % reduction in TPC compared to fresh samples. This might be because of prolonged heating time, exposure to oxygen and thermal deterioration. Drying, a heat treatment process cause rupturing of cell walls and other sub-cellular compartments of the fruit, thereby facilitating migration of cellular components with consequent release of the phenolic compounds. Similar decrease was observed by Zielinska and Michalska (2016) for blueberries, Horuz et al. (2017) for sour cherries, and Samoticha et al. (2016) for chokeberries. The TPC of the fresh, untreated, and pretreated samples followed the order: Fresh > P7 > P5 > P4 > P3 > P1 (control) > P2 > P6. Again the sunflower oil aided chemical dipping (P7) better preserved the TPC of the samples after drying, compared with other pretreatments and control. This shows that the sunflower oil coating can aid the inactivation of the oxidative enzymes and promote better retention of the phenolic compounds. It can also be attributed to the thermal and oxidative stabilities of sunflower oil over olive oil, due to high content of tocopherol and oleic acid (Xu et al., 2014; Vásquez-Parra et al., 2013). The short time-high temperature blanching also had a comparable TPC retention capacity with sunflower-aided CP, indicating that the phenol compounds are not so much susceptible to short time hot water blanching. This is also expected since blanching helps in inactivating spoilage/oxidative enzymes in food, and at short time heating less phenolic compounds is released from the fruit matrix.

3.9. Total antioxidant activity

The variation of the TAA after drying is shown in Table 3. The fresh hog plum has an antioxidant activity of 854.01 mg/100g. This value was also in the range reported by Esua et al. (2016) for hog plum fruit as 856.70 mg/100g. The application of the HACD reduced the TAA from 854.01 to the lowest value 73.68 mg/100g i.e. about 91 %. Similarly to

TPC, prolonged drying time and long exposure to oxygen was responsible for greater degradation of the TAA. This is due to the depletion of phenolic structure like polyphenols which act as strong antioxidants that complement and empowers the functions of antioxidant vitamins and enzymes as a defense against oxidative stress by excess reactive oxygen species (ROS) and heat treatment.

Zielinska and Michalska (2016) reported similar observation for blueberry fruits and Taşkın et al. (2018) for European cranberrybush. The TAA of the fresh, untreated, and pretreated samples followed the order: Fresh > P1 (control) > P7 > P6 > P5 > P4 > P3 > P2. The untreated and sunflower oil aided chemical (P7) pretreated, dried samples showed higher antioxidant retention activity. The untreated and P7 pretreated samples was significantly ($p < 0.05$) different from other pretreated samples. Similar to the TPC, P2 showed poor antioxidant retention ability. The antioxidant activity of pretreatment P3 was not significantly different from P4 and same for P5 and P6. These are probably due to same oil type used for P4 and P5, and the hot water blanching common to P5 and P6. The high antioxidant retention activity related to sunflower oil is still as a result of its high tocopherol (vitamin E) (Vásquez-Parra et al., 2013). Rizvi et al. (2014) stated vitamin E in food act as an efficient chain breaking antioxidant that prevents the production of reactive oxygen species during oxidation, and it also helps in tighten the cell membrane for better cell stability.

4. Conclusions

The effects of sunflower oil/olive oil aided-chemical and PP on the drying and quality characteristics of hog plum fruits were studied. Higher drying temperature recorded faster drying rate and increased shrinkage. Effective moisture diffusivity and activation energy ranged from 2.37×10^{-8} to 7.11×10^{-8} m²/s and 21–45 kJ/mol respectively. Increase in rehydration temperature increased the rehydration capacity and effective diffusivity (1.53 – 5.37×10^{-8} m²/s) of the dried hog plum fruit. Pretreatment with sunflower (9.48%) + K₂CO₃ at 28 °C had the shortest drying time (780 min) and highest effective diffusivity at 60 °C, highest rehydration ratio at 28 °C, highest retention rate for AA, TPC, and TAA, although its antioxidant activity was comparatively the same with untreated fruit. Treatment with hot water at 96 °C for 15s increased the effective moisture diffusivity by 20 % at 50 °C, reduced the activation energy by 45 %, and highest rehydration capacity at 60 °C. Olive oil + NaOH pretreatment exhibited poor drying and quality characteristics. Modified Henderson and Pabis (highest R² = 0.9997, lowest RMSE = 0.006221, and SSE = 0.001741) and Vega-Gálvez (highest R² = 0.9989, lowest RMSE = 0.001086, and SSE = 0.01165) outperformed other fitting models more frequently in predicting the drying kinetic and rehydration kinetic of hog plum respectively. Sunflower oil-aided CP is suggested for the industrial process of hog plum due to its better drying and quality characteristics. Also, this study can be used for designing drying equipment and control systems for hog plum fruits.

Declarations

Author contribution statement

John O. Ojediran, Abiola F. Olaniran: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Clinton E. Okonkwo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yetunde M. Iranloye, Adejoke D. Adewumi, Oluwakemi Erinle, Yemisi Tokunbo Afolabi: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Oladayo Adeyi, Abiola Adeyi: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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